October 2019

COMBINING HUMAN FACTORS AND DATA SCIENCE METHODS TO EVALUATE THE USE OF FREE TEXT COMMUNICATION ORDERS IN ELECTRONIC HEALTH RECORDS

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A Dissertation Presented

by

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Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

September 2019

Mechanical and Industrial Engineering

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DEDICATION

To my parents, wife and son.

Thank you for your love, patience, and support.

ACKNOWLEDGMENTS

This work was funded in part by Agency for Healthcare Research and Quality grants R21HS024755 and R01HS025136-01A1.

I would like to sincerely thank my advisor Dr. Jenna Marquard for her patient guidance and encouragement throughout my graduate studies at UMass Amherst. It would have been impossible to pursue my graduate studies without her trust and support. I would also like to thank Dr. Elizabeth Henneman and Dr. Hari Balasubramanian for their helpful comments and suggestions at varying stages of this project. I would like to extend my gratitude to Dr. Benjamin Marlin for introducing me to machine learning and being a member of my committee.

I would like to thank Sripathi Ramasubramaniam for encouraging me to apply to schools in US and take up graduate studies. I would also like to thank Prof. Stephen Roberts for introducing me to health care systems and inspiring me to work on improving safety and quality of healthcare.

I would like to thank Dr. Aaron Z Hettinger for providing inspiration for this research. I would also like to thank him for insightful suggestions and clinical perspective throughout the research study. I would also like to thank Dr. Raj M Ratwani for providing me with an opportunity to work with Medstar Health Research Institute and supporting me with funds for the study interviews. Special thanks to Daniel Hoffman who helped me extract data from electronic health record database, develop codebook for content analysis and conduct interviews. I would also like to thank Joanna Grimes for helping with classification of medication names into medication classes and providing clinical perspective. I also appreciate all the help and support from everyone at Medstar Health Research Institute. I have been fortunate to work with them and learn from them. I would also like to thank all the participants who participated in this research study. A big thanks to all my friends and lab mates for making life at UMass happy and memorable. Finally, I would like to thank *Ishwara* for blessing me with a loving family and providing an opportunity to work with wonderful people.

ABSTRACT

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SEPTEMBER 2019

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Medication errors are a leading cause of death in the United States. Electronic Health Records (EHR) along with Computerized Provider Order Entry (CPOE) are considered promising ways to reduce these errors. However, EHR systems have not eliminated medication errors. Moreover, in some cases they have facilitated errors due to issues such as poor usability and negative effects on clinical workflows. The use of unexpected free text within a CPOE system can serve as a marker that the system does not adequately support clinical workflow. Prior studies have looked at the use of free text within medication orders, but the inclusion of medication related information in *communication for non-medication orders* (CNMOs), a type of free text order, has not been adequately studied. This mixed-methods study identified the prevalence, nature and reasons for the inclusion of medication related information in CNMOs using a large sample of CNMOs placed at a mid-Atlantic hospital system in 2017, and via interviews with physicians. The study found that more than 42% of CNMOs contain medication related information. Moreover, the use of CNMOs varied significantly across provider types, hospital locations, patient settings and other factors. The study found 10 themes that might cause providers to adopt such workarounds, including missing functionality and poor usability. The

study also identified several general challenges in communicating medication information in the EHR, and potential solutions to mitigate these challenges. This dissertation also demonstrates how natural language processing could be used to identify medication related CNMOs.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

Communication is a critical component for safe and effective health care delivery. Communication failures contribute to a majority of sentinel events that occur in hospitals[1] and 38% of malpractice incident claims involve miscommunication between providers.[2] Communication inefficiencies among care providers cost US hospitals $12 billion annually.[3] This year, the Joint Commission identified *improving provider to provider communication* as a national patient safety goal.[4]

Electronic Health Records (EHRs) are now ubiquitous, with 99% of large hospitals using a certified EHR.[5] They contain myriad types of information, including diagnoses, allergies, family history, immunizations, hospitalizations, procedures, surgeries, lab reports, provider notes, and treatment plans. EHRs have the potential support provider to provider communication using tools within the EHR such as e-mail, instant messaging, medication orders, lab orders, patient notes, and communication orders. With increasing use of EHRs in place of face to face communication[6], it is essential that these technologies support effective provider to provider communication.

Multiple studies have focused on how barriers for effective provider to provider communication could inform EHR design[7,8], but it remains unclear what information is best included in the EHR and what should remain external to the EHR.[7] Consequently, it is important to understand the information content of EHR fields that providers currently use for communication. Computerized Provider Order Entry (CPOE) is an EHR component that supports entering and communicating orders and instructions. There are many order types within CPOE, including medication orders, laboratory orders, imaging orders, and communication orders. Though CPOE has many potential benefits, it has not eliminated medication errors.[9,10] Additionally, there are several unintended consequences of CPOE.[11] Campbell et al. identified 380 instances of CPOE unintended consequences, and categorized them into 9 themes.[12] Some of these consequences result from physicians using CPOE in unexpected ways due to technical issues[12], lack of system support[13], emotional and cultural issues[14], and the system being inefficient and inconvenient.[15] Though physicians are cognizant of the challenges with CPOE, they often are unaware of the unintended consequences or errors associated with using CPOE in ways it was not designed for.[16]

In the EHR used in this study, orders are grouped under the broad categories. For example, all medication orders are grouped under 'Medications', and communication orders such as "Notify Provider", "Communication for Non Med Order", and "Communication for ED phone call" are grouped under 'Communication Orders'.

CPOE orders typically allow providers to enter data in structured and/or unstructured (free text) formats. For medication orders, providers use both structured and free text fields, but with set content. However, there are some order-types with no set content. These order-types are usually solely free text and are used by providers as they deem fit.

Communication for Non Med Order (CNMO) is one type of free text order that providers use as they deem fit. CNMOs can be used to provide information about issues such as changing patient clothing or replacing IV lines. Ideally, all medication related information would be included within CPOE medication orders, but anecdotal evidence suggests medication information is being included in CNMOs. This creates potential for a patient not to receive a medication, experience a delay in receiving the medication or receive a medication that should have been discontinued. Additionally, CPOE features such as decision support, allergy alerts, and medication interaction checks cannot be utilized. The use of CNMOs for medication related information would be especially problematic and could potentially cause medication errors if the receiving physician or nurse does not see the CNMO in addition to the medication order. It is unclear whether this is happening because other CPOE order types do not support providers' desired communication information, or if providers do not know where in the EHR this information is intended to be located.

By analyzing free text CNMOs, and conducting interviews with providers, we may be able to understand the prevalence, nature, and rationale for why CNMOs are being used to communicate medication related information. A study on medication orders analyzing all 2,412 hypoglycemic drugs entered through free text in EHRs for 2,091 patients during 2010, showed that 9.3% of hypoglycemic agents were entered as free text orders.[17] The study found that 92 drug-drug interaction alerts were not triggered and only 25.9% of the patients had diabetes recorded in their problem list because the medication information was entered as free text. The study showed that analyzing EHR data can uncover the prevalence and severity of the use of free text to order medications. However, the study analyzed only one type of medication and the identification of reasons for the use of free text to order medication were based on the authors' perspectives, not on physician or stakeholder feedback. Similarly, previous studies looking at the use of free text for medication ordering within CPOE have all focused on the free text within the medication order field to identify discrepancies between structured and unstructured fields.[18,19]

This study will evaluate the use of free text CNMOs within CPOE to identify the types of information contained in CNMOs (Chapter 3), identify the prevalence and nature of medication related information in CNMOs (Chapter 4), understand use of CNMO from the physician perspective and identify the reasons why they include medication related information in CNMOs

(Chapter 5) and develop a prototype tool for automatically identifying CNMOs containing medication related information (Chapter 6).

CHAPTER 2

LITERATURE REVIEW

The Health Information Technology for Economic and Clinical Health (HITECH) Act of 2009 stimulated adoption of EHRs across United States. EHRs have now been widely adopted in hospitals in the United States.[5] Computerized Provider Order Entry (CPOE), defined by the Agency of Health Research and Policy (AHRQ) as a process by which providers directly enter medical orders into a computer application, is becoming an integral component of most EHRs. CPOE offers many potential benefits over traditional paper orders, including features to support safe medication use. One study estimated that the adoption of CPOE reduced medication errors by approximately 17.4 million (bounds 0.09–27.1 million) over a 1-year period.[20] Unfortunately, several studies have reported how CPOE contributes to unintended consequences and facilitates errors.[11,12,21,22] This literature review outlines these potential benefits and negative consequences within the following categories: structured order entry, order sets, decision and cognitive support, communication, and workflow and sociotechnical systems. These benefits and drawbacks provide context for why CNMOs may be used in CPOE systems, and the potential negative consequences of using CNMOs in unexpected ways.

The studies reviewed range from quantitative analyses of large datasets, to small qualitative studies and case examples. Because this study focuses on a quantitative analysis of a large dataset, we describe these types of analyses first, followed by studies with smaller sample sizes. The studies also have occurred within an evolving policy and technical landscape related to EHR development and implementation, so we note the timeframe from the analysis. Appendix A includes a table containing citation of the study, year of publication, type of study and relevant details about the study such as sample size, period of study, number of hospitals/ units involved in the study etc.

2.1 Structured Order Entry

CPOE provides access to legible, digital orders, so may reduce inaccuracies while prescribing, transcribing and interpreting orders.[23–26] CPOE includes structured fields to enter data, and providers must complete required fields. By having providers choose from pre-existing lists, CPOE can serve as a form of checklist and behavior influencer.[23,27] Providers may be less likely to miss key fields such as dose information, duration, and route information while ordering, thus preventing certain omission errors. CPOE helps in documenting elements such as medication orders and test results, and can improve compliance to guidelines and regulations.[28] The data stored in CPOE systems can also support secondary data analysis and research.

However, CPOE does not guarantee that orders are complete and accurate. In a retrospective study of 3850 computer-generated prescriptions received by a commercial outpatient pharmacy chain across three states over 4 weeks in 2008, 452 prescriptions (11.7%) contained 466 total errors.[29] The study found that 61% of CPOE medication errors had important information such as dose, duration, and frequency missing, and 16% of orders had conflicting information.[29] Singh et al. analyzed pharmacists reported prescriptions containing inconsistent communication (mismatch between the structured template and the associated free-text field) over a 4-month period at a tertiary care facility. [18] They found that 0.95% (532/55,992) orders were reported to contain inconsistent information and that medication dosage information was the most inconsistent data element (239/532; 45%) in prescription orders. Another study reviewed 2914 electronic prescriptions that contained free-text fields, and found that there was inconsistent information in 16% of the prescriptions with free text; 84% amongst them had potential for adverse events and 17% had potential for severe harm including death.[19] Based on interviews with 20 participants at five pharmacies in 2014 , Odukoya et al. noted that wrong or missing data result in additional work for pharmacists, increased frustration and can delay patient care.[30] A case study in 2005 found that a patient suffering from hypokalemia (low blood potassium) became hyperkalemic(high blood potassium) due to missing CPOE information.[31] Based on analysis of 46 patient safety events submitted to Manufacturer and User Facility Device Experience (MAUDE) database from January 2008 to July 2010, Magrabi et al. noted that overdoses were attributed to mismatches of the system with clinical workflow.[32] They found that incorrect medication dose information resulted in administration of an analgesic medication three times the maximum dose and eventually resulted in renal failure and death. Medication related information placed in CNMOs may increase these problems. Hence it is essential that we understand what medication related information is being included in CNMOs.

Based on a large study in 2004 involving EHR data from several hospitals in US, Australia and Netherlands; and 340 hours of observation and 59 formal interviews at four US hospitals, and 18 interviews with stakeholders in several public hospital sites in Australia, Ash et al. noted that CPOE can cause cognitive overload because it over emphasizes structured data entry.[11] Providers resort to workarounds due to poor user interfaces and cumbersome data entry processes.[11] A 2005 study involving 14 interviews and 27 observations at three hospitals, found that these rigid structures not only make data entry and retrieval tedious, they also make it hard for the providers to integrate information available across multiple screens.[33] Providers get lost in searching for information and lose focus on the overall patient case.[11,34] Thus, CPOE can reduce the cognitive focus of providers on the patient case because of fragmentation and loss of an overview of the data.[11]

2.2 Order Sets

Order sets are collections or groups of clinically-related orders, designed to be used in a wide variety of clinical scenarios including “hospital admission (e.g. cardiology admission), condition (e.g. myocardial infarction), symptom (e.g. chest pain), procedure (e.g. angiography), or treatment (e.g. chemotherapy)”.[27] CPOE systems can therefore help support evidence based medicine. Various studies have found increased adoption of evidence-based medicine associated with implementation of CPOE as well as improvement in delivery of care, reduction of mortality rates, length of stay and considerable financial return.[35–37] These benefits of CPOE are not restricted to specific patient conditions or physician tasks. Several studies have shown CPOE’s positive impact during admission and discharge, pre-operative and post-operative care, and on tasks like insulin administration, and for the management of conditions like pneumonia and myocardial infarction. For example, a 2006 study that conducted a pre-post implementation analysis of order sets at emergency department in one academic medical center, found the “management of septic shock in the emergency department to be associated with statistically rigorous fluid resuscitation of patients, administration of appropriate initial antibiotic treatment, and a lower 28-day mortality” after implementation of standardized order sets.[38] Another study in 2004 which reviewed patient charts at a hospital that had the primary diagnosis of acute myocardial infarction (including segment elevation myocardial infarction (STEMI) and non-segment elevation myocardial infarction (NSTEMI) found that more patients received appropriate medications in a timely fashion.[39]

Based on a 2012 study that analyzed order set usage logs from a purposive sample of seven sites during 1 year period, Wright et al. noted that personalized order sets can lead to non-standard care practices.[27] In a 2007 viewpoint paper that discussed the use of order sets based on literature, Bobb et al. noted that the availability of the system does not guarantee its use by providers.[40] A 2014 viewpoint paper that provided guidelines for standard order sets based on literature, noted that even if the order sets are used, they can promote outdated practices if they are implemented without careful clinical review or are inadequately maintained.[41]

Order sets can facilitate errors if they are not linked appropriately. For example, a case study of fatal arrhythmia in 2016 found that transition to electronic order sets contributed to mismanagement of the patient's low magnesium and potassium levels because magnesium and potassium guidance were linked on the prior paper order set, but were not linked in the electronic version.[42]

2.3 Decision and Cognitive Support

A 2001 meta-analysis of studies that measured the impact of CPOE at a hospital on the safety and quality of the medication process found that CPOE provides decision support in numerous ways, including scales and references for certain medications like potassium and insulin.[23] It also supports frequency and dosage calculations for complex conditions, treatments and procedures such as renal insufficiency and cancer treatment.[43–45] A 2001 pre-post implementation study of a decision support system with a 9-week control period followed by an 8-week intervention period found a significant change in the distribution of tests ordered resulted from the intervention (p=0.048).[46] They found that CPOE can include recommendations and suggestions for complex decisions on appropriate tests, studies, and actions to be taken.

CPOE also provides cognitive support via guidelines to medication dosages and alternatives to medication prescriptions. For example, a 2001 study that conducted a pre-post implementation analysis of all orders entered through a computerized system at an urban academic medical center over 2 year period found that “use of a computerized guideline resulted in a change in use of the recommended drug (nizatidine) from 15.6% of all histamine(2)-blocker orders to 81.3% (P<.001). Implementation of dose selection menus resulted in a decrease in the SD of drug doses by 11% (P<.001). The proportion of doses that exceeded the recommended maximum decreased from 2.1% before order entry to 0.6% afterward (P<.001). Display of a recommended frequency for ondansetron hydrochloride administration resulted in an increase in the use of the approved frequency from 6% of all ondansetron orders to 75% (P<.001). The use of subcutaneous heparin sodium to prevent thrombosis in patients at bed rest increased from 24% to 47% when the computer suggested this option (P<.001)”.[45] Another pre-post intervention study of a decision support system, at an urban university-affiliated public hospital, involving 78 house staff rotating on the 6 general medicine services in 1998, found that “compared with the control group, intervention physicians wrote 32 percent fewer orders (11.3 versus 16.7 orders per physician; P = 0.04) and had 28 percent fewer patients for whom they either initiated or renewed an order for vancomycin (7.4 versus 10.3 orders per physician; P = 0.02). In addition, the duration of vancomycin therapy attributable to physicians in the intervention group was 36 percent lower than the duration of therapy prescribed by control physicians (26.5 versus 41.2 days; P = 0.05)”.[47]

Embedded reminders and alerts can help providers take preventive measures, thus improving timely adherence to guidelines. For example, a randomized control study of a reminder decision support system involving 48 intervention physicians and 41 control physicians, for a period of 6 months in 1997 found that “intervention physicians ordered the suggested corollary orders in 46.3% of instances when they received a reminder, compared with 21.9% compliance by control physicians ($p < 0.0001$)”.[48] In a 2001 pre-post intervention study of a decision support system, assessing the effects of computerized reminders on the rates at which four preventive therapies were ordered for inpatients during an 18-month study period involving 6371 patients admitted to a general-medicine service (for a total of 10,065 hospitalizations) found that “patients with at least one indication, computerized reminders resulted in higher adjusted ordering rates for pneumococcal vaccination (35.8 percent of the patients in the intervention group vs. 0.8 percent of those in the control group, $P<0.001$), influenza vaccination (51.4 percent vs. 1.0 percent, $P< 0.001$), prophylactic heparin (32.2 percent vs. 18.9 percent, $P<0.001$), and prophylactic aspirin at discharge (36.4 percent vs. 27.6 percent, $P<0.001$)”.[49]

CPOE can also help in error checking features, such as checking for inappropriate medications. For example, a pre-post intervention study of decision support system, assessing its use to prevent potentially inappropriate medication use among patients 65 years or older admitted to a large, urban academic medical center in Boston, Massachusetts, from June 1, 2004, through November 29, 2004, found that “the mean (SE) rate of ordering medications that were not recommended dropped from 11.56 (0.36) to 9.94 (0.12) orders per day after the implementation of a CPOE warning system (difference, 1.62 [0.33]; $P<.001$)”.[50]

Literature reviews based on studies till 2014 have identified that CPOE with clinical decision support systems help in identifying drug-drug and drug-allergy interactions [51–53]. Studies have also found that CPOE helps in checking for duplicate tests, therapies and medications. For example, a randomized controlled trial that included all inpatients at a large teaching hospital during a 15-week period, found that “there were 939 apparently redundant laboratory tests among the 77,609 study tests that were ordered among the intervention (n = 5,700 patients) and control (n = 5,886 patients) groups. In the intervention group, 69% (300 of 437) of tests were canceled in response to reminders. Of 137 overrides, 41% appeared to be justified based on chart review. In the control group, 51% of ordered redundant tests were performed, whereas in the intervention group only 27% of ordered redundant tests were performed (P <0.001)".[54] Another study in 2013 that analyzed a sample of 41,306 patient admissions with at least one B-Type Natriuretic Peptide (BNP) test at LVHN between January, 2008 and September, 2011, found that "CDS intervention reduced BNP orders by 21% relative to the mean".[55] Another study in 2014 assessing the cost benefits of using CDS in a hospital found that "the clinical decision support blocked 11,790 unnecessary duplicate test orders in 2 years, which resulted in a cost savings of $183,586".[56]

Though decision support systems can help providers make better decisions, studies have found that these can cause unintended consequences. A large qualitative study, that included 390 hours of observation of 95 clinicians, and 32 interviews at five hospitals found that overdependence on decision and cognitive support can make it hard or impossible for providers to work on a COPE systems using different decision or cognitive support features, or during instances without access to technology.[57] The study also found that computer system downtime can "wreak havoc in the ER" in absence of alternate systems. A 2005 JAMA editorial noted that order entry is fundamentally a collaborative, distributive procedure requiring cognition across groups and yet, CPOE systems are often designed based on the assumption of a straightforward stepwise linear process.[58] A 2009 review article based on a literature search for CPOE evaluations between 1990 and June 2007, noted that CPOE often fails to address this need for collective cognition.[59]

CPOE also lacks some cognitive support features such as efficient display of relevant critical information. For example, a large qualitative study between 2002 and 2004 at a tertiary-care teaching hospital which surveyed house staff (N = 261; 88% of CPOE users); conducted 5 focus groups and 32 interviews and observations with house staff, information technology leaders, pharmacy leaders, attending physicians, and nurses; shadowed house staff and nurses, found that CPOE lacks certain features such as dosing calculations.[9] Another qualitative study in 2005 involving 14 interviews and 27 observations at three hospitals, found that "the most important requirement from the physician's perspective would be an efficient display of relevant information provided first in the form of a summarized view of the patient's current treatment, followed by in a more detailed focused display of those items pertinent to the current situation. The CPOE system examined obviously failed to provide the physicians this critical summarized view".[34]

Aarts et al. conducted interviews a study in 2007 with 21 experts involved in the design, implementation and evaluation of CPOE, and found that providers have to use aids such as paper notes to keep track of information.[21] Another drawback is that even if systems exists, sometime providers do not use functions as per recommendations. For example, a 2008 simulation study by Henneman et al. found that providers do not verify patient identity while using CPOE.[60] They found that 23 of the 25 providers ordered test on wrong patient because they failed to verify the birth dates of patients having same name in CPOE.

CPOE error checking systems are not fool proof. For example, a large qualitative study in 2007, that included 390 hours of observation of 95 clinicians, and 32 interviews at five hospitals, found that allergies mentioned in free text fields are not available for error checking.[57] A literature review in 2004, found that CPOE can also generate an overload of reminders, alerts, or warning messages, causing alert fatigue.'[11] A literature review article in 2008, found that providers are known to ignore these excessive reminders, alerts, and warnings.[61]

At times, CPOE systems lack features because of incomplete software releases, and can misrepresent data due to poor interfaces or misleading functions. For example, a study that compared facilities that had CPOE with those that did not have CPOE using a national voluntary medication error-reporting database Medmarx, found that CPOE could lead to medication errors because of faulty computer interface, miscommunication with other systems, lack of adequate decision support and human error.[62] A case study in 2005, that analyzed dosing error related to computer-based ordering of potassium chloride, found that missing critical information in CPOE order and several usability issues with CPOE contributed to error.[31]

Software bugs such as mistakes in weight-based dose calculation while converting from lbs. to kg have been found to cause Adverse Drug Events. A 1999 pre-post CPOE implementation study that analyzed all patients admitted to three medical units for seven to ten-week periods in four different years, found that "The rate of intercepted potential ADEs climbed substantially from baseline to periods 1 and 2; it rose from 15.8 per 1,000 patient-days at baseline to 31.3 in period 1 and 59.4 in period 2 (P = 0.15) before falling to 0.5 in period 3. These increases in errors were largely related to POE's initial structure for potassium chloride orders, which made it easy to order large doses of intravenous potassium without explicitly specifying that it be given in divided doses (i.e., not more than 20 milliequivalents at a time)".[63] These bugs can be identified and fixed to eliminate errors, but need to be found at the testing stage to avoid errors that can jeopardize patient care. Fixing an alert from CPOE can cause errors as providers are unsure of changes that happen to the order while fixing.[64] These errors can happen due to selection or typographic errors or lack of familiarity and poor predictability of the system.

2.4 Communication

CPOE can help make communication timelier, through features such as text messages between providers. A pre-post intervention study of CPOE in 2007, assessing time to time from a patient's arrival at the emergency department to thrombolysis, during 1 year period, found a significant reduction in time from arrival to evaluation and treatment after implementation of CPOE.[65]

But, CPOE can create an illusion of improved communication.[11,66,67] Multiple studies have found that CPOE promotes asynchronous communication between providers.[67–69] In this asynchronous communication model, physicians may assume an order is read by the nurse when it actually is not.[68] Due to lack of feedback within CPOE and reduced communication between providers, providers may not be sure if the information has reached another person and/or cannot immediately clarify some of the orders given by other providers, causing uncertainty, delays of care, misinformation and error. For example, a retrospective study conducted in 2005, found that "among 1942 children who were referred and admitted for specialized care during the study period, 75 died, accounting for an overall mortality rate of 3.86%. Univariate analysis revealed that mortality rate significantly increased from 2.80% (39 of 1394) before CPOE implementation to 6.57% (36 of 548) after CPOE implementation. Multivariate analysis revealed that CPOE remained independently associated with increased odds of mortality (odds ratio: 3.28; 95% confidence interval: 1.94 – 5.55) after adjustment for other mortality covariables".[66] The study found that there was diminished opportunities for face to face communication and lack of feedback after implementation of CPOE. Another study in 2008 that measured nurse attitudes pre and post CPOE implementation using survey at six internal medicine wards (with response rates 54.3% (76/140) pre implementation and 52.14% (73/140) post implementation), found that "synchronisation and feedback mechanisms in nurse-physician collaborations have been impaired after the CPOE system was introduced".[67]

Multiple studies have found that CPOE reduces provider face to face communication time.[6,68–70] In an observational study, Shu et al. recorded a total of 1729 observations over 1554 hours involving 43 interns pre implementation and recorded a total of 953 observations over 962 hours involving 29 interns post implementation, and found that physicians spent significantly less time talking to other physicians; 39% of their time after implementation of CPOE compared to 50% of their time pre implementation.[70] In a study by Taylor et al. involving 75 patient-nurse-physician triads prior to CPOE introduction and 123 triads after the introduction of CPOE found that "Face-to-face communication was significantly reduced (67% vs 51%, p=0.03). Total Agreement Score was significantly lower after the implementation of EMR (p=0.03). Additionally, fewer patients accurately predicted their expected length of stay after EMR (34% vs 26%, p=0.001)".[6] In another study, Beuscart-Zephir et al. examined the impact of CPOE in three hospitals in France in 2005 and found that physicians and nurses work in an asynchronous mode, and leave to the system the coordination of their actions.[69] They also found that doctors and nurses had less time to interact and discuss medications. A 2001 study that reexamined observation, focus group and oral history data from four different sites to understand how CPOE alters communication , found that CPOE reduced face to face communication was found to adversely affect team relationships, undermine team spirit, cohesion and rework.[68]

Pirnejad et al. examined the effects of CPOE on nurse-physician collaboration in hospitals in the Netherlands using survey at six internal medicine wards (with response rates 54.3%

(76/140) pre implementation and 52.14% (73/140) post implementation), and concluded that CPOE separates the work of physicians from that of nurses.[67] They noted that this makes it difficult for providers to get mutual feedback, and thus they face challenges in coordinating and integrating their work. A study by Saddik et al. in 2014 measured nurse perceptions of CPOE features on workflow and nurse physician communication using survey questionnaire administered to 146 of the 173 nurses, and found that additional work was required by nurses for follow up with physicians.[71] In another study, Fields et al. interviewed nurses in 2009, and found that the nurses felt the need to seek out the physician to better understand the care plan and the nurses needed additional information with regard to medications because physicians had entered orders off-floor.[72]

A qualitative study reporting findings of 390 hours of observation of 95 clinicians, and 32 interviews at five hospitals in 2009, found that though CPOE provides flexibility by allowing orders to be written off-floor (or outside the hospital), it can reduce situational awareness between providers due to lack of face to face communication.[73] Because multiple providers can write orders simultaneously on same patient, the orders might appear to conflict when in fact they are not, or providers can inadvertently duplicate orders. For example, an anesthesiologist might write a pre-op order for *dopamine* for a procedure tomorrow while hospitalist not expecting to see the specific medication might just cancel the order.[73] Writing orders off-floor is problematic because the nurse does not always know that a new order has been placed, which can delay time sensitive medications.[68] A 2003 study by Cheng et al. based on observation of work patterns of 50 individuals on the ICU care team, including the physicians (attendings, fellows, residents, interns, medical students), the nursing staff (day and evening nurses, charge nurses, resource nurses, unit clerks), two pharmacists, and one respiratory therapist (RT) for 86 hours, found that CPOE changed workflows and led to new forms of communication such as frequent ad hoc verification tasks to check for an order's existence and correctness.[74] The authors noted that these ad hoc processes are informal and thus prone to more error and neglect if the workload becomes heavy. While examining nurse physician communication in a Dutch hospital a decade after adopting CPOE using survey data from 49% of 217 physicians and 56% of 587 nurses working in inpatient departments of a university hospital, in 2011, Khajouei et al. found that providers used workarounds to communicate information and restored the feedback loops by using paper artifacts.[75] Specifically, when responding to the question "How do you usually coordinate medication ordering activities with other nurses?" 66.4 % (194/292) participants responded positively to using "By printout labels of Medicator".

When examining unintended consequences of CPOE based on 390 hours of observation of 95 clinicians, and 32 interviews at five hospitals in 2006, Campbell et al. found that misinformation and errors occur due to problematic electronic data presentations; confusing order option presentations and selection methods; inappropriate text entries.[12] In another study by Ash et al. in 2003 that included a total of 19 observations, 19 informal interviews, 14 formal interviews, 3 focus groups, found that providers can inadvertently write order on wrong patient thus providing wrong information.[76]

2.5 Workflow and Sociotechnical Systems

CPOE has shown to have a positive impact on provider workflow and productivity. For example, an observational time and motion study conducted from March 1 to March 17, 2011 that compared two similar community hospital pharmacies one without CPOE implementation and the other with CPOE implementation, found that CPOE allowed pharmacists to process more orders per hour and allocate more time to clinical functions, thus improving their efficiency and productivity.[77]

Based on survey data from 49% of 217 physicians and 56% of 587 nurses working in inpatient departments of a university hospital, a 2011 study, found that CPOE systems are built assuming idealized workflows that often do not reflect actual clinical practice.[74] A 2003 study based on observation of work patterns of 50 individuals on the ICU care team, including the physicians (attendings, fellows, residents, interns, medical students), the nursing staff (day and evening nurses, charge nurses, resource nurses, unit clerks), two pharmacists, and one respiratory therapist (RT) for 86 hours, found that sometimes only a part of the clinical workflow is supported by CPOE.[73]

CPOE has also been found to be inflexible with ordering, for example by a patient to be admitted into the department or hospital before placing orders, thus causing delays in care.[9,66] In a large qualitative study between 2002 and 2004 at a tertiary-care teaching hospital Koppel et al. surveyed house staff (N = 261; 88% of CPOE users); conducted 5 focus groups and 32 interviews and observations with house staff, information technology leaders, pharmacy leaders, attending physicians, and nurses; shadowed house staff and nurses, identified and quantified how CPOE facilitated medication error risks, identifying 22 sources.[9] They found that more than 90% of the respondents had difficulty specifying medications and problems ordering off-formulary medications at least once in the past three months, pointing to the aforementioned inflexibility of CPOE. They also found that CPOE also removes asynchronous steps and informal mechanisms such as checks by pharmacists, and notes or clarifications for complex orders that help with decision making, order review, and error checking, thus increasing the risk of errors. Based on a large study in 2004 involving EHR data from several hospitals in US, Australia and Netherlands, and 340 hours of observation and 59 formal interviews at four US hospitals, and 18 interviews with stakeholders in several public hospital sites in Australia, Ash et al. noted that, orders are often entered by junior residents on a series of patients, after patient rounds based on notes made during the rounds.[11] However, since orders are entered in an environment away from patients, outside the context in which patient order was discussed and away from those who could correct misinterpretations, order entry in CPOE can be prone to errors.[11] When individuals encounter trouble entering medication orders using a highly-structured, constrained format, they may opt to use free text CNMOs.

A literature review evaluating the effect of CPOE on outcomes pertaining to the medication process in inpatients based on articles in MEDLINE (1966 to August 2006), EMBASE (1980 to August 2006) and the Cochrane library, noted that CPOE often does not take into context the social requirements of the system.[61] In a 2005 JAMA editorial Wears et al. attribute mismatch between CPOE and its requirements to misleading theories about technology and clinical work.[58] They describe this misleading theory as a narrow view that “technical problems require technical solutions” and they suggest a need to view the “clinical workplace as a complex system in which technologies, people, and organizational routines dynamically interact”.

CPOE also has indirect effects on outcomes by affecting people involved in the care process. In 2005, based on a secondary analysis of data collected using 19 observations, 19 informal interviews, 14 formal interviews, 3 focus groups, Sittig et al. found that negative emotions such as guilt, shame, anger, anxiety and frustration were associated with the use of CPOE.[14] Another study by Ash et al. in 2007 that involved 390 hours of observation of 95 clinicians, and 32 interviews at five hospitals , found that CPOE implementation caused shifts in power structure due to forced work redistribution and changes to workflow.[78] They also found these changes in power structures caused perceived loss of control and autonomy amongst clinicians, and increased power of nurses and information technology specialists and the formation of coalition. These coalitions decided important functions in CPOE such as what medications should be in order sets, which were not trusted or welcomed by other providers.

2.6 Summary

CPOE has many features that can help in reducing or preventing errors. The wide range of potential CPOE benefits include reduction of medication errors during prescribing, transcribing and dispensing, reduction in length of stay, decreased adverse medication events, increased adherence to medical guidelines and appropriate medical decisions, and decreased duplicate orders.

However, CPOE can also contribute to errors and facilitate new errors. Hence, it is important to understand the technical and clinical implications of each feature. Based on analysis of 390 hours of observation of 95 clinicians, and 32 interviews at five hospitals Ash et al. identified 380 instances of unintended consequences of CPOE.[79] They found that the highest proportion of unintended consequences were due to the decision support features within CPOE.[80] As noted, free text fields within CPOE, such as those found in CNMOs, are not included in decision support. Thus, it is incredibly important to understand how these free text fields are being used. Appendix A shows summary of citations used in this literature review.

CHAPTER 3

CONTENT ANALYSIS OF FREE TEXT COMMUNICATION ORDERS

3.1 Methods

I conducted a retrospective analysis of Communication for Non Med Order (CNMOs) placed at six different hospitals in the mid-Atlantic region during 2017, comprising Emergency, Inpatient, Outpatient, Observation and Ambulatory surgery patient types. All CNMOs placed during 2017 were extracted for analysis (n = 667,429). A subset of the data was randomly sampled based on the recommended number of samples required to estimate the true proportion mean with the required margin of error (0.99%) and confidence level (99.9%). This is based on the following calculation

$$X = Z^2\, p(\,1 - p)$$

$$n = N \frac{X}{((N-1)E^2 + X)}$$

Where Z is the Z value (3.3 for confidence level of 99.9%)

E is the margin of error (0.01)

N is the size of the population

n is the sample size

p is the sample proportion (assumed as 0.5)

This calculation is based on the Normal distribution and assumption that the data are independent and identically distributed. A sample of 26,524 CNMOs provided an error rate < 0.99% and a confidence level of 99.9%. The sample was stratified based on patient type, hospital location, month, weekday, and hour to reflect the frequency and nature of CNMOs written at various settings.

The interface for entering CNMOs within the EHR used in this study has a “Details Tab” and “Order Comments Tab” with free text fields. These include “Verbatim Order” and “Special Instructions” (both within the Details Tab), and “Order Comments”. The “Verbatim Order”, “Special Instructions”, and “Order Comments” fields were concatenated into a single string, and this string was considered as the final order for analysis. Multiple CNMOs contained the same free text, resulting in a sample of 5,574 unique order text strings. Because CNMOs have no set content, providers can use these orders as they deem fit. We therefore conducted a qualitative thematic analysis of these 5,574 strings. A codebook describing representative themes was iteratively developed (5 iterations) by two research team members using a sample of 50 CNMOs. Each CNMO could include multiple themes. Inter-rater reliability was calculated for 10% of unique free text CNMOs (n = 558) and was high (Cohen’s kappa = 0.82). The results below report on the full set of 26,524 CNMOs, based on the analysis of the 5,574 unique strings.

3.2 Results

Sixteen themes were identified. Figure 4 shows the distribution of the themes in the coded CNMOs. Appendix B specifies the definition for each theme, inclusion and exclusion criteria for associating CNMOs with each theme and free text examples assigned to each theme shown in Figure 4. Medication related information was the most frequent theme included in the CNMOs (11,166/ 26,524; 42%). Patient status information (ADT: Admission, Discharge, and Transfer) was the second most common theme in the CNMOs, followed by Protocols, Documentation and Transportation. A very small proportion of the CNMOs included information related to patient goals, diet, education and non-clinical tasks.

Many of the information types in the CNMOs were associated with other standard orders in the EHR. These order categories are highlighted in dark gray in Figure 1.

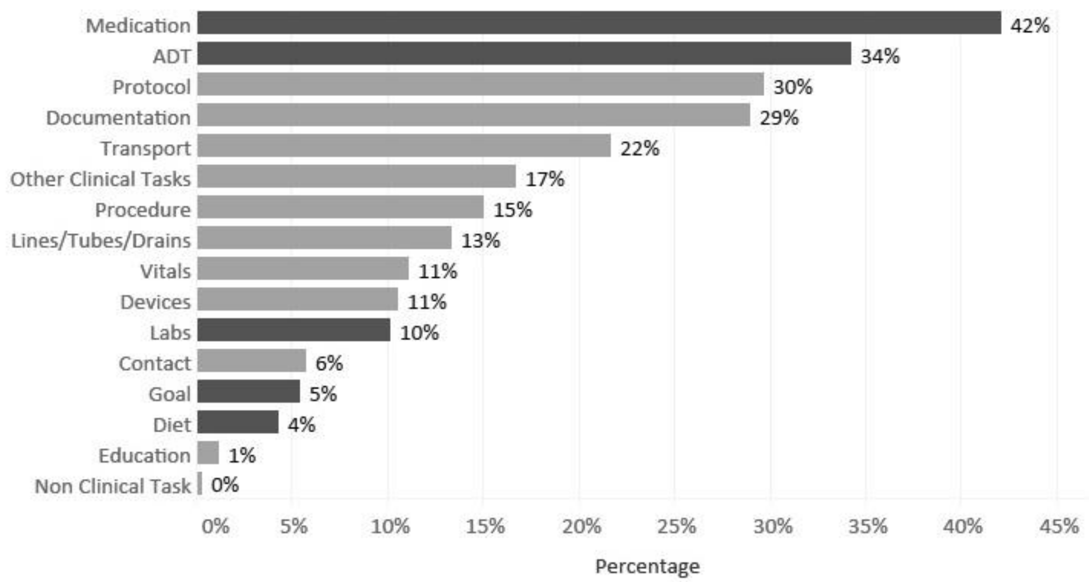

Figure 1: Distribution of themes in Communication for Non-Med Orders

3.3 Discussion

Surprisingly, a large proportion of the CNMOs were used to communicate information about medications (42%), even though this order type is specifically termed **communication for non-med order**. CNMOs in the dark gray categories may pose an elevated risk to patient safety. These free text CNMOs may be used as workarounds and contain information that should be included with more appropriate order-types, such as medication orders. Some of these CNMOs could pose an elevated risk to patient safety, when correct and complete information is not communicated through the expected pathway.

Table 1 shows examples of text from CNMOs that are potentially risky because the information is not associated with standard CPOE order. For example, one physician wrote "increase argatroban now by 0.1 mcg/kg/min" in the CNMO. If this increase is not reflected in the medication order and/or a nurse does not see this in the medication order, the patient's blood may thinned too much and the patient could have unnecessary bleeding. In another example, a physician wrote "Please keep him NPO after TEE since he is going to surgery in the afternoon" in the CNMO. If this information is in a CNMO instead of a diet order, a nurse may miss this information and give food to the patient. This error may delay the surgery and negatively affect patient care.

Table 1: Example CNMOs

Category	**Low risk example**	**Potentially high-risk example**
Medication	"Make sure patient has taken meds"	"increase argatroban now by 0.1 mcg/kg/min"
Admission / Discharge / Transfer	"will need a taxi to go home	"Must void before DC if no foley catheter in place".
Labs	"please ensure troponins are drawn and sent to lab. Thanks"	"Draw labs from central line"
Diet	"PO challenge"	"Please keep him NPO after TEE since he is going to surgery in the afternoon"

CNMOs are traditionally used as low-level information sharing fields regarding patient care. Some of the content might go unnoticed as there are other designated places within the EHR where other providers might expect this information. Higher-risk information about themes such as diet and medications may not be seen by the providers because of three main reason. First, the provider may expect information in a CNMO to be in the associated medication or diet order fields. Unlike 'Communication for Non Medication Order', 'Communication for Lab Add on' orders (another type of communication order) are always displayed along with other laboratory orders. Second, CNMOs are not associated with an EHR task list so there is no cognitive cue to nurses that a task is pending. Third, the CNMOs appear at the bottom of the orders list, so providers must look at the bottom of the screen to find these orders. For patients with numerous medication and lab orders, providers must scroll to view CNMOs, making CNMOs riskier for more complex or acute patients.

Providers who write these CNMOs may not be cognizant of other options available within the EHR to write similar information. The large number of order types and the confusing or inappropriate order names might contribute to unexpected use of the system. It might be too cumbersome to enter information in designated areas of the existing EHR system where one might expect that information, or the EHR might not allow providers to enter the information or make changes to existing orders. Therefore, it is important to identify common EHR workaround patterns related to CNMOs and reason for these workarounds. We should also identify error rates that occur as a result of these workarounds. Using this information, we can identify EHR design changes and provider training, and prioritize their development based on risk mitigation. The next chapters attempt to address these issues.

CHAPTER 4

UNDERSTANDING THE USAGE PATTERN OF FREE TEXT COMMUNICATION ORDERS FOR MEDICATION INFORMATION

4.1 Methods

I chose to focus on medication related information because a large proportion of CNMOs contained medication information even though there was a separate CPOE order type for medications and these CNMOs had high potential for medication error. To understand more detailed patterns associated with CNMOs identified as medication related, I divided the 26,524 CNMOs into two groups, depending on whether they contained medication related information (11,166/ 26,524; 42%) or not (15,358/ 26,524; 58%). As in the previous analysis, all coding was based on the 5,574 unique order text strings, which were then rolled up to the full set of 26,524 CNMOs. I coded each CNMO with its hospital location, patient setting, action provider type, ordering provider type, action provider identification number, ordering provider identification number, the medication names and classes mentioned in the order, medication risk level, and the actions specified in the order. *Hospital location* means the individual hospitals within the hospital system. *Patient setting* represents the different settings (e.g., inpatient, outpatient) where the patients are given care by the providers. *Action provider types* are those who interact with CPOE system to place the order. *Ordering provider types* are those individuals who direct the order to be placed in the CPOE. They sign and own the orders. Ordering providers can be the action providers, or they can ask another provider to place the order in EHR system. *Ordering provider identification number* and *action provider identification number* are numbers unique to individual providers.

I then coded the content of each of the 11,166 CNMOs containing medication information with the medication names, medication classes, medication risk levels, and actions specified in the order. *Medication names* are the exact medication names mentioned in the order, and *medication classes* are groups of medications used for a common purpose. *Medication risk level* means whether each medication name mentioned in the order would be considered high risk. *Actions specified in the order* are specific clinical tasks requested from other providers. I calculated descriptive statistics for each category to identify whether there appear to be systematic differences in ordering patterns when medication information appears in CNMOs.

4.2 Results

The comparative results are based on analysis of all 26,524 CNMOs, separated into those containing medication information (11,166/ 26,524; 42%) and those not containing medication information (15,358/ 26,524; 58%).

4.2.1 Variation across Hospital Locations

Figure 2 shows the variation in use of CNMOs containing medication information across hospitals. The second largest number of CNMOs containing medication information were written at Hospital 6, but this hospital also had the largest number of CNMOs overall. When normalizing the number of CNMOs containing medication information by the total number of CNMOs written, this hospital had the lowest proportion of CNMOs with medication information. Hospital 4 had the lowest number of CNMOs containing medication information, but the highest proportion of overall CNMOs containing medication information.

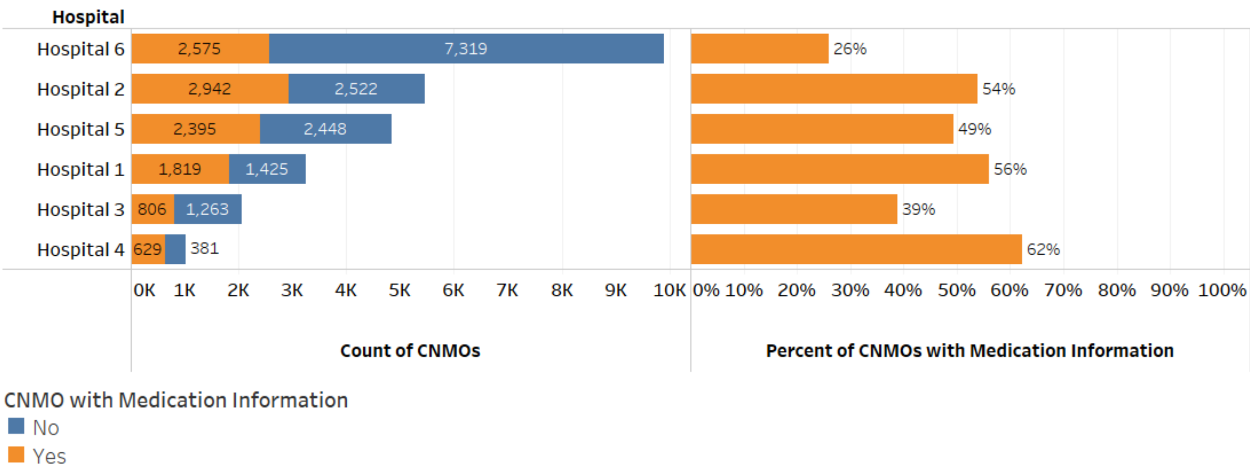

Figure 2: Variation in CNMO usage across hospital locations

4.2.2 Variation across Patient Settings

Figure 3 shows the variation in CNMOs containing medication information for different patient types. Providers caring for inpatients wrote many CNMOs containing medication information, but also had more than twice the number of total CNMOs than ambulatory surgery patients. When taking this base rate into account, approximately 62% of CNMOs written in the ambulatory surgery setting contained medication information compared to 38% of CNMOs written in the inpatient setting. Providers caring for patients in the emergency department wrote a very low number of CNMOs containing medication information and their proportion of CNMOs was also the lowest.

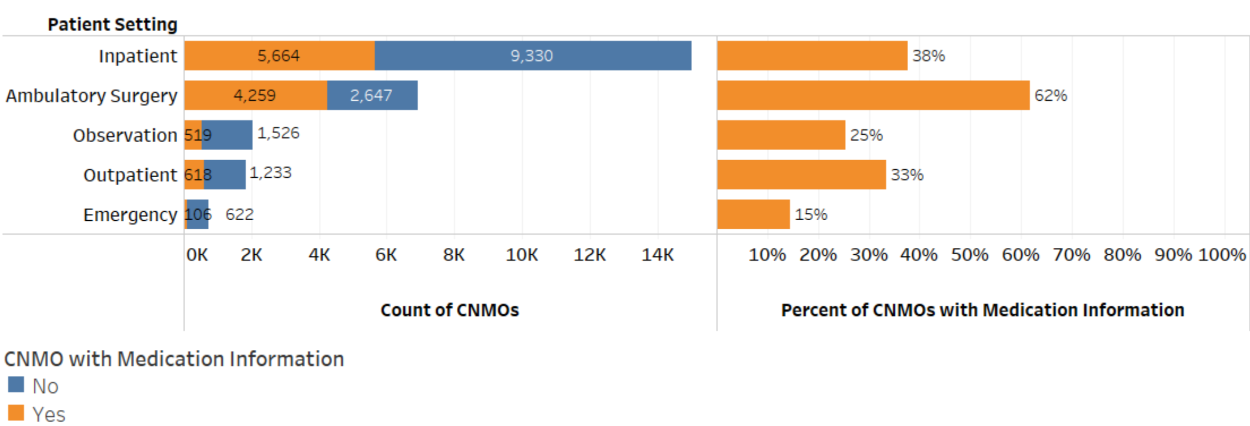

Figure 3: Variation in CNMO usage across patient types

4.2.3 Variation across Hospital Locations and Patient Settings

Figure 4 shows the variation in CNMOs containing medication information for the five patient setting types at the six hospitals. The proportion of CNMOs containing medication information in the different patient settings at various hospitals ranged from 7% to 84%. In hospitals 1, 2, 3 and 4, the number of CNMOs containing medication information written in the inpatient setting was larger than the number of CNMOs containing medication information in the ambulatory setting. In all hospitals except hospital 6, more than 70% of CNMOs written in the ambulatory setting contained medication information.

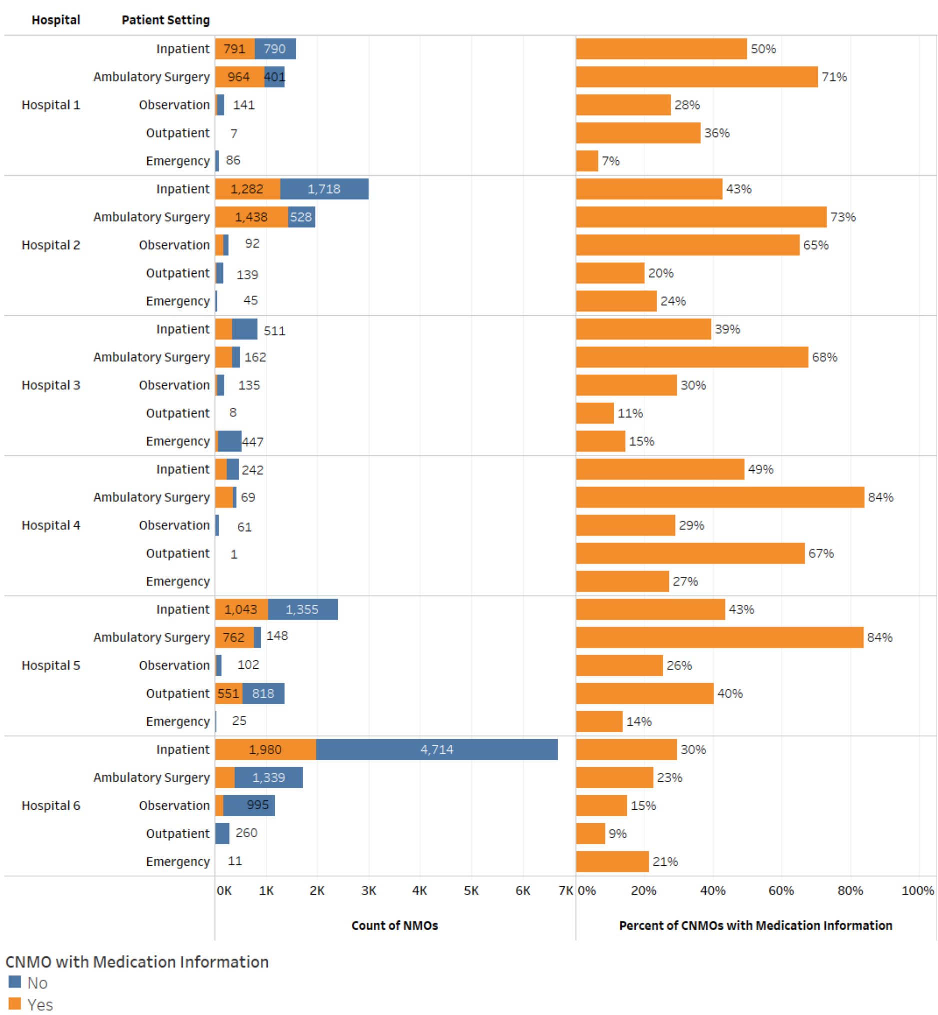

Figure 4: Variation in CNMO usage across hospital locations and patient types

4.2.4 Variation across Action Provider Types

Figure 5 shows the variation in CNMOs containing medication information for different action provider types, for those who wrote at least 50 CNMOs (a cutoff to consider only those provider types who use CNMOs regularly.) Operating room charge nurses, resident physicians, registered nurses (RNs), nurse practitioners, and physician assistants were the five action provider types ordering the most CNMOs. The proportion of CNMOs containing medication information for action provider types who entered at least 50 CNMOs ranged from 4% (Occupational therapists) to 68% (Anesthesiologists).

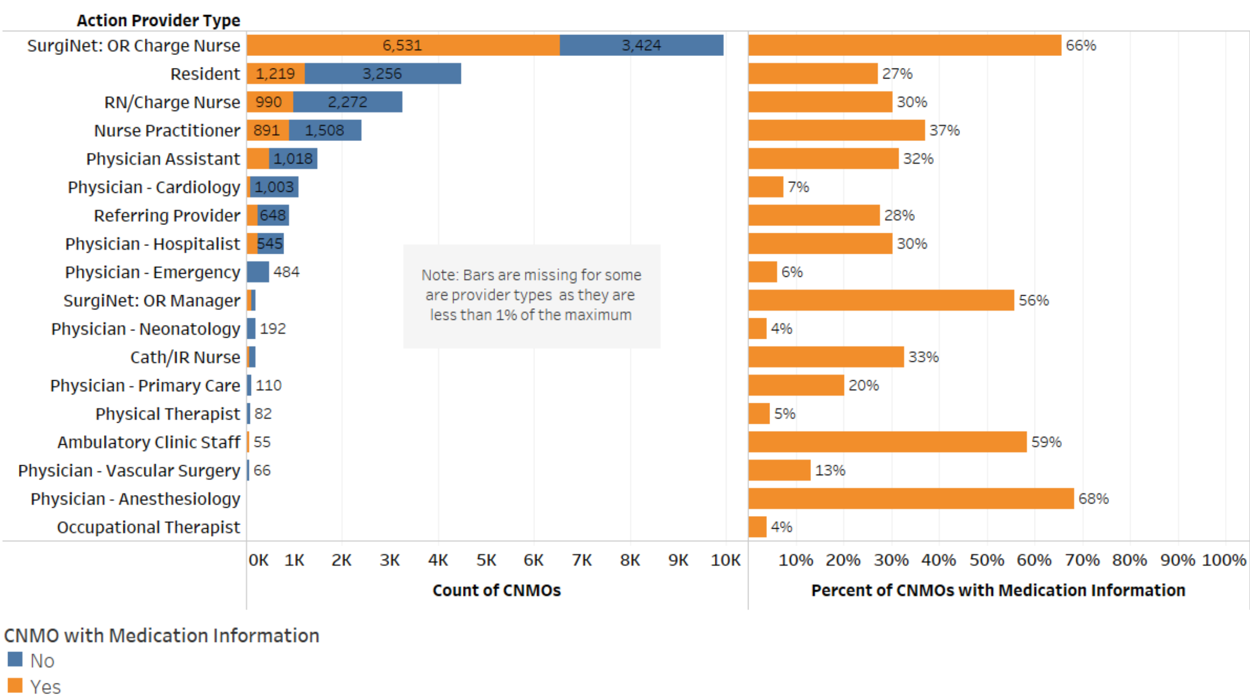

Figure 5: Variation in CNMO usage across action provider types

The scatter plot in Figure 6 compares the count of CNMOs ordered and proportion of their CNMOs containing medication information. Operating room charge nurses wrote approximately 10,000 CNMOs, more than double the number of CNMOs written by the closest action provider type (resident physicians). More than 65% of CNMOs by Operating room charge nurses contained medication information compared to 27% by resident physicians.

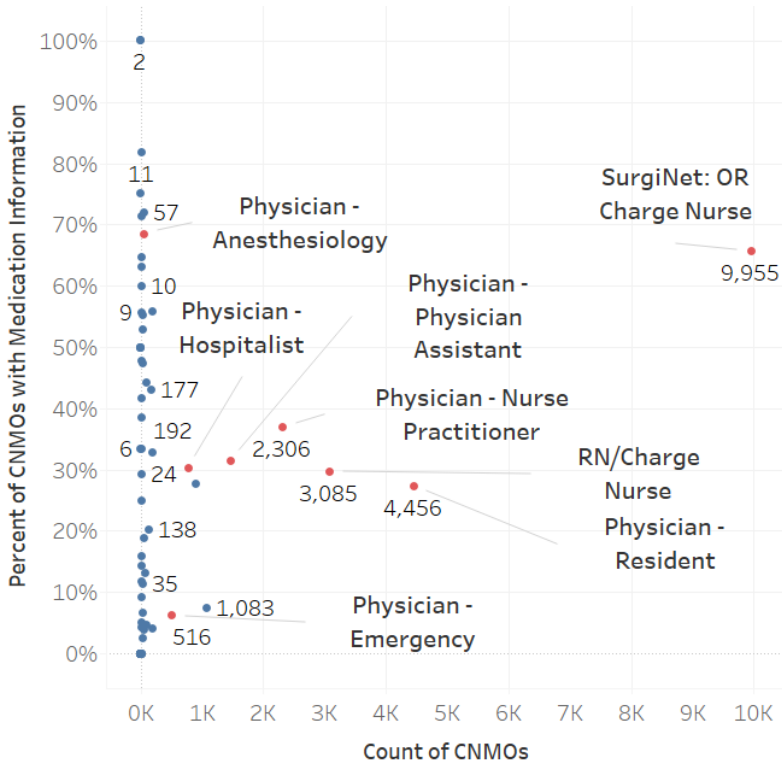

Figure 6: Count of CNMOs versus Percent of medication related CNMOs across action provider types

4.2.5 Variation across Action Provider Type and Hospital Location

The proportion of CNMOs containing medication information for action provider types at different hospitals ranged from 0% (Emergency Physicians at Hospital 5) to 85% (OR Charge Nurses at Hospital 5). Figures 7 and 8 show the variation in CNMOs containing medication information for different action provider roles at each hospital location. OR charge nurses had the highest proportion of their CNMOs with medication information, ranging from 37% (Hospital 6) to 85% (Hospital 5). CNMOs ordered by Emergency physicians containing medication information ranged from 0% (Hospital 5) to 24% (Hospital 2). The proportion of CNMOs with medication information ordered by residents ranged from 19% (Hospital 1) to 34% (Hospital 3).

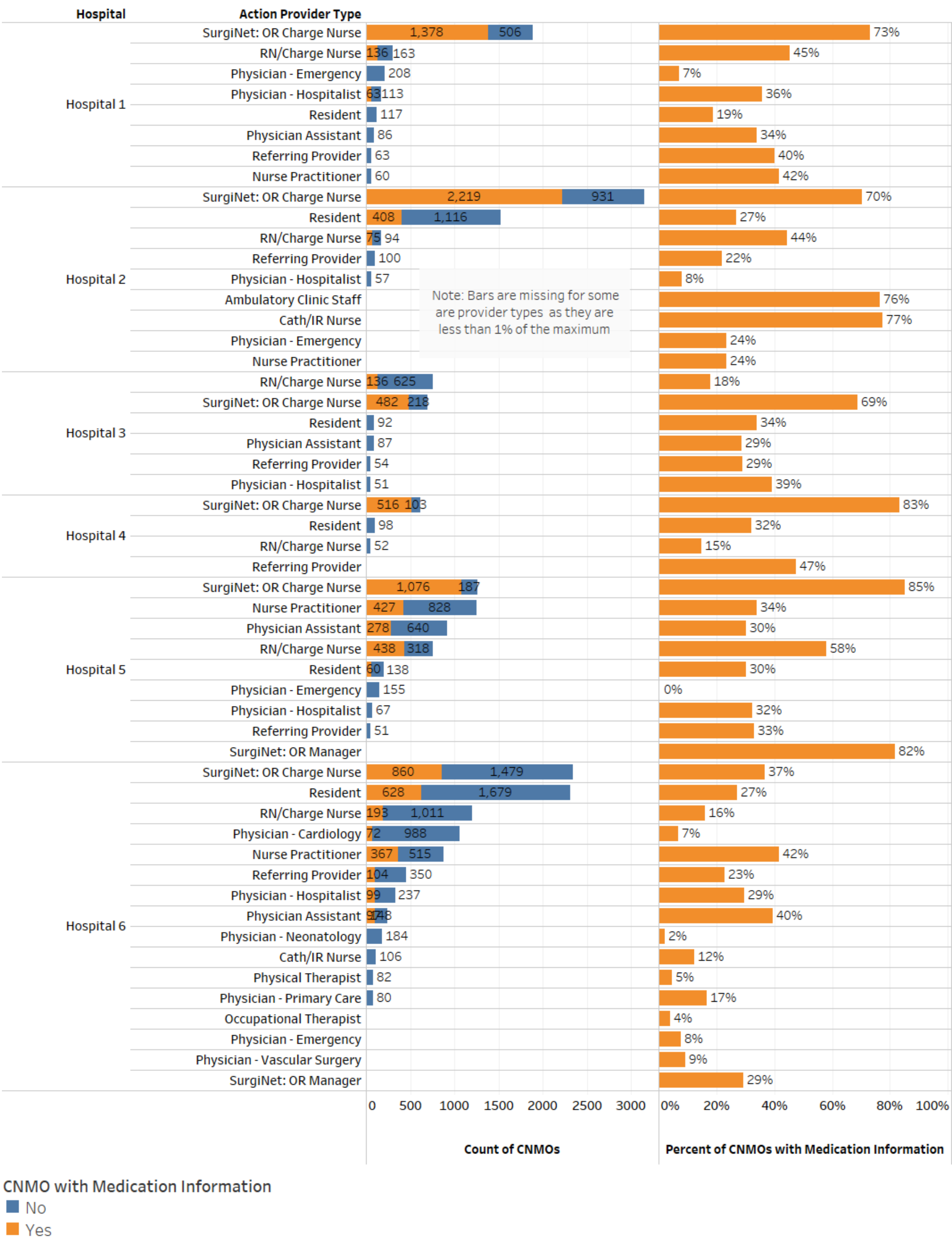

Figure 7: Variation in CNMO usage across hospital locations and action provider types

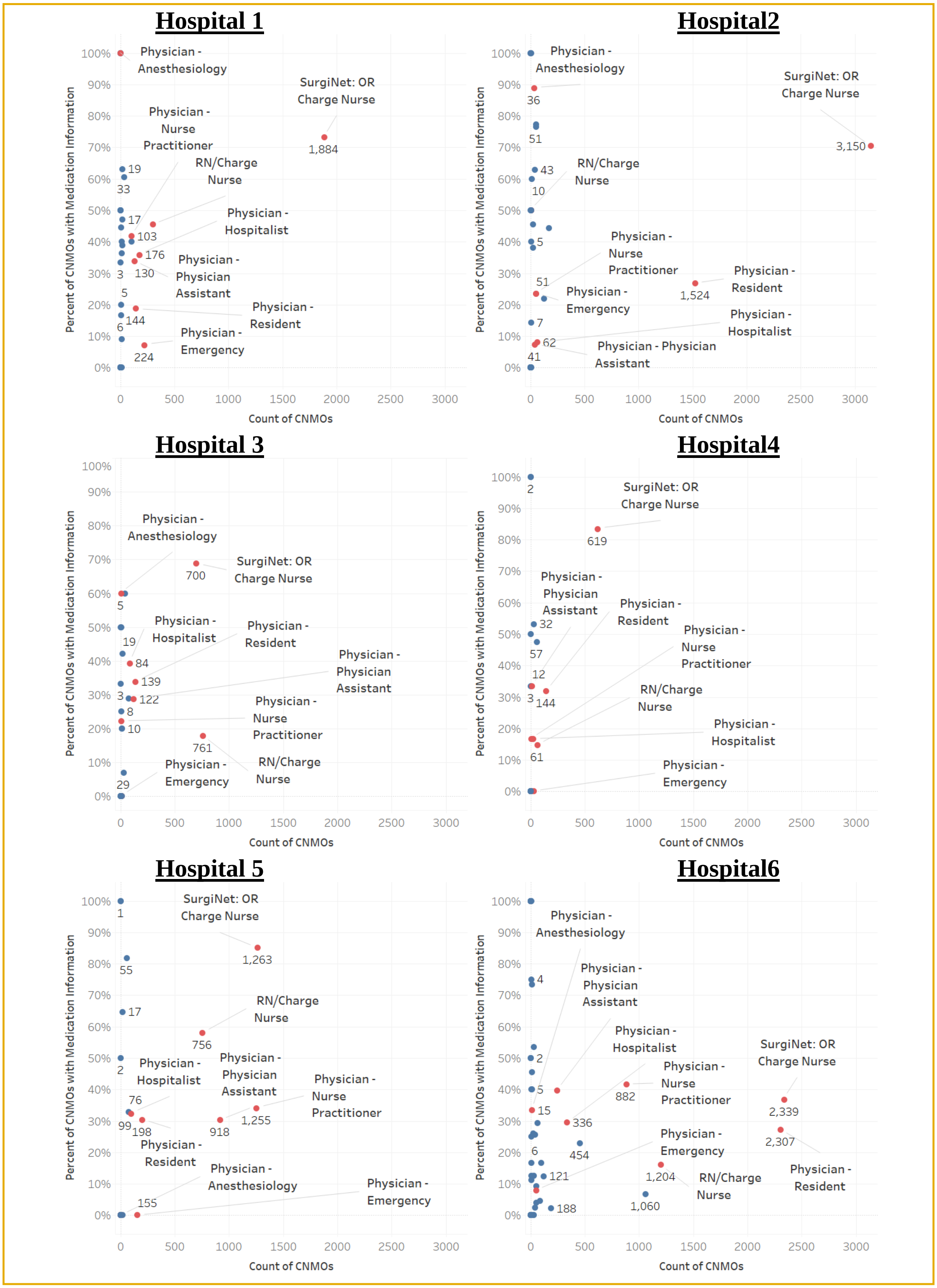

Figure 8: Count of CNMOs vs Percent of medication related CNMOs across action provider types for each hospital

4.2.6 Variation across Ordering Provider Types

There were over 50 ordering provider types. Figure 9 shows the variation in CNMOs containing medication information for different ordering provider types with at least 50 CNMOs. Resident physicians, anesthesiologists, certified registered nurse anesthetists (CRNAs) / anesthesiologist assistants (AAs), nurse practitioners and physician assistants were the five ordering provider types with the largest number of CNMOs. Certified registered nurse anesthetists (CRNAs) / anesthesiologist assistants (AAs), anesthesiologists, physician orthopedics, referring providers and nurse practitioners were the five ordering types with the highest percentage of their CNMOs containing medication information.

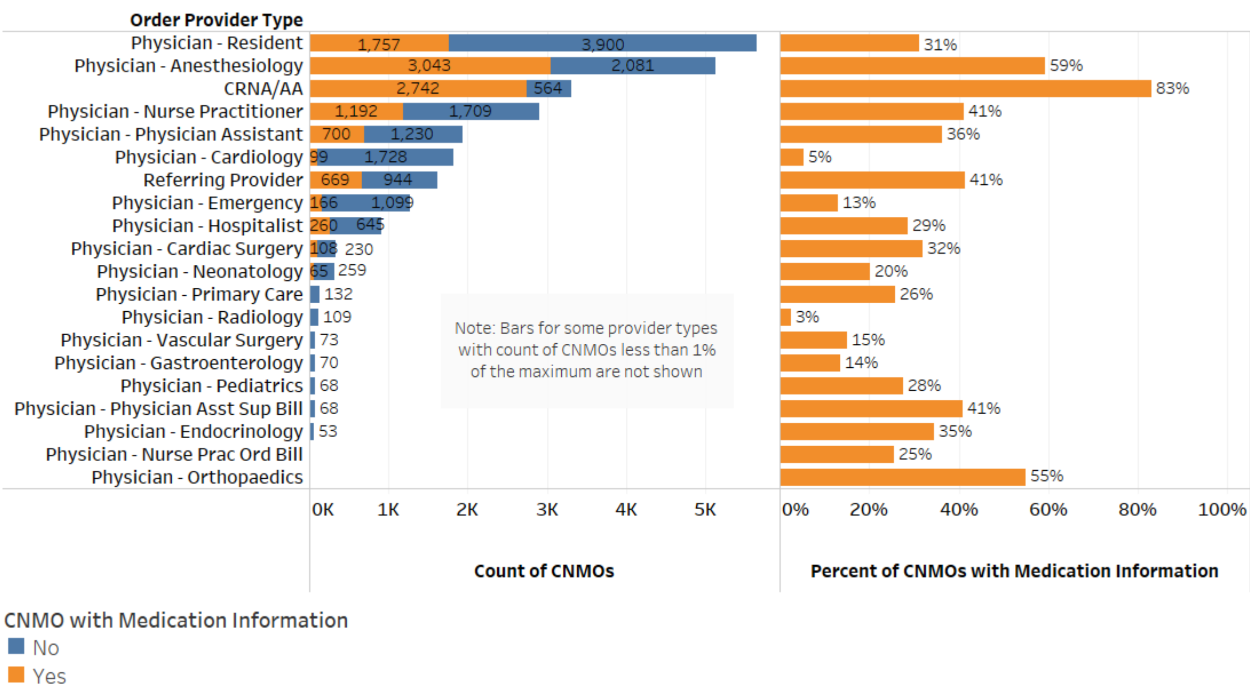

Figure 9: Variation in CNMO usage across ordering provider types

The scatter plot in Figure 10 compares the count of CNMOs ordered and proportion of their CNMOs containing medication information. More than 82% of CNMOs by CRNAs contained medication information. Nurse practitioners, who ordered a similar number of CNMOs, had 41% of their CNMOs containing medication information.

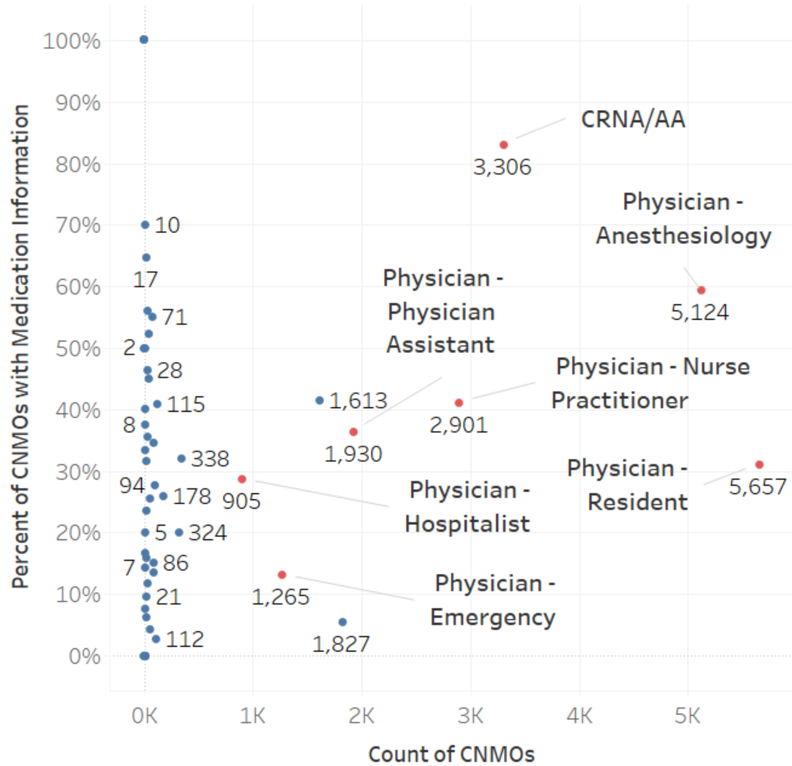

Figure 10: Count of CNMOs versus Percent of medication related CNMOs across ordering provider types

4.2.7 Variation across Ordering Provider Type and Hospital Location

There is a large variation in the proportion of CNMOs containing medication information for different ordering provider roles at each hospital. The proportion of CNMOs containing medication information ranged from 0% to 92%. Figures 11 and 12 show the variation in CNMOs containing medication information for different ordering provider roles at each hospital location. CRNAs had the highest proportion of their CNMOs containing medication information, but the proportion of their CNMOs containing medication information varied from 10% (hospital 6) to 92% (Hospital 4). The proportion of CNMOs containing medication information ordered by residents ranged from 19% to 37%. None of the CNMOs ordered by emergency physicians at Hospital 5 contained medication information, while 19% of CNMOs ordered by emergency physicians at Hospital 3 contained medication information.

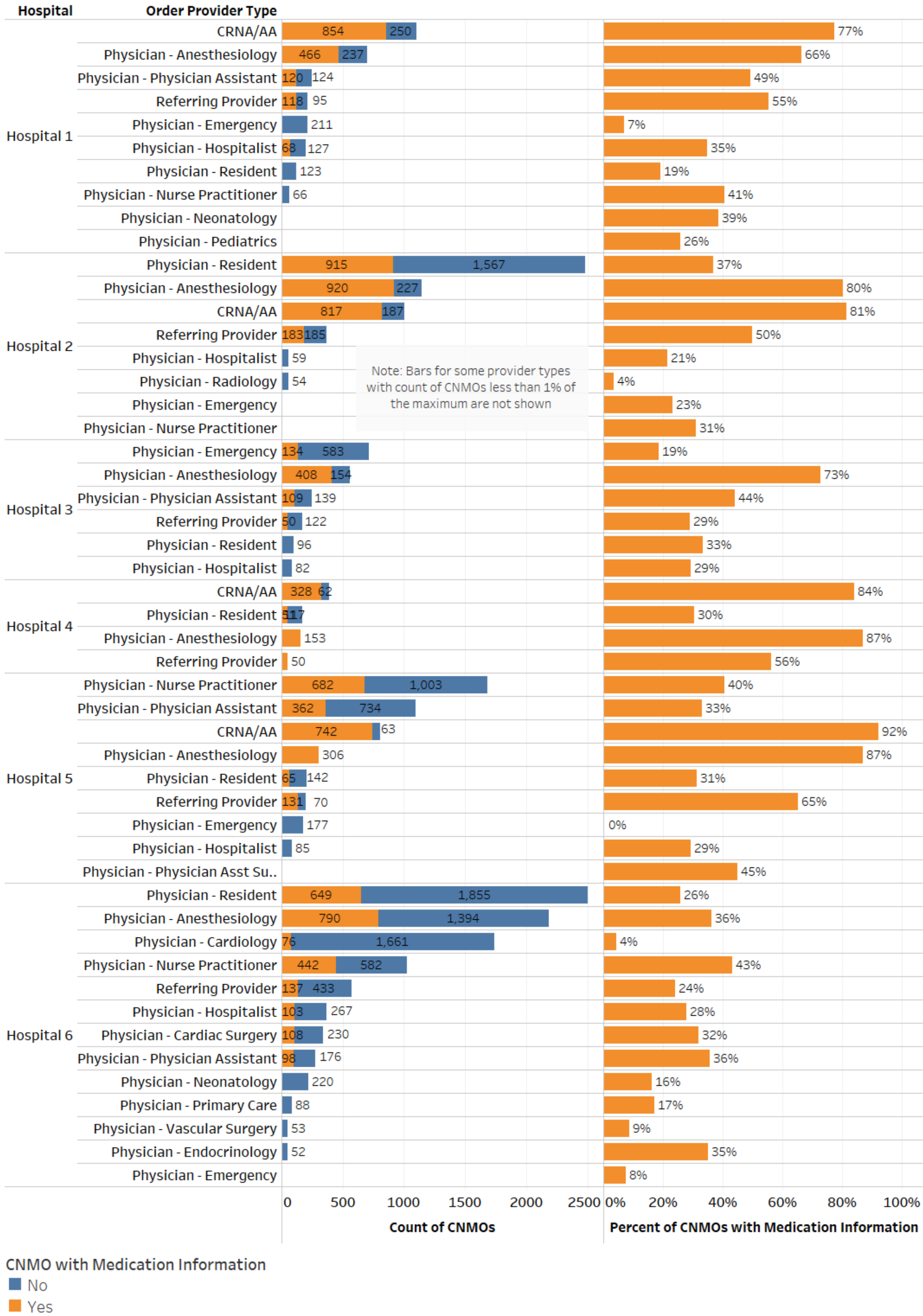

Figure 11: Variation in CNMO usage across hospital locations and ordering provider types

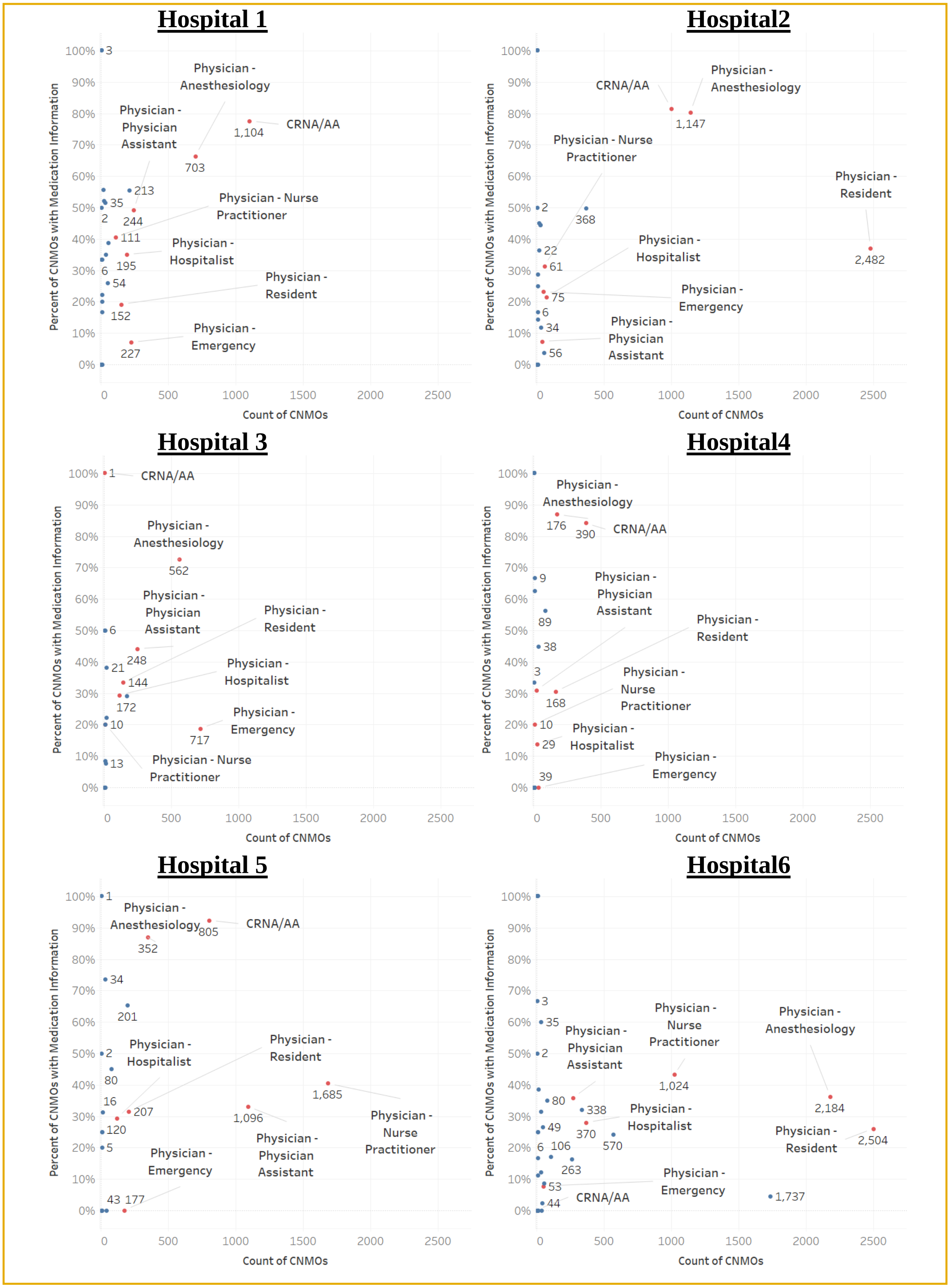

Figure 12: Count of CNMOs vs Percent of medication related CNMOs across ordering provider types for each hospital location

4.2.8 Variation across Individual Providers

Figure 13 shows the variation in CNMOs containing medication information across the 14,232 action providers. Each dot in the graph represents one individual action provider. The highest number of CNMOs at each hospital written by individual action providers ranged from 80 to 260. The proportion of CNMOs by individual action providers containing medication information ranged from 0% to 100%. At all hospitals, there was a subset of action providers who wrote more CNMOs compared to other providers (toward right side of each graph). At hospitals 1, 2, and 4, these high-volume action providers seemed to have a high proportion of their CNMOs containing medication information (toward the top of each graph). In hospitals 5 and 6 these high-volume action providers seemed to have a low proportion of their CNMOs containing medication information (toward the bottom of each graph). There was no specific pattern at Hospital 3.

Figure 14 shows the variation in CNMOs containing medication information across the 6,989 ordering providers. The highest number of CNMOs at each hospital written by individual ordering providers ranged from 70 to 500. The proportion of CNMOs by individual ordering providers containing medication information ranged from 0% to 100%. The proportion of CNMOs containing medication information ordered by individual ordering providers seemed to be uniform in hospitals 3. However, in other hospitals there was considerable variation across individual ordering providers. Like action providers, at all hospitals except Hospital 3 there was a subset of ordering providers who wrote more CNMOs compared to other ordering providers (toward right side of each graph). At hospitals 1, 2, and 4, these high-volume ordering providers seemed to have a high proportion of their CNMOs containing medication information (toward the top of each graph). At hospitals 5 and 6 these high-volume ordering providers seemed to have a low proportion of their CNMOs containing medication information (toward the bottom of each graph). There was no specific pattern at Hospital 3 as all but 1 ordering provider had a lower number of CMNOs.

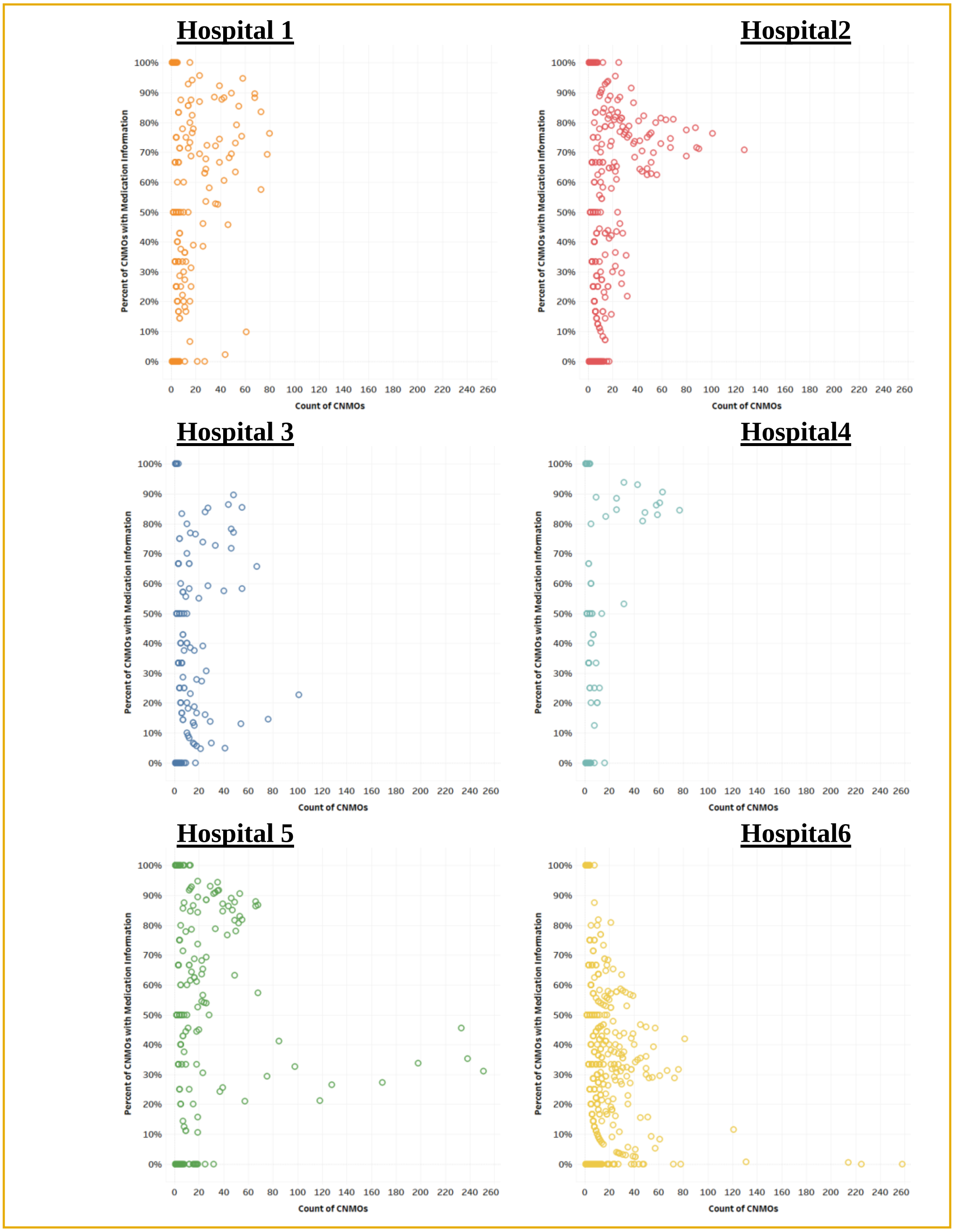

Figure 13: Count of CNMOs vs Percent of medication related CNMOs for individual action providers across hospitals

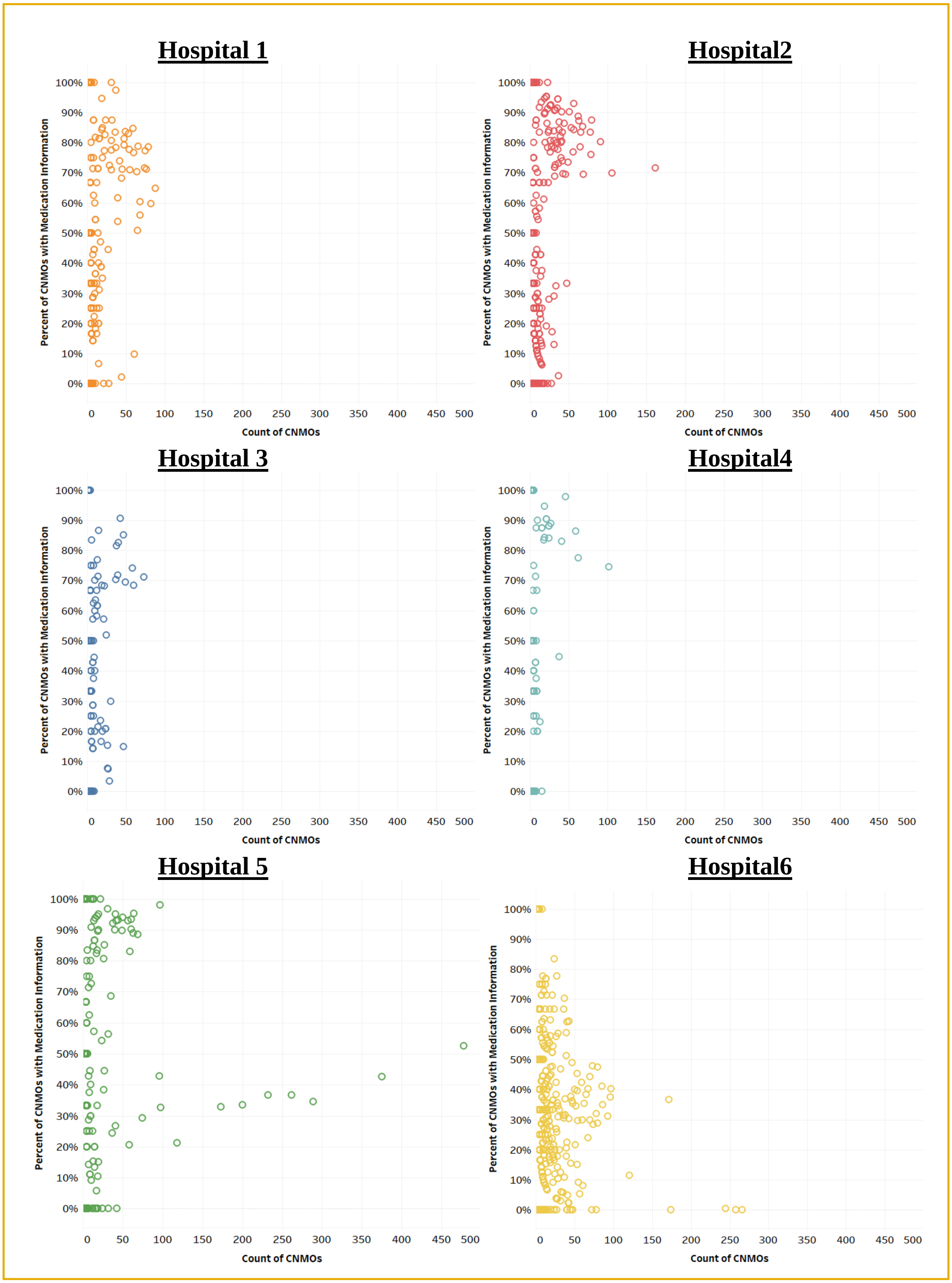

Figure 14: Count of CNMOs vs Percent of medication related CNMOs for individual ordering providers across hospitals

4.2.9 Prevalence of Individual Medication Names and Medication Classes

There were over 200 different medication names referenced in the CNMOs. Figure 15 shows the top 25 medication names referenced in the CNMOs. Naloxone, Heparin, Flumazenil, Dextrose and Glucagon Hydrochloride were the five medication names most frequently mentioned in CNMOs. 1,470 CNMOs mentioned more than one medication name. The complete list of medication names in the CNMOs is shown in Appendix C. 26% of the CNMOs contained medication information without mention of specific medication name(s).

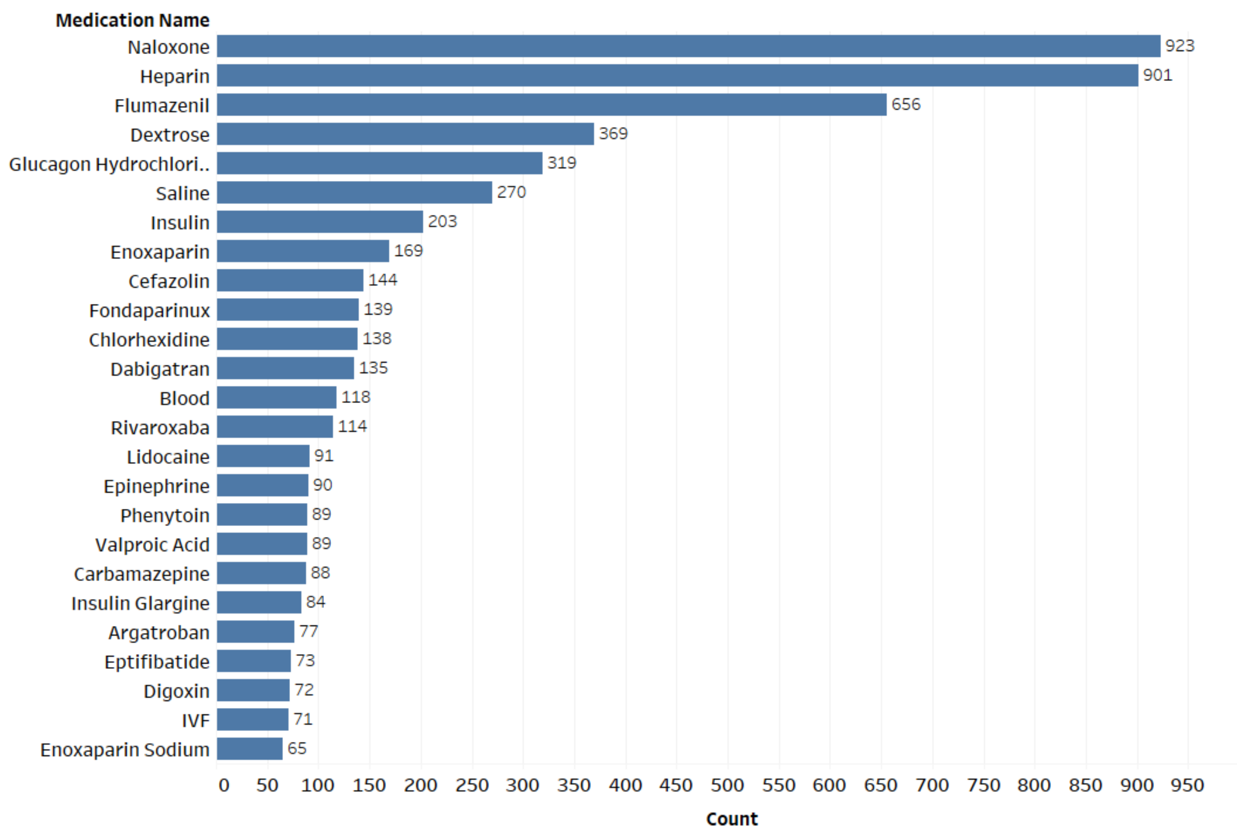

Figure 15: Prevalence of medication names in CNMOs

Figure 16 shows the prevalence of medication names referenced in CNMOs across hospitals. A substantial proportion of CNMOs containing medication information did not mention a specific medication name, ranging from 21% (Hospital 6) to 88% (Hospital 2). Heparin was the most common medication name mentioned in CNMOs at Hospital 1 (14%) and

Hospital 2 (3%). Carbamazepine, Phenytoin and Valproic Acid were the most common medications mentioned in CNMOs at Hospital 3 (11%). Dextrose was the most common medication name mentioned in CNMOs at Hospital 4 (7%). Enoxaparin was the most common medication name mentioned in CNMOs at Hospital 5 (7%). Naloxone is the most common medication name mentioned in CNMOs at Hospital 6 (34%). Naloxone was not mentioned at all in CNMOs written at hospitals 1, 2, 3, or 4.

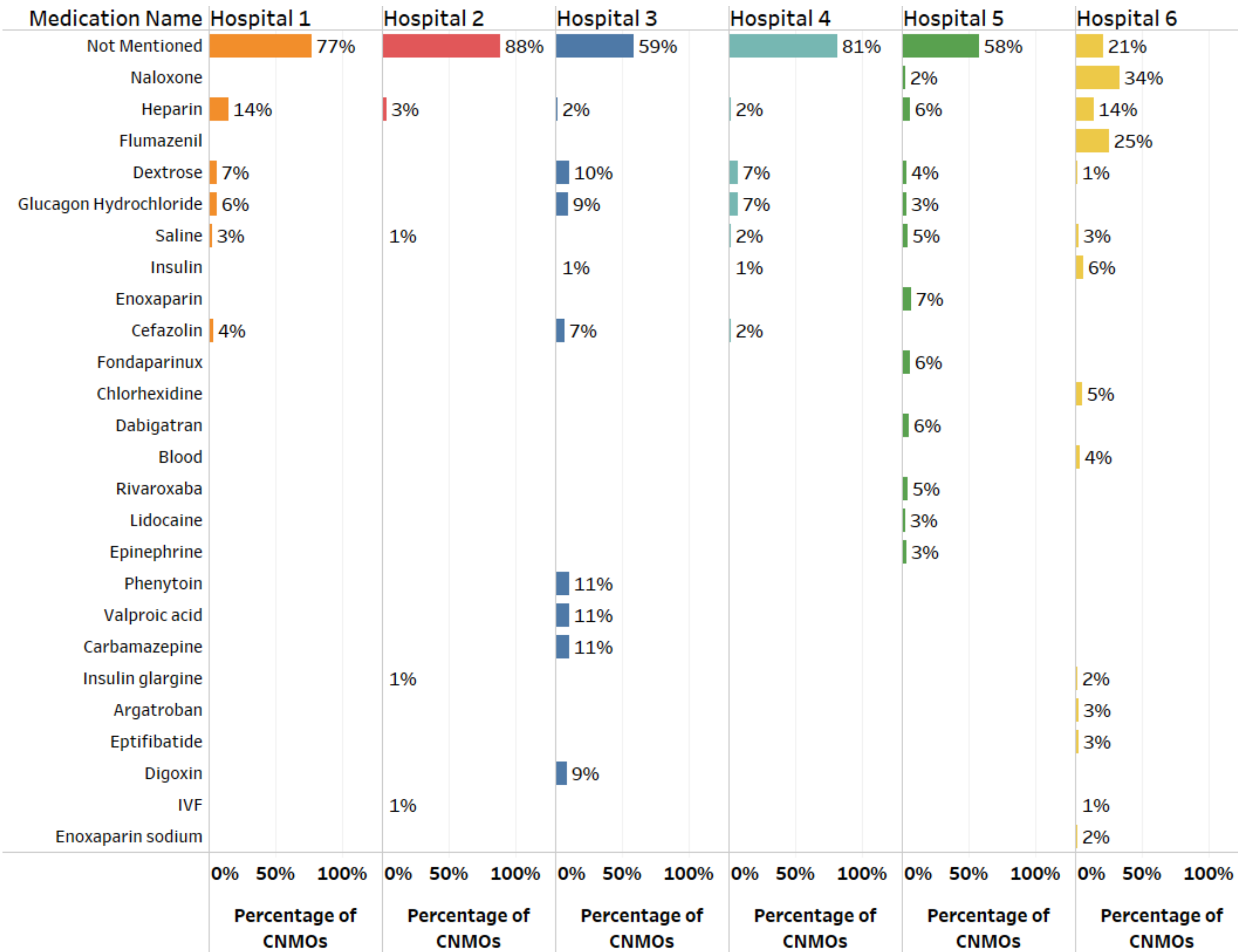

Figure 16: Prevalence of medication names in CNMOs across hospital locations

Individual medication names were assigned to medication classes, based on their intended use. For example, Aspirin can be used as an antipyretic (to reduce fever) or as antiplatelet (to avoid blood clots). Such medications can belong to two medication classes. Based on the clinical context of the surrounding text in the CNMO, the medication names were assigned to most probable medication class by a clinically trained researcher. Some CNMO texts mentioned the term 'order set'; for example, "Pls discontinue PACU order set". These orders were assigned to the class 'Order Set'. Figure 17 shows the top 25 medication classes mentioned in CNMOs. Order sets were the most common, followed by antidotes, analgesics, anticoagulants and endocrine metabolic agents. An order set is a group of predetermined medications, ordered together for a clinical condition or diagnosis. When physicians communicate about order sets in CNMOs, the medication names contained in the order sets are not explicit. The complete list of medication classes mentioned in the CNMOs is shown in Appendix D.

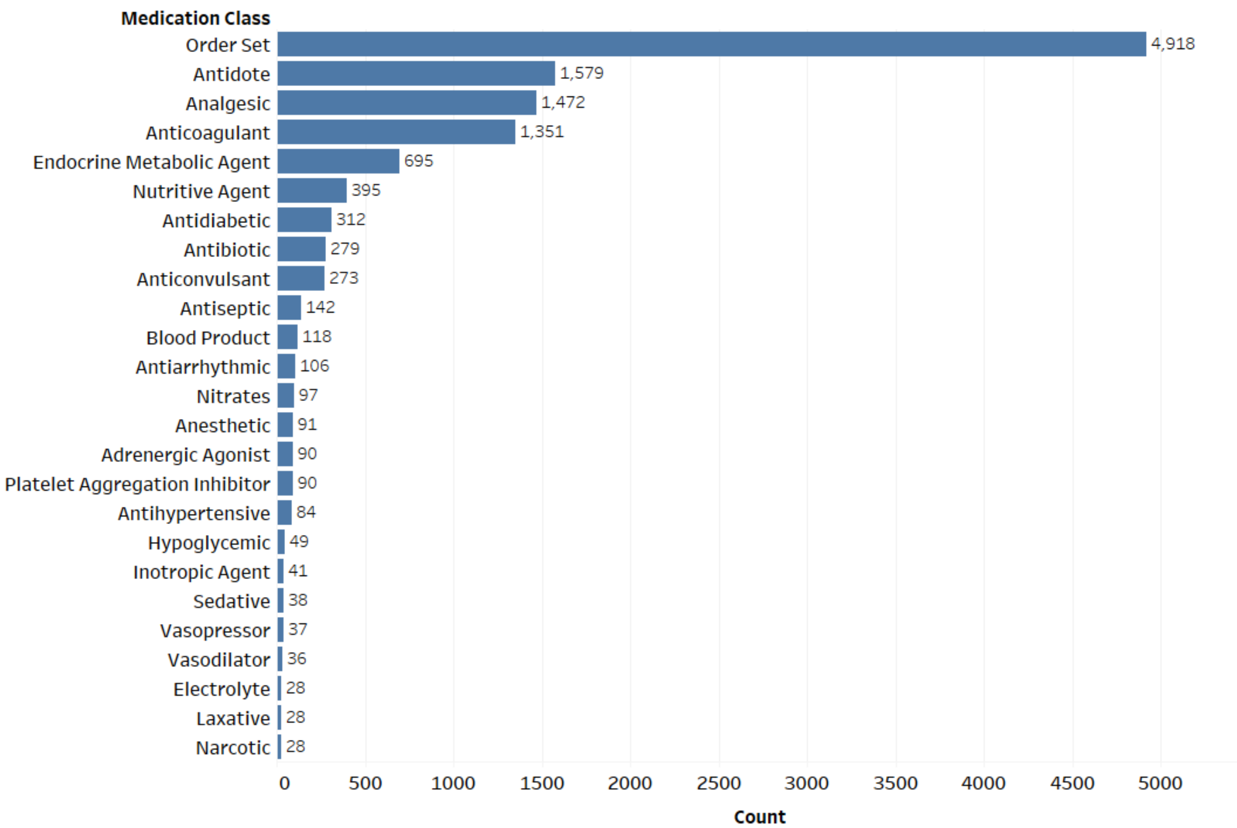

Figure 17: Prevalence of medication class in CNMOs

Figure 18 shows the distribution of medication classes mentioned in CNMOs at each hospital. At all hospitals except Hospitals 6, a substantial proportion of CNMOs containing medication information mentioned Order Sets, ranging from 40% (Hospital 3) to 70% (Hospital 4). At Hospitals 1 and 2, analgesics were the most common medication class mentioned in CNMOs (20%, 19%). Anticonvulsants were a common medication class mentioned in CNMOs at Hospital 3 (33%) but were not mentioned in CNMOs at the other hospitals. Endocrine Metabolic Agents were the most common class mentioned in CNMOs at Hospital 4 (13%), Anticoagulants were the most common medication class mentioned in CNMOs at Hospital 5 (28%) and antidotes were the most common medication class mentioned in CNMOs at Hospital 6 (59%).

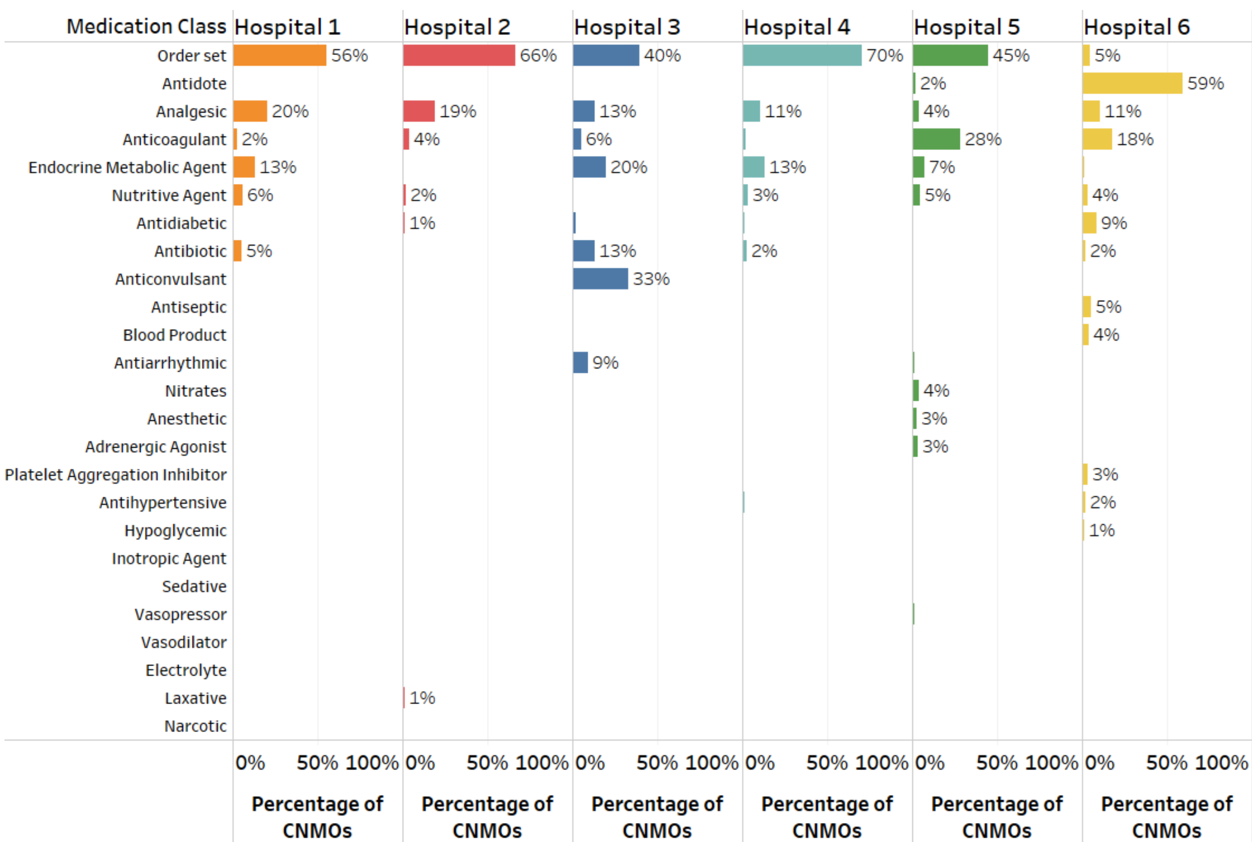

Figure 18: Prevalence of medication class in CNMOs across hospitals

4.2.10 Medication Risk Assessment

Incorrect administration of some medications can cause significant patient harm and are considered high risk. A list of internationally recognized high-risk medications was used to identify CNMOs containing high-risk medication information.[81] This list includes medications belonging to the following medication classes: Anti-infectives, Psychotropics, Potassium, Insulin, Narcotics, Chemotherapeutic agents, Heparin, and Epidural Neuromuscular blocking agents. Figure 19 shows a comparison of the proportions of CNMOs containing low and high-risk medication information. While Hospital 6 had lower proportion of CNMOs containing medication information overall (26%), its proportion of CNMOs containing high-risk medication information was the highest (15%) of all hospitals. Hospital 4 had 62% of CNMOs containing medication information, but only 2% of CNMOs with high-risk medication information.

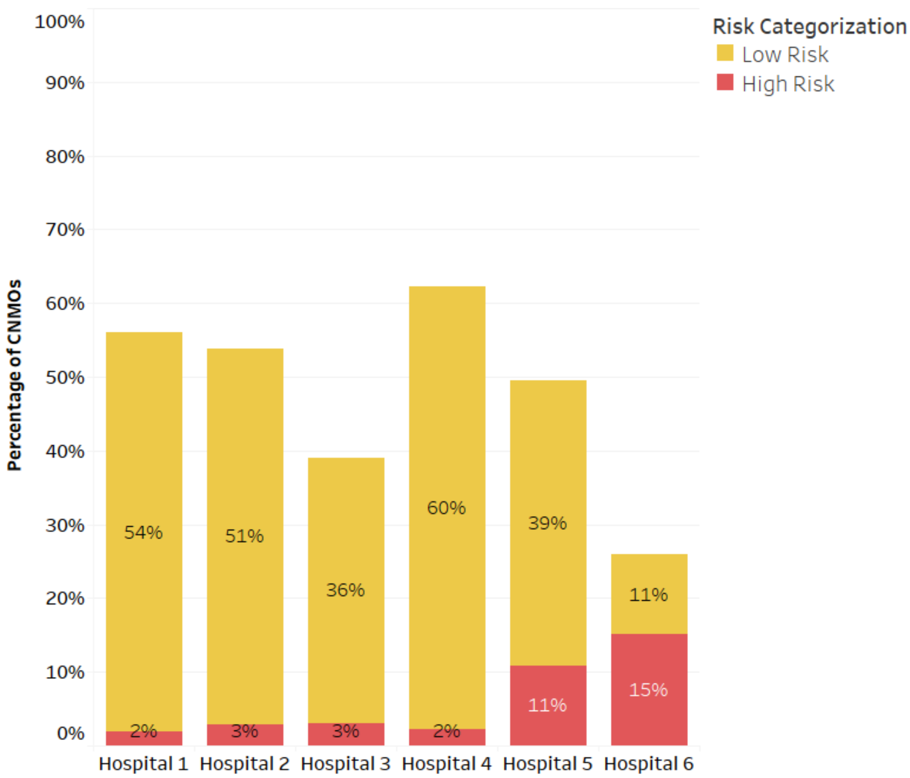

Figure 19: Comparison of CNMOs containing medication and high-risk medication information across hospitals

Figure 20 shows the proportion of CNMOs containing high-risk medication information at each hospital by action provider types with at least 50 CNMOs. 29% of CNMOs written by OR charge nurses and 25% of CNMOs written by OR nurse managers at Hospital 6 contained high-risk medication information, compared to less than 0.5% of CNMOs written by the same action provider types at other hospitals. Cardiologists wrote the highest proportion of CNMOs with high-risk medications at Hospital 1 (35%). At Hospitals 2 and 5, RNs wrote the highest proportion of CNMOs with high-risk medications (11%). Vascular surgeons wrote the highest proportion of CNMOs with high-risk medications at Hospital 3 (20%). Nurse Practitioners wrote the highest proportion of CNMOs with high-risk medications at Hospital 4 (17%).

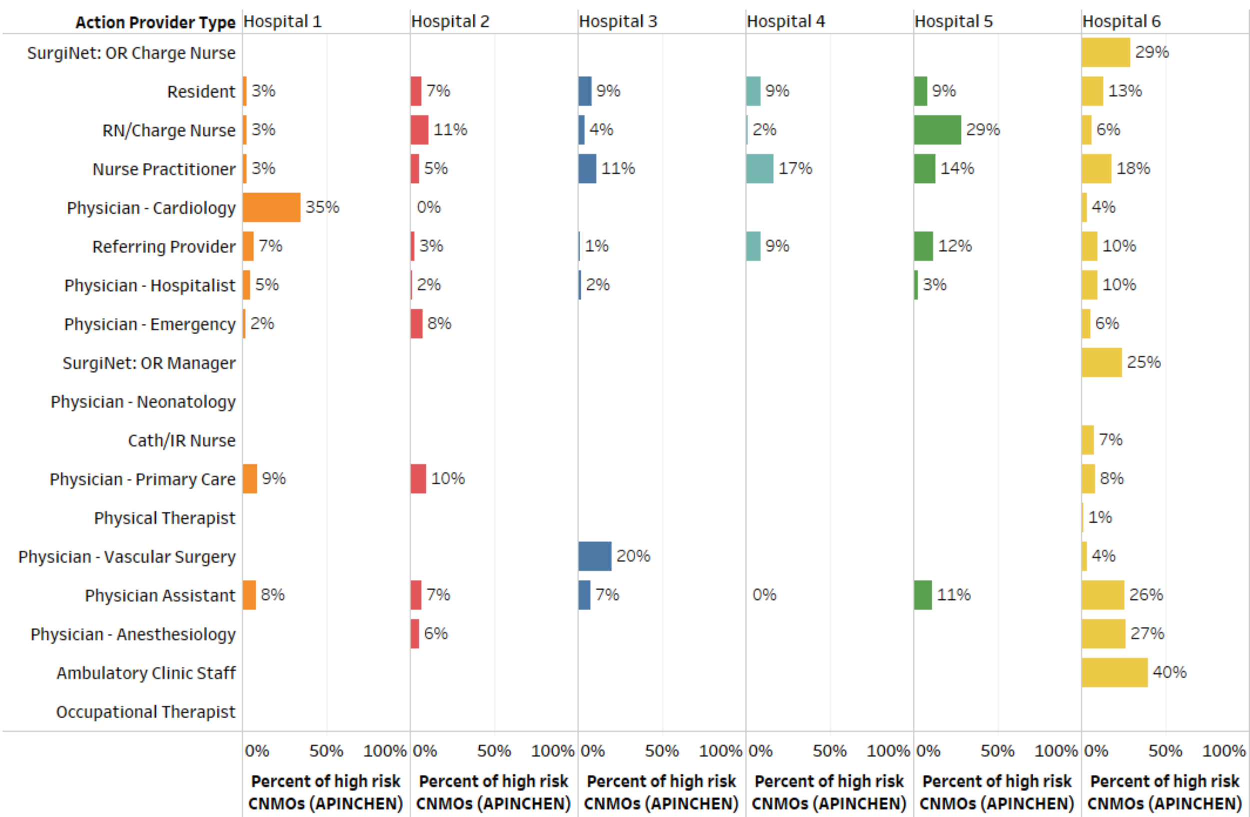

Figure 20: Variation in use of CNMOs for high-risk medication information by action provider types across hospitals

Figure 21 shows the proportion of CNMOs with high-risk medication information at each hospital by ordering provider types with at least 50 CNMOs. None of the CNMOs written by CRNAs contained information about high-risk medications, though this order provider type had a high proportion of CNMOs containing medication information. 17% of CNMOs written by Anesthesiologists at Hospital 6 contained high-risk medication information, compared to less than 0.2% of CNMOs written by the same provider type at other hospitals. Similarly, Emergency physicians at Hospital 2 (7%), residents at Hospitals 4 and 6 (6%, 4%) and Nurse practitioners and Physicians Assistants at Hospital 5 (9%, 5%) had relatively high proportions of their CNMOs containing high-risk medication information.

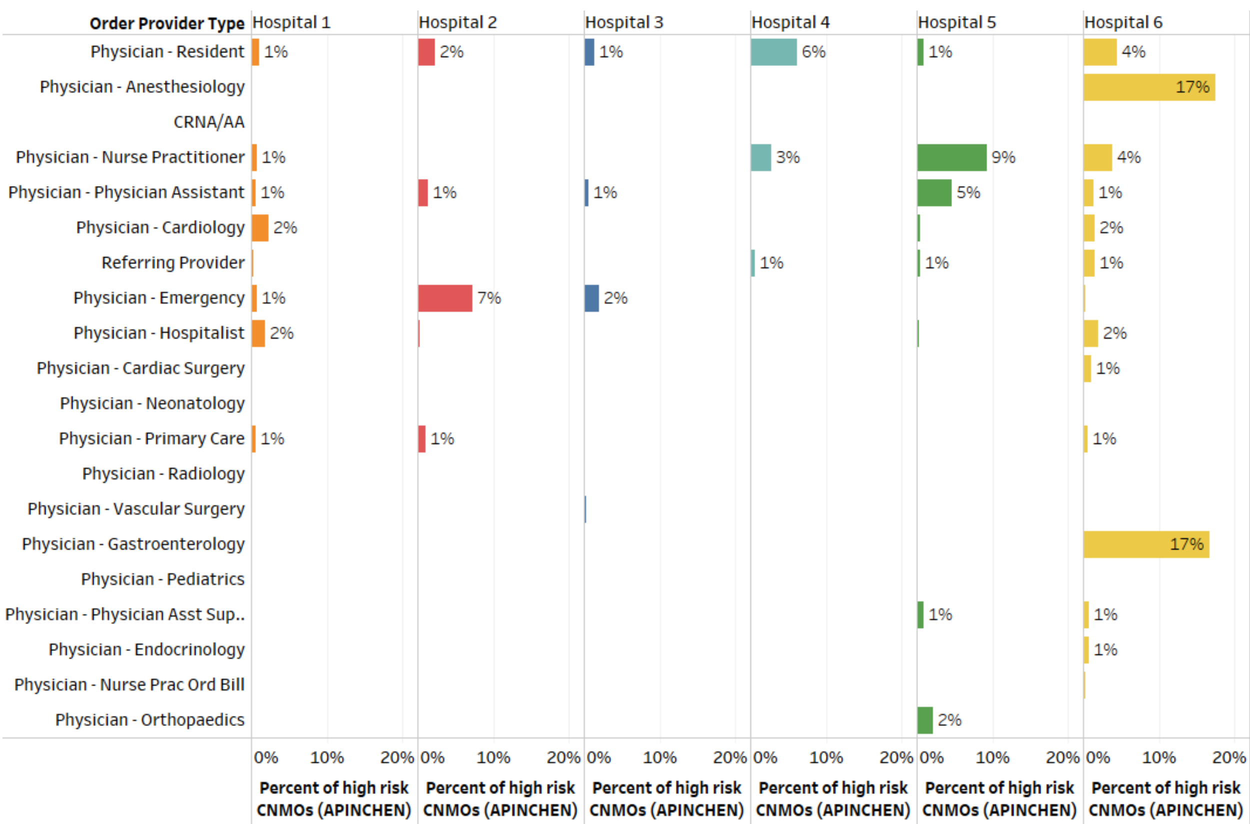

Figure 21: Variation in use of CNMOs for high-risk medication information by ordering provider types across hospitals

4.2.11 Actions Specified

Providers use CNMOs to communicate about specific clinical tasks that they want from other providers. Analyzing the actions specified in CNMOs can give sense for tasks that are difficult to communicate using standard CPOE medication orders. A list of action words was used to classify the CNMOs containing medication information into actions. Appendix E shows description of words used to classify the CNMOs into actions. Figure 22 shows the types of actions specified in CNMOs containing medication information. Discontinuation of medication(s) was the most common action specified in CNMOs containing medication information. The “Other action” category was common and included CNMOs that asked for information regarding medications, or were used for confirmation or documentation of a medication. CNMOs were infrequently used for negative actions (i.e., asking providers to not do a specific task).

The CNMOs with give, continue, resume, modify, do not stop, and do not hold actions pose risks of omission errors, which occur when a necessary medication or therapy is not carried out (omitted). CNMOs with discontinue, stop, hold, do not give, do not resume, and do not modify actions pose risks for commission errors, which occur when wrong medication is given or administered (committed). About 24% of CNMOs containing medication information had a risk of a commission errors and 9% of CNMOs containing medication information had a risk of an omission error. Classification of potential medication errors is important because they require different remedies.[82]

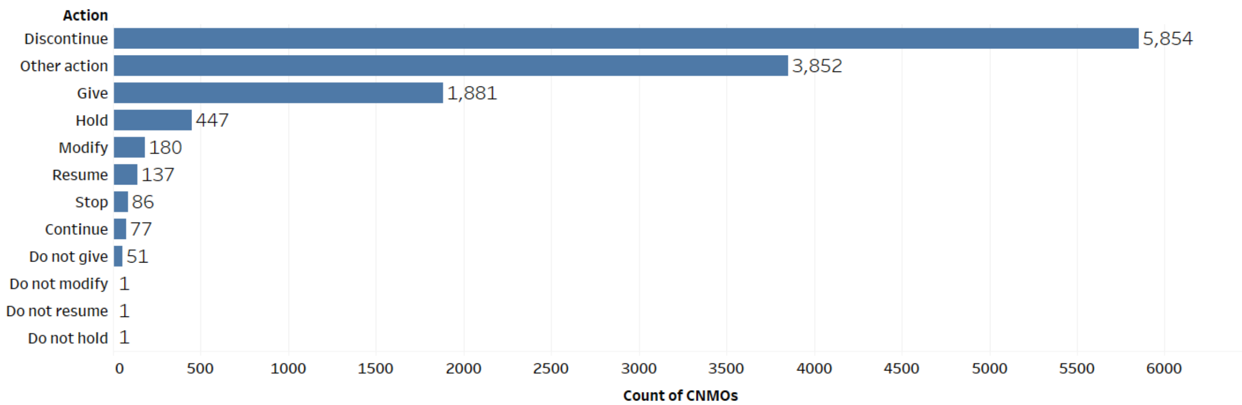

Figure 22: CNMO Actions

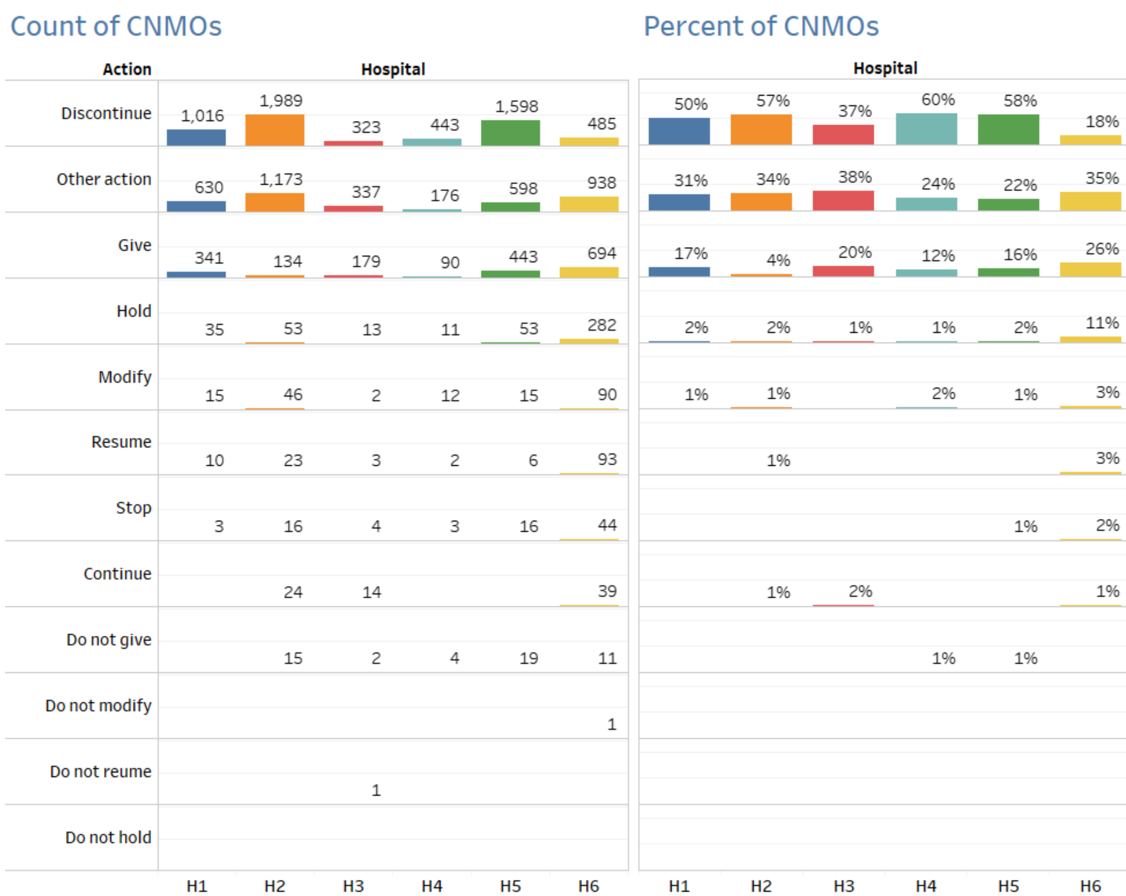

Figure 23: Variation CNMO actions across hospitals

Figure 23 shows the variation in actions across hospitals. The left chart shows the counts of actions across hospitals and the right plot shows the percent of actions specified in medication related CNMOs at each hospital. Medication related CNMOs specifying "Other action" varied from 22% (Hospital 5) to 38% (Hospital 3). Aside from "Other action", giving a medication was the most frequent action specified in medication related CNMOs at Hospital 6 (26%). At all other hospitals, discontinuing a medication was the most frequent action. 11% of medication related CNMOs at Hospital 6 requested to hold medications; at other hospitals, this action was rare. The remaining actions accounted for only 1-2% of the medication related CNMOs.

4.3 Discussion

The prevalence rates identified do not have the same margin of error and confidence level as described in chapter 3, because we do not have enough number of samples for each stratification group. For example, if we needed same level of confidence to compare that the rates of use of CNMO at each hospital. i.e we would need a sample 24,862 CNMOs from 249,025 orders written at Hospital 6; 13,338 sample CNMOs from 25,793 orders written at Hospital 4 and so on. With only 1,010 samples from hospital 5 the rates identified at for this hospital would have margin of error of 4.6% instead of 0.99% at 99.9% confidence level. This is a limitation in the analysis.

The use of CNMO varied significantly across hospitals, ranging from just over 1,000 CNMOs at Hospital 4 to approximately 10,000 CNMOs at Hospital 6. This difference in the raw number of CNMOs placed by providers at different hospitals may be a reflection of the hospital size and the patient load at the respective hospitals. However, the huge variation in the percent of these CNMOs containing medication information likely reflects differences in CPOE usage patterns across locations and differing provider communication needs at these locations. The use of CNMOs is not only varied by hospital location but also by patient setting. In all hospitals, providers in the inpatient setting wrote large number of CNMOs while, providers in emergency setting wrote a lower number of CNMOs. Moreover, the proportion of CNMOs with medication information in inpatient setting was higher compared to Emergency Setting. This may be due to differences in the workflow or communication needs between these settings. In the emergency setting, providers are caring for patients for only few hours so communication needs to be timely and/or urgent. Inpatient setting providers are caring for patients for longer time, so a significant part of their communication may revolve around future plans and actions. Also, inpatient providers are often required to engage in long-term communicate across multiple teams and specialties as compared to providers in emergency or observation settings.

Within the outpatient setting, only Hospital 5 providers wrote a large number of CNMOs compared to other hospitals, though its overall patient load was comparable to other hospitals. Similarly, within the ambulatory surgery setting, the proportion of CNMOs with medication information was lower at Hospital 6. These results highlight that differences in usage that exist across and within hospitals. Studying and comparing communication in these different settings can provide insights into reasons for using CNMOs to communicate medication related information. The reason for workarounds may depend on factors such as hospital or unit policy, culture, technology support (or lack of it), complexity with patient care needs and understanding, and comfort between providers at a personal level. By considering these factors and understanding what works for providers in settings at hospitals with lower use of CNMOs for communicating medication-related information, we can move towards solutions that improve provider communication.

The results also highlight differences in usage of CNMOs by provider types. In terms of volume, OR Charge Nurses, Residents and Registered Nurses enter many CNMOs while physicians enter small number of CNMOs. When looking at the provider types it is important to understand difference between ordering providers and action providers. While ordering providers own the order, the actual order is physically entered into the system by the action providers. In many cases the ordering and action providers may be the same. For example, Resident and Nurse Practitioners are both ordering and action providers for approximately 80% of their CNMOs. However, in some cases, the ordering providers are not the action providers. For example, OR Charge Nurses are action providers for approximately 10,000 CNMOs while they are ordering providers for less than 50 CNMOs. Similarly, Anesthesiologists and CRNAs are ordering providers for approximately 5,000 and 3,000 CNMOs respectively while they are action providers for only approximately 50 CNMOs. Over 80% of CNMOs where CRNAs were the ordering provider type contained medication information. It is useful to know this difference and understand difference in workflow, so we can target interventions to specific user groups.

Also, different provider types obtain different EHR training based on their roles. Physician training may focus largely on placing orders in the EHR while nurse training may focus on executing orders in the EHR. These imagined work roles and training may not reflect actual work roles. Hence, physicians or nurses might use EHRs in non-ideal ways that gets work done, as they have a partial view of the system design. Moreover, the system may not have the necessary features to support desired communication, or the features may be too cumbersome for providers to use – leading them to use workarounds such as CNMOs. These factors must be considered while developing systems, policy and training to support provider communication.

There is also significant variation in the use of CNMOs across individual providers. Across all hospitals, there were providers who used 100% of their CNMOs to communicate medication related information. But, there were also providers who did not use CNMOs for communicating medication related information, even though they wrote many CNMOs. This stark contrast highlights that there may be fundamental differences in provider perspectives with respect to the use of CNMOs. These differences might arise from their experience with the EHR, clinical training, rapport with the team, or personal working styles. The variation is potentially problematic, as nurses need to understand the unique ordering patterns of individual physicians.

At all hospitals except Hospital 6, a large proportion of CNMOs containing medication information did not mention specific medication names. This inclusion of non-specific information in CNMOs may lead to users viewing incomplete and confusing information. EHR functions such as decision support systems, dosage alerts, interaction alerts cannot be used without more specific information.[83]

Naloxone, Heparin, Flumazenil and Dextrose were the most common medications mentioned in CNMOs. However, Naloxone and Flumazenil are mentioned only in CNMOs at Hospital 6, highlighting unique challenge at this hospital compared to other hospitals. While Naloxone is used for treating narcotic overdose, Flumazenil is used for treating drowsiness caused by sedatives or medication overdose. Mentioning these specific medication names in CNMOs highlight that there are challenges with medications around patient condition reversal.

Another important insight from the medications mentioned in CNMOs is the type of challenges that persist in at different hospitals. For example, Naloxone and Flumazenil are used as reversal agents and might be needed more urgently. Heparin is usually used as an anticoagulant and may require more planning, adjustment according to the patient's coagulation test results. Differences in the prevalence of these medication in the CNMOs at different hospitals may suggest specific communication challenge at these hospitals in respect to urgency, uncertainty, planning and other aspects of communication and clinical needs.

The three medications Phenytoin, Carbamazepine and Valporic Acid were often mentioned together in the CNMOs. Similar to Naloxone being mentioned only at Hospital 6, these medications were mentioned only in CNMOs at Hospital 3. Moreover, these medications were mentioned in the context of ordering labs for patients taking these medications. This may be some sort of a protocol that providers follow at Hospital 3, which may be handled differently at other hospitals. Understanding these differences by analyzing usage patterns across hospitals can help policy makers learn from other hospitals especially in a hospital system. These differential policies may be problematic for providers who practice at multiple hospitals. Moreover, it is interesting to note that there is an order associated with labs orders namely “Communication for Lab Add on”. It is not clear if providers didn’t know about the option of using “Communication for Lab Add on” or if providers were purposefully choosing to use CNMOs instead of “Communication for Lab Add on”. Such insights from analyzing free text orders can be used to target specific challenges and issues with use the EHR system in unintended ways.

Most of the not mentioned medications in the CNMOs were linked to CNMOs tagged as Order Sets. Order Sets were mentioned in a large proportion of CNMOs in all hospitals except Hospital 6. This may indicate that a different policy is in place for handling communication related to Order Sets in Hospital 6 compared to other hospitals.

There was significant variation in the prevalence of medication classes mentioned in CNMOs at different hospitals. In the CNMOs mentioning medications, the Anticonvulsant and Antiarrhythmic medication classes were mentioned only at Hospital 3, while Antidotes were mentioned only at Hospital 6 and Analgesics were much more commonly mentioned in Hospitals 1 and 2. Anticoagulants were more commonly mentioned in Hospitals 5 and 6. This highlights that hospitals may have unique challenges with respect to the use of different medication classes, meaning they may require different solutions related to the use of CNMOs.

The set of medications contained in an order set is not necessarily clear from the free text. The medications in an order set are usually decided by working committees within hospitals and hence there might be slight differences between order sets at different hospitals. Future research could focus on understanding how these differences affect workflows at different hospitals. Within the CPOE, future studies could also analyze medication administration records for individual medications associated with the order sets mentioned in the CNMO orders, to explore potential patient safety issues.

At Hospitals 5 and 6, over 10% of the CNMOs contained information about high-risk medications, while at other hospitals it was only 2-3%. Though Hospital 6 had lowest percent of CNMOs with medication information, it had the largest proportion of CNMOs containing information about high-risk medications. Anticoagulants, especially heparin, were the most common high-risk medication mentioned in CNMOs. It appears that addressing challenges with ordering heparin drips would address a significant amount of the high-risk CNMOs.

High-risk CNMOs are unique to different provider types at different hospitals. Cardiologists in Hospital 1, RNs in Hospitals 2 and 5, Vascular Surgeons at Hospital 3, Nurse Practitioners at Hospital 4 and Ambulatory staff and OR Charge Nurses in Hospital 6 were the provider types who wrote a larger proportion of high-risk medications. This indicates that specific provider groups need to be targeted to address communication challenges with high-risk medications at these hospitals.

Discontinuing orders was the most common action specified by providers. Discontinuation of medications is especially challenging because providers might fail to see that the orders were or should be discontinued. Though the orders drop off the medication list when discontinued, detecting these changes to the medication list in the EHR interface is difficult. In a study by Koppel et al, 51% participants (n=261) responded that discontinuation failures occur “for at least several hours” from not seeing patients’ complete medication records.[9] Though this was reported over a decade ago in 2005, when EHRs were introduced, it is surprising to see that same problem exists now. CNMOs might be used as a safety net by providers to alert other providers about these changes. However, this is also not ideal as providers can miss this information in CNMOs. Changes to the EHR interface enabling better detection of changes in medications is necessary. Another challenge with discontinuation is that procedure linked medications are not cancelled when procedures are cancelled.[9] Hence, providers might forget to cancel orders, leading to commission errors. One potential solution is to allow providers to tag procedure-linked medications while ordering medications so they can follow up on these orders based on the status of the procedure.

‘Other action’ was the second most common action specified in CNMOs. These actions were related to documentation and requests for verifications, actions not considered as risky as other actions. However, they highlight important gaps in the functionality of EHRs. Providers use CNMOs to communicate this information because the EHR system does not have straightforward communication support for these types of medication specific information.

We can identify usage patterns of CNMOs for patients with multiple chronic conditions who have many medications compared to other patients. These chronic/ critical patients account for 71% of US medical spending.[84] Analysis of CNMOs related to this patient group can provide insights into types of challenges associated with this high expenditure group. However, this will require more clinical context and patient-specific data.

The results from this analysis provide important insights, but the results are constrained by the analysis of CNMOs without clinical context of why the order was placed. Interviews with clinicians could help to understand these reasons. The analysis is also limited to one health system and to sampled CNMOs from one year. Development of NLP tools to analyze text could provide means to analyze all orders across hospital systems.

CHAPTER 5

UNDERSTANDING THE USE OF FREE TEXT COMMUNICATION ORDERS FROM THE PHYSICIAN PERSPECTIVE

5.1 Introduction

In Chapter 3, we analyzed the contents of CNMOs and found that approximately 42% of the CNMOs contained medication information. This workaround is a matter of concern for patient safety. It is important to analyze and understand the reasons why providers opt to use such workarounds, so we can develop better systems to support their needs. This chapter provides background on medication errors and safe medication practices, why communication of medication information is essential, the methods I used to understand physician perspectives on the use of the EHR to communicate medication information, and the results from the analysis.

5.2 Background

5.2.1 Medication Error and Safe Medication Practices

A medication error can be defined as a failure in the treatment process that leads to, or has the potential to lead to, harm to the patient.[85] Medication errors may account for up to 33% of all errors that occur in the hospital setting.[86] Unintended medication discrepancies occur in about 66% of hospital admissions.[87] It is projected that a hospital inpatient can expect an average of one medication error each inpatient day.[88] Medication errors and related injuries are therefore a serious cause for concern.

Medication errors include errors in prescribing, dispensing, transcribing, and administration.[89] These errors are either omission errors or commission errors. Omission errors are errors that occur when a necessary medication is not given (omitted). Commission errors are errors that occur when wrong medication is given or administered (committed). Classification of medication errors is important because the probabilities of errors of different types are different, as are potential remedies.[82] The American Society of Hospital Pharmacists (ASHP), classifies medication errors into the categories shown in Table 2.[90] The error types discussed below are not mutually exclusive and many errors may fall into more than one category.

Table 2: Classification of medication errors by ASHP

Error Type	**Description**
Prescribing Error	Error that occurs due to incorrect drug selection, dose, dosage form, quantity, route, concentration, rate of administration, or instructions for use of a drug product ordered or authorized by physician (or other legitimate prescriber); This also includes illegible prescriptions or medication orders
Omission Error	Error that occurs when a necessary therapy/medication is not carried out.
Wrong time Error	Administration of medication outside a predefined time interval from its scheduled administration time
Unauthorized drug error	Administration of medication not authorized by a legitimate prescriber
Improper dose error	Administration of a dose that is greater than or less than the amount ordered by the prescriber or administration of duplicate doses to the patient.
Wrong dosage form error	Administration to the patient of a drug product in a different dosage form than ordered by the prescriber
Wrong drug preparation error	Incorrectly formulated or manipulation of drug before administration
Wrong administration technique error	Inappropriate procedure or improper technique in the administration of a drug
Wrong patient error	Administration of medication to wrong patient
Deteriorated drug error	Administration of a drug that has expired or for which the physical or chemical dosage-form integrity has been compromised
Monitoring error	Failure to review a prescribed regimen for appropriateness and detection of problems
Compliance error	Inappropriate patient behavior regarding adherence to a prescribed medication regimen (noncompliance)

To address these errors, providers are traditionally taught about a standard medication practice, termed the five rights: right patient, right drug, right time, right dose, and right route.[91] Three more rights have been added to this list: right reason, right documentation, and right response.[92] Though these are considered as standard safe medication practices, many errors have happened even when providers follow the five rights to the best of their abilities.[93] A major criticism of this standard practice is that it focuses on individual performance rather than reliability and safety of the health system.[94] Various factors such as drug product nomenclature (look-alike or sound-alike names, use of lettered or numbered prefixes and suffixes in drug names), equipment failures or malfunctions, improper transcriptions, inaccurate dosage calculations, inappropriate abbreviations used in prescribing, labeling errors, and excessive workload can lead to medication error.[90] Computerized systems, forcing functions and standardized protocols are considered powerful strategies compared to training and education which rely purely on individuals.[94] In this context, the electronic health records (EHRs) may help in reducing medication error through use of computerized provider order entry (CPOE), pharmacy dispensing systems, barcode medication administration (BCMA), and electronic medication reconciliation.[95,96] These interventions are aimed at addressing system issues. However, it is possible to have a fully implemented EHR including CPOE, yet have suboptimal prescribing, dispensing, transcribing, and administration processes. These systems are often built in silos and not all information is exchanged between these systems. Even when a decision support system or a drug interaction alert system is in place, their alerts (or lack of) are incomplete and not always trustworthy. Similarly, workarounds by providers contribute to unintended consequences due to lack of correct and complete information. A recent study by Schiff et al. found that 51.9% of the medication error reports were CPOE-related and 86.9% of them could have been potentially prevented.[97]

5.2.2 Communication of Medication Information

In a hospital setting, communication of medication information is complex, involving multiple providers such as attending physicians, resident physicians, primary nurses, secondary nurses and pharmacists. Multiple systems such as CPOE, BCMA, telephones, and pagers are used for communication when available.

Physicians typically prescribe medications and make decisions on different aspects of medication such as what medication to give, why to give the specific medication (Reason), how much to give (Dosage), when to give (Time), how often to give (Frequency), and how to give (Route) before writing a medication order. CPOE systems supports physicians in carrying out this task by checking for order completeness. They can also check for inappropriate dosages, inappropriate routes and drug interactions. Once the order is written, it is received by nurses and pharmacists as appropriate. The pharmacist checks the order and ensures the correctness of information in the medication order and dispenses the medication. The dispensed medication is received by the nurse who also verifies and checks the order for missing or incorrect information. Before administration, the nurse often uses BCMA to verify that correct patient receives the correct medication, and then administers the medication. The nurse enters order completion information in the EHR, which enables everybody involved to know the patient has received the medication. Though the process described above seems linear, there is a lot of non-linearity in the medication process, especially around critical or complex medications. For example, in the case of some emergencies such as treatment of anaphylaxis (severe allergic reaction), active bleeding, or symptomatic hypoglycemia (low blood sugar), nurses are empowered to dispense medicines from dispensing units and administer medications. Based on the emergency and the medication involved, they get only a verbal order from the physician. They might write an order later in the CPOE system and get it signed by the physician, or the physician can write the order retrospectively. In another situation, a physician might want to dispense or administer medications conditional on a patient's medical condition. An order might therefore be active in the CPOE system, but the medication can be dispensed by the pharmacist / administered by the nurse only as needed. The CPOE systems allow for PRN orders ("pro re nata" / as required orders) but can be challenging to carry out as the requirements can change over time based on patient condition and CPOE systems may not adequately reflect the developments. Another complex situation arises when medications are contingent on surgery schedules. For example, a physician might want to stop heparin (an anticoagulant medication) prior to surgery and want to resume after completion of the procedure. However, the schedule might not be finalized. A timed medication order may not be helpful in practice, but the physician must communicate this information to the care team in order to avoid any delay in care or error in medication administration. Such complex and critical medication information requires close communication between providers, so everyone in the care team is aware of the situation and plan. It is in this context that providers rely on face to face communication, telephone calls, pager texts, and medication orders in CPOE. Even with use of CPOE systems, communication of medication information in these situations can be challenging. The use of CNMOs can be a workaround in such situations but carries potential patient safety risks.

5.2.3 Qualitative Analysis Methods

Identifying the reasons why these workarounds happen needs probing. It is essential to inquire into providers' experiences and understand the problem in context. These requirements satisfy the conditions identified by Patton as suitable for qualitative analysis.[98] In their study on "Qualitative methods in research on health care quality" Pope et al. identify that qualitative methods can identify the reasons why certain changes or improvements occur or do not occur.[99] Qualitative methods are effective in uncovering problems as well as suggesting solutions. I chose to conduct interviews with providers to understand the reasons for use of CNMOs for medication information.

Interviewing is a technique where "knowledge is produced through the interaction between an interviewer and an interviewee".[100] Interviews are appropriate if available evidence is limited.[99] There are three types of interviews: structured, semi-structured and unstructured interviews. Structured interviews are "verbally administered questionnaires, in which a list of predetermined questions are asked, with little or no variation and with no scope for follow-up questions to responses that warrant further elaboration".[101] Unstructured interviews are "interviews in which neither the question nor the answer categories are predetermined".[102] Semi-structured interviews are interviews in which the researcher asks a series of predetermined questions, but it also allows the interviewer or interviewee to diverge in order to pursue an idea or response in more detail.[103]

Semi-structured interviews are more common in health care related qualitative research as they are based on loose structure of open ended questions to explore experiences and attitudes.[104] Semi-structured interviews help uncover issues or concerns that have not been anticipated by the researcher. [99] They offer generation of a broad range of information on a per person basis as compared to focus groups.[105] This is crucial factor to consider because access to care providers is sparse and difficult. Certain personal and sensitive information is more likely to be discussed in face to face conversation as compared to other methods. Participants in interviews may "feel pressure to conform to social expectations and may under-report certain behaviors or thoughts".[106] Some aspects of face to face interaction such as politeness, non-verbal communication, and small talk can lead participants to open up and talk.[107]

5.3 Methods

In Chapter 4, we found that discontinuing, giving, and holding medications were the most common actions required by ordering providers. We also found that two high-risk medications, anticoagulants and anti-diabetics (Insulin), were commonly found in CNMOs. Moreover, CRNAs and Resident physicians were common provider types who wrote many CNMOs. Considering these factors and the accessibility of provider-types, six case scenarios were developed targeting physician participants. Participation in the study was voluntary and the study was approved by the Institutional Review Board. Participants were compensated with a $150 check for their time.

Eight physicians (1 Attending, 7 Residents) at Hospital 5 were recruited to participate in a semi structured interview. The participants were given six case scenarios. The description of case scenarios is shown in Table 3.

For each case scenario, they were asked to share how they would typically communicate medication information to nurses and tracks the task completion using the EHR. They were also asked if they would use CNMOs to communicate to the nurses and possible reasons for the use of CNMOs. To understand if the physicians were aware of how the system displays CNMOs, providers were asked about where and how these CNMOs appear for nurses. Participants were also asked about the general challenges they have with using the EHR to communicate medication information, and suggestions for improving the EHR to address these challenges. The full interview guide is shown in Appendix F.

Table 3: Case scenario descriptions

Case Scenario	Description
Case 1: Discontinuing orders	Ms. Gonzales has a surgery scheduled for tomorrow. She is on the anticoagulation medication enoxaparin (Lovenox) and you want her off the medication 12 hrs. prior to the surgery.
Case 2: Safety/ Caution	Mr. Smith is on an insulin protocol and may have a procedure in the afternoon requiring NPO (Nothing Per Oral) status. You want to let nursing know to hold insulin if MR. Smith is NPO for the procedure and doesn't eat lunch.
Case 3: Sequential ordering	Mr. Williams is on anticoagulation medication heparin drip. You want to move him from heparin to Eliquis. Specifically, you want to stop the heparin drip 30 minutes before giving the first dose of Eliquis
Case 4: Canceling/ modifying an order component	Ms. Jones is on IV potassium. She has received first two doses from the Potassium Chloride 10meq IV Q1hr X4 doses order and her level has normalized. Now, you want to cancel the third and fourth doses of potassium, from the Potassium Chloride 10meq IV Q1hr X4 doses.
Case 5: Changing infusion rates	Mr. Lee is on Diltiazem drip, and you want to increase the rate from 10mg/hr to 12mg/hr.
Case 6: Changes to medication - Temporary State	Your patient Ms. Garcia with hypertensive emergency has improved substantially. Her blood pressure is currently 140/80 on a rate of 0.5mg/hr and she will be getting switched to oral medications. You are unsure if she will need Nicardipine drip so you want to keep Nicardipine on standby in case her condition worsens.

Following the interview, participants were asked to fill out a survey questionnaire to collect demographic information including clinical role, years of clinical experience, years of EHR experience and frequency of use of CNMOs. While all physicians had attended medical school, only some of them had experience using EHRs as a student. When considering years of EHR experience, use of EHRs as a student was included. Likert scale questions were asked to understand 1) factors due to which physicians are likely to use CNMOs 2) physician perception of the ease and effectiveness of using EHRs and CNMOs for communicating information to nurses and 3) physician's perceived risks of using CNMOs for the given scenarios. The reasons why physicians are likely to use CNMOs were developed based on analysis of action requirements in the CNMOs from Chapter 4, interactions with an ICU nurse and ICU physician resident, and observations in the ICU and Emergency units. These reasons were included in the Likert scale questionnaire. The questionnaire is shown in Appendix G.

5.4 Results

The attending physician had over ten years of clinical experience and 4 years of experience using EHRs. The resident physicians had clinical experience between 1 to 4 years and their experience with EHRs ranged from 1 to 13 years. All participants stated that they use CNMOs in their daily routine. The frequency of their use of CNMOs is shown in Figure 24.

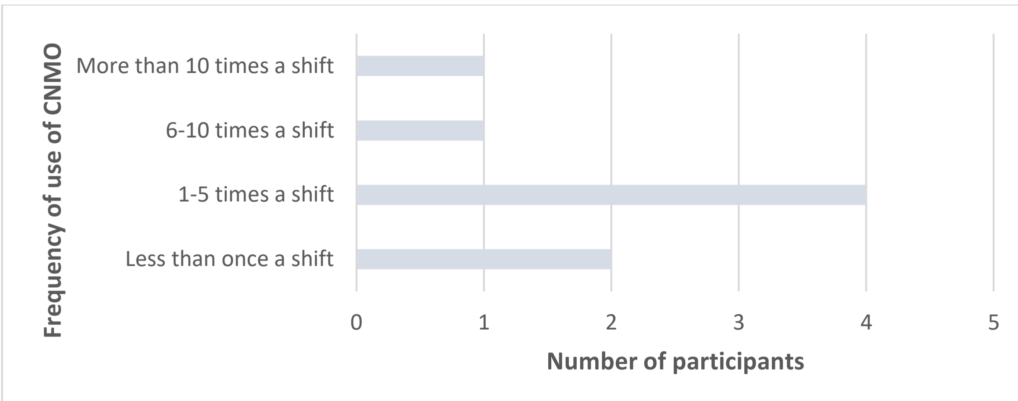

Figure 24: Frequency of CNMO use

Based on participants' responses, their use of CNMOs seems to have changed over time, as providers increase their use of CNMOs as a workaround. As one noted: "*Most of the people that I know, when I started my residency, they were using 'if the patient has to go off monitor', if the patient has to use NG tube, okay to use NG tube, okay to use central line, stuff like that. But now, with the passage of time I found it more useful for the things like that, that we really want to communicate. Like keeping the patient NPO, give this med, something important that I already mentioned.*"

Though all physicians stated that they routinely use CNMOs, their perception of its use in each of the six case scenarios varied significantly. For example, Participant 2 stated that they would use CNMOs in 4 of the 6 cases, while Participant 3 stated that they would not use CNMOs in any of the cases (Figure 25). One participant mentioned that they would not use a

CNMO for medication information, stating that "*It (CMNO) doesn't couple the information to the medication itself so that is a reason not to use it. It's a medication order not a non-medication order. It's all in the name 'non-med order*'". Another participant said that "*if I need to talk to nurses then I always pick communication for non-med order*". One participant mentioned that they use CNMOs based on how the order is displayed to the nurses, noting that "*I have heard nurses say they prefer we don't use it, because apparently they don't see it on their screen. Which I find kind of funny, because if the order is on our end as a communication order, the whole point of that is for them to read it. But I have had nurses come and tell me that they can don't it on their end or it does not flash as a priority for them*".

Figure 25 shows the strategies mentioned by participants in each scenario to communicate information to the nurses. Participants were much more likely to modify an existing order or create a new order to inform nurses, or verbally communicate the information to nurses either by phone or in person. Additionally, participants mentioned that they would rarely contact pharmacists or write additional comments in the medication order. In rare situations (NPO status or surgery schedule-based medications), participants mentioned that they would use strategies such as placing a sign at patient bedside or informing patient to refuse medication to ensure that medication plan gets executed.

Figure 26 shows the number of participants who mentioned that they would use the specific strategies for communicating medication information in each scenario. The number of participants who mentioned using CNMOs for the different case scenarios varied between 1 and 4. The use of CNMOs was most common in Case 6, related to temporary changes to a medication, while the use of 'order comments' section in the medication order was most common in Case 3, related to sequential ordering of medications.

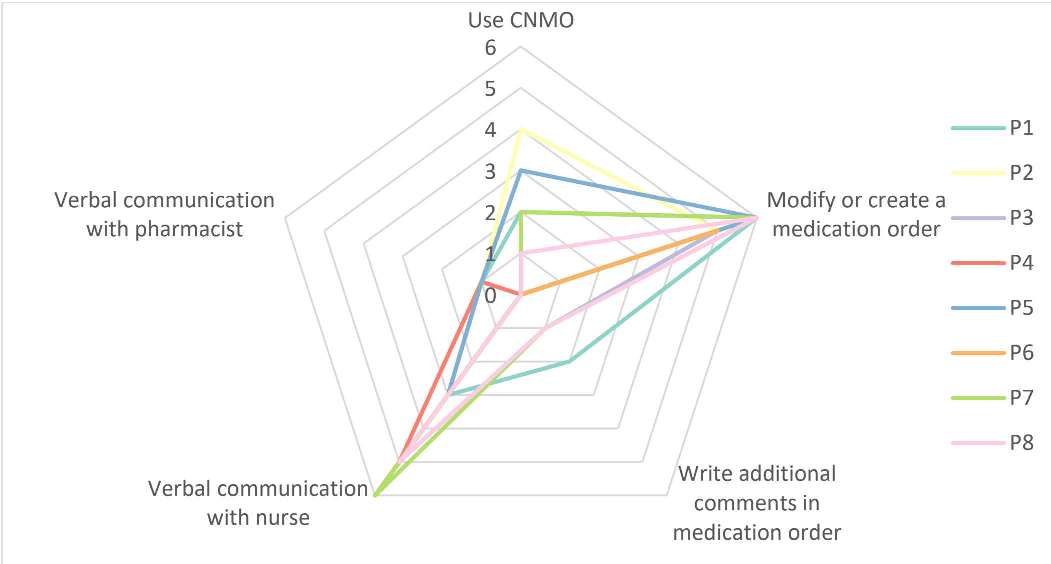

Figure 25: Strategies used by participants for communication

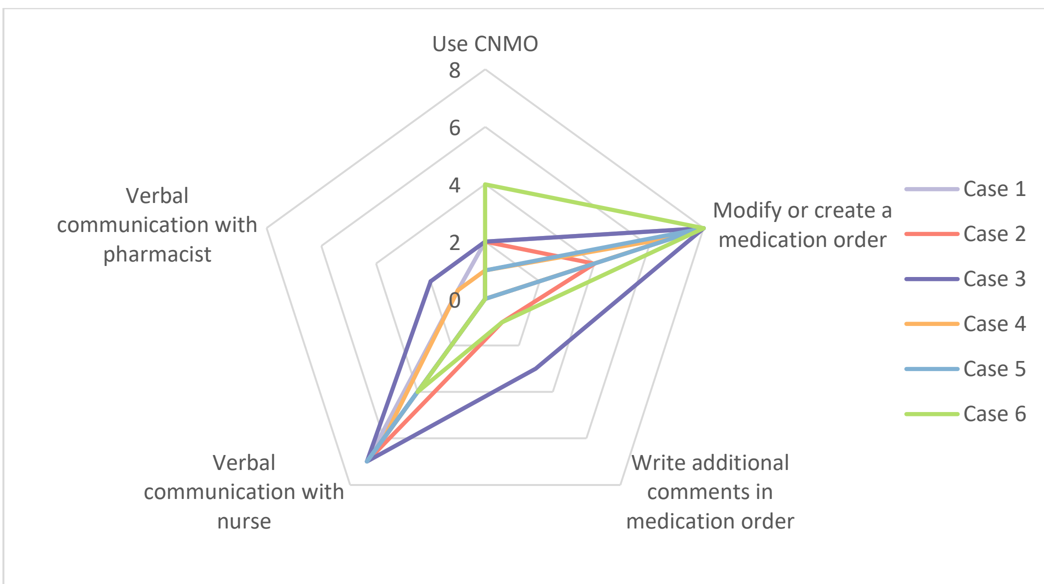

Figure 26: Strategies used for communication in each case scenario

Figure 27 shows the number of participants who mentioned during the interview that it was challenging to use the EHR for communicating the medication information in that case scenario. Cases 3 and 6, related to sequential ordering and temporary changes to a medication, were considered challenging by majority of the participants.

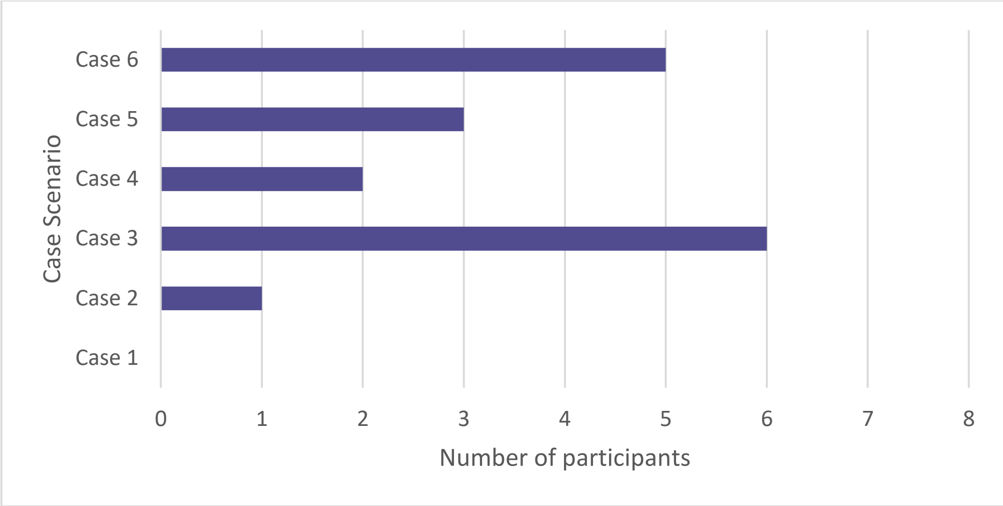

Figure 27: Variation of difficulty in using the EHR by case scenarios

Difficulty using the EHR for communicating the medication information in the case scenarios also varied across participants. Shown in Figure 28, two participants felt that it was difficult to use the EHR in 4 of the 6 case scenarios while two participants felt that it was easy to use EHR in all the case scenarios.

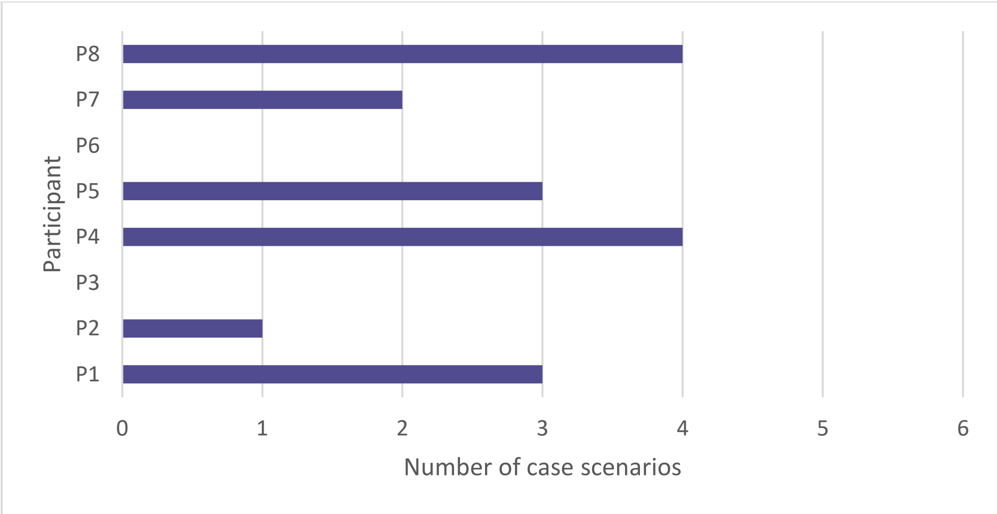

Figure 28: Variation of difficulty in using EHR by participants

5.4.1 Ease and Effectiveness of Use of CNMOs Compared to the EHR

Figure 29 shows the comparison of *ease of use* of CNMOs and the EHR standard orders for communicating medication information. Communicating medication information using the EHR standard orders was stated to be more difficult than communicating using CNMOs. For the case scenarios, 11 participant responses indicated that it was 'not at all' easy to communicate using the EHR standard orders compared to only 2 responses while using CNMOs.

CNMOs were also considered slightly more effective than EHR standard orders for communicating medication information in the case scenarios. In this context, 'effective' pertained to the clinical task being completed correctly. Figure 30 shows the comparison of effectiveness of use of CNMO and EHR standard orders for communicating medication information. For the case scenarios, 13 responses indicated that it was 'very' or 'extremely' effective to communicate using CNMOs compared to only 5 participant responses while using EHR standard orders. However, neither CNMOs nor EHR standard orders were considered effective for the case scenarios. Note: There are 48 responses in total. Each participant responded 6 times (once for each scenario).

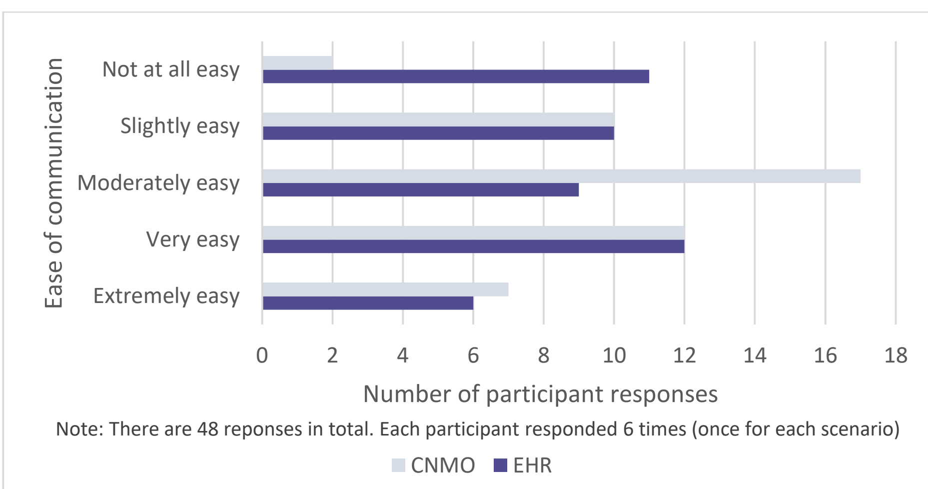

Figure 29: Comparison of ease of use of CNMOs and EHR standard orders for communicating medication information

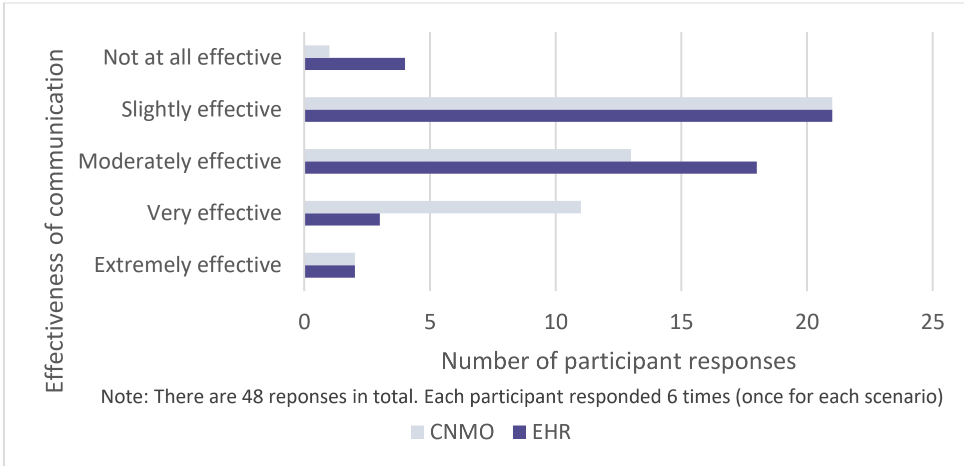

Figure 30: Comparison of effectiveness of use of CNMOs and EHR standard orders for communicating medication information

Shown in Figure 31, 4 out of 8 participants indicated that it was not at all easy to communicate using EHR standard orders in Scenario 6. Only one participant indicated that it was 'not at all' easy to communicate using CNMOs. In all the case scenarios, communication was deemed easier using CNMOs compared to EHR standard orders.

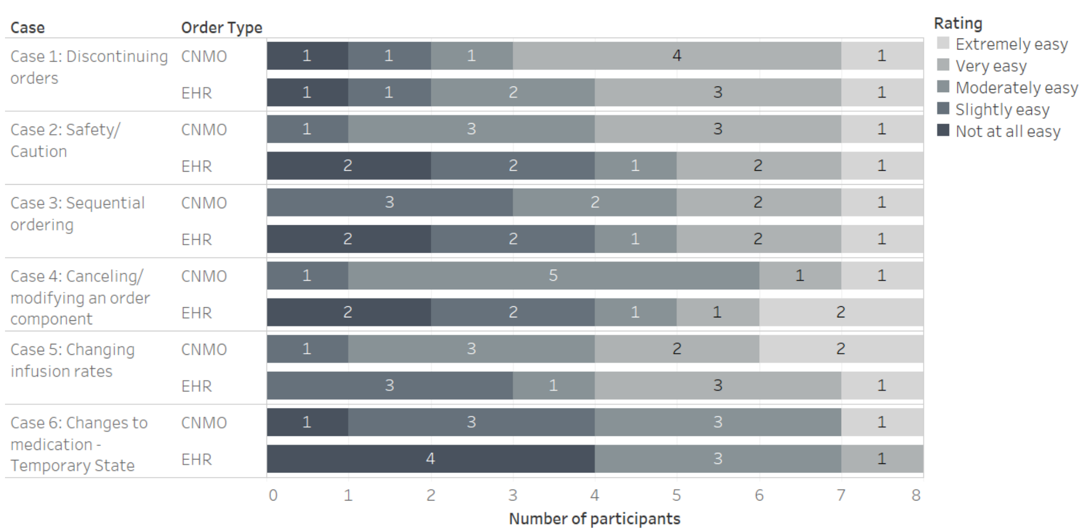

Figure 31: Comparison of ease of using CNMOs and EHR standard orders for communicating medication information

Shown in figure 32, 6 out of 8 participants indicated that EHR standard orders were ‘not at all’ or ‘slightly’ effective in Case 6. For cases 1 and 4, only one participant indicated that EHR standard orders were ‘extremely’ effective. In all other cases, all participants indicated that EHR standard orders were only ‘moderately’ or ‘slightly’ effective.

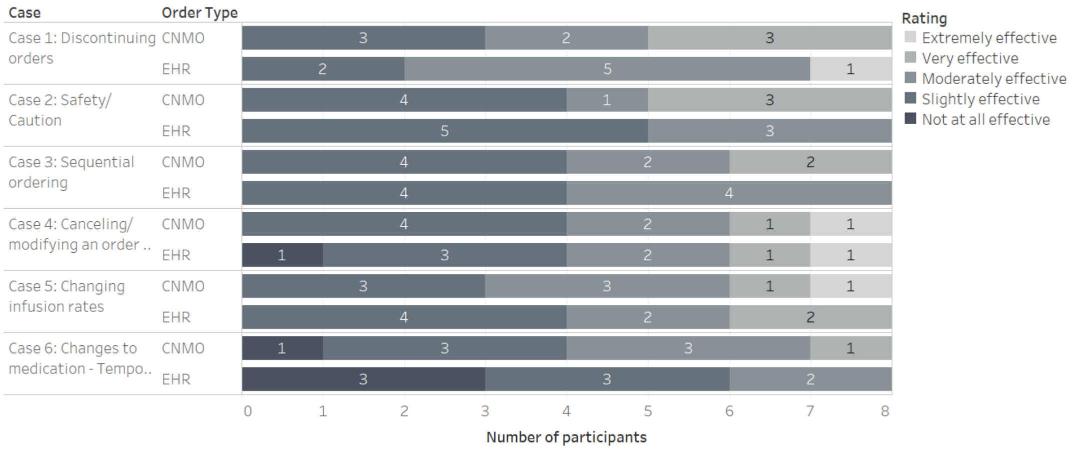

Figure 32: Comparison of effectiveness of using CNMO and EHR standard orders for communicating medication information

3 out of 8 participants indicated that CNMOs were ‘very’ effective in Cases 1 and 2, 2 out of 8 participants indicated that CNMOs were ‘extremely’ or ‘very’ effective in cases 3, 4 and 5, while only one participant stated this in Case 6. The rest of the participants indicated that the CNMOs are only ‘moderately’ or ‘not at all’ effective in all the cases.

5.4.2 Reasons for Using CNMOs

Figure 33 shows the participants ratings of factors due to which physicians are likely to use CNMOs. 7 out of 8 participants indicated that they are ‘extremely’ or ‘very’ likely to use CNMOs as a place to document verbal communications; 5 out of 8 participants indicated that they are 'extremely' or 'very' likely to use CNMOs when there was no other place in the EHR to document such information.

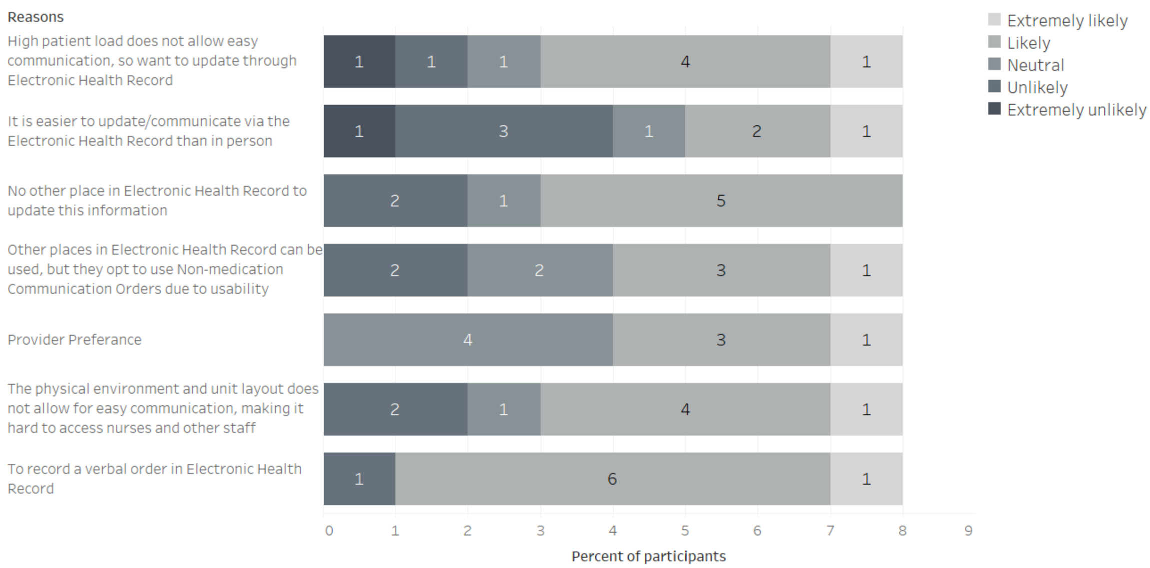

Figure 33: Reasons for using CNMOs

Participants mentioned several reasons for using CNMOs to communicate medication information with nurses. Ten themes emerged from the interview data 1) Missing EHR system functionality, 2) Poor EHR system usability, 3) Difficulty in verbal communication, 4) Need for flexibility, 5) Need for team situation awareness, 6) Need for redundancy, 7) Need for documentation, 8) Need for reminders, 9) Training, and 10) Provider preference.

5.4.2.1 Missing EHR System Functionality

EHR systems may lack functions required by providers to carry out clinical tasks. If an ordering-related function is missing, providers using the system must find new ways to get work done (i.e., workarounds). One of the participants mentioned that "*For most CNMOs we use because there is no specific order in the system. For okay to travel off monitor, okay to use central line, there is no order. So I would use CNMO. If order for NPO is already there, there is* *an order for discontinue medication in that case I would just follow that order*". System functionality can also be considered 'missing' if providers are not aware of functionality or if it is difficult to find.

Even after years of EHR development, certain high frequency ordering functionalities are not available in the system, perhaps due to their complexity. When dealing with such orders, physicians rely on CNMOs to provide clarifications. "*There are something that do not have orders in the system that we have to hand write*".

Missing EHR system functionality can also arise when the system design does not meet practical clinical requirements. For example, bridging medications have special requirements, as they are time sensitive. A physician might want to bridge Heparin with Eliquis. Based on clinical needs, this bridging should happen in specific time range (e.g., 30 min.) Physicians can mention start and stop times for these medications in the medication orders. However, these start or stop times in the order are not useful as nurses tend to optimize their work and combine all medications for a patient. Unless they are instructed by physicians verbally or through an order, or they have prior knowledge about such medications, there is no way for the nurses to know that the medications are time sensitive and need to be bridged in that time range. As identified by Campbell et al., such mis-matches between intended and actual work processes force providers to adopt workarounds that can have unintended consequences.[12] Another example of missing functionality in EHR systems occurs when a single clinical requirement is spread across different orders. As an illustration, a patient can be required to be NPO, but this must be reflected in medication orders as well as diet orders. This duplication can be a challenge for users, as they must make changes to multiple orders for a single clinical requirement.

5.4.2.2 Poor EHR System Usability

Poor EHR usability was one the common reasons cited by participants for using CNMOs for medication information. Usability issues can arise when there is mismatch between user expectation and system behavior. When physicians write instructions for nurses, physicians expect that nurses can read the instructions and act on them. However, only parts of the order might be readable on a given screen, or parts of the order might be hard for nurses to access (several clicks to drill down and get detail). One participant mentioned *"If you want to explain more than what is in the order comments, sometimes it does not appear the whole line. So for radiology they are not able to see the comments, they can see only the special instruction area. So if you want to explain in detail, so if something is missing you can write in communication order".* Another example of poor usability is when nurses are not alerted when an order is discontinued in the system. Even though the order might drop off the list, it is hard for nurses to realize that a medication is off the list when the patient has many orders.

5.4.2.3 Difficulty in Verbal Communication

In a busy hospital environment, it can be difficult for the physicians to get in contact with the nurse who might be attending to other patients. Nurses may not be reachable by phone or physicians may have to walk to another location to update the nurse in person. In such situations CMNOs can be used by physicians to communicate with nurses without having to disturb them. Nurses can see the CNMO anytime based on their availability. Another challenge with communication is that patient care must be continuous though providers change. When a shift change happens, information must be conveyed to the new team during handoffs. In such situations, physicians might opt to use CNMOs to avoid lapses in communication. One participant noted that *"We are not here 24hrs, nurses are not here 24hrs. If there is a verbal* *communication gap, not very often, but there is something in the electronic system so people can keep track. Mostly for nurses because they have to do drugs and all that stuff. So they see this communication orders mostly. I think it is easier for them to follow up"*

5.4.2.4 Need for Flexibility

Many medication orders are complex because the nurses must either give medications only at certain times based on patient condition or they may have to titrate medications based on a patient's goal. These criteria can also change over time. In such situations, it is not only essential for orders to have flexibility to meet clinical requirements but also have capacity to allow physicians to communicate freely with nurse where they can provide clarifications. CNMOs provides physician with this capability: "*Can explain why you want to keep it (medication) and rationale for doing"*. CMNOs also help physicians in achieving complex workflows. For example, when discussing holding medications, participants mentioned that they want to use CMNOs, with one participant stating, "*When you want to hold a medication and not return then just to keep in room*". This is hard to achieve in the EHR using a standard medication order because there is no hold status for an order in EHR. When an order is active, nurses have to give the medication; when an order is discontinued, nurses are required to stop medication. Moreover, if medications like drip bags are not used, they must be returned to pharmacy. If the same medication is required a short time later, it must be reordered by the physician, and dispensed again from the pharmacy before a nurse can administer it, potentially causing significant delays. A CNMO allows the nurse to hold the medication while order is still active. One participant noted, *"(CNMO is) Even more important. Because the active order is still in *** (EHR) but you want the nurse to hold the medication. This way, if active order is in the system but if the nurse switches or she is in lunch break, another nurse comes and night shift happens* *they will probably start continuing the drip. So you want to leave the order in there and just keep communicating with the nurse".*

5.4.2.5 Need for Team Situation Awareness

All members of the care team need to be updated on patients care plan. When physicians communicate with nurses verbally, other team member such as pharmacists might not be aware of the updates. By using CNMOs, "*Everyone will know what was communicated*". Also, when team members change during shifts, new team members may not be aware of changes. In such situations, physicians might opt to use CNMOs, with one participant stating, "*It (CNMO) not only helps nurses, but also night time residents*"

5.4.2.6 Need for Redundancy

Physicians want to make sure that the nurses receive and understand the information communicated to them, and that updates to medications are carried out as intended. To achieve this, physicians may use multiple modalities and communicate the same information to the nurses using CNMOs in addition to, making changes to medication order and/or talking to them verbally over phone or in person. Thus, CNMOs may be used as a safety net. One participant stated that, "*Just to make sure as a safety net. I did inform the nurse verbally. I also change the order in the computer but want to make sure*".

5.4.2.7 Need for Documentation

Use of CNMOs for medication information can be a defensive approach. One participant mentioned that they use CNMOs "*to record any verbal communication*", while another mentioned that *"I use (CNMO) for things that I want to stay on record".* Participants also mentioned that nurses would request physicians to write a CNMO, so they can have something documented in the system.

5.4.2.8 Need for Reminders

When dealing with several patients and their growing demands, it is essential for providers to be reminded about changes and updates to care plans. CNMOs can help physicians to stay on top of important changes to care plan: "*There is something in the system that we can keep track of*". Talking specifically about Case 1, one participant said that "*I would put a communication order in the system, communication for non-med order, So even after surgery, if I forgot to put the Lovenox back in after surgery, the nurse can see and remind the MD that we held Lovenox so now we can restart the med".*

5.4.2.9 Training

Training is an important aspect of learning how to use a system. Resident physicians can learn workarounds from their mentors. One participant stated that "*I have been told to use communication orders; I was told it is for nurses to see. It's a way for nurse to see orders. Communication between nurse and resident is through that order*"

5.4.2.10 Provider Preference

The EHR offers many pathways for physicians to get work done. When a physician has multiple choices, they may choose the one they are most comfortable with or the one that is most familiar to them. In the case of updating medication information to nurses, physicians can use CMNOs based on their personal preference. One participant noted that "*If you feel comfortable with the nurse and have an understanding, you can give a communication order through EMR to* *'hold off drip. and transition with PO and if BP isn't within goal she can restart the drip.' ; But if it is going to cause confusion or if drip and PO medication are going to run, then for patient safety it is fair to completely remove the drip out, give the PO, repeat the BP, then give more meds later if needed*"

5.4.3 Physician Perception about Use of CNMOs by Nurses

Nurses are the consumers of the CNMOs written by physicians. They act on the information contained in CNMO. Hence, for effective use of CNMOs, it is important for physicians to know how these orders are received (seen) by nurses and how they support (or do not support) nurses in the medication process. As one physician points out, this can drastically change their usage of CNMOs "*I already knew how much they (nurses) can see. So I am already using non med communication orders only for simple tasks*". When physicians were specifically asked if they knew where the CNMO orders appeared for the nurses, only 4 out of 8 participants responded positively. Only 3 out of 8 participants knew that that nurses are not required to sign off for task completion. These 3 participants said they would not change their usage of the CNMO as they are already aware about their behavior. Of the remaining 5 participants, only one participant said that they would decrease the use of CNMO after knowing how CMNOs are accessed by nurses. The rest of the participants said they would increase the usage of CNMOs because they help with documentation, follow up and can be used as reminders.

5.4.4 Risks Using CNMOs for Communicating Medication Information

The information in CNMO can be missed by the nurses as these are not associated with the medication orders. One participant noted that "*As residents we put these orders (CNMOs) in and inform nurses, we leave and hand off to night residents/ intern and a lot of times over night* *we communicate NPO after 12 but then see that the patient did get breakfast or got medication overnight which delays surgery*".

The information can also be missed because the CNMO is read by shift nurse but not by the new nurse after shift change. One participant stated that "*Sometimes we do communication order, a nurse from today can see that order but the nurse tomorrow may not access that order. It is not something that would pop on her screen. That is why we prefer more verbal*".

Another risk with the CNMOs is that these can contribute to commission errors, as the orders remain in the system unless a nurse deletes them. There is chance that the same task, such as giving a medication or increasing the drip rate, can happen more than once. Such critical changes can negatively affect patient care. One participant stated that "*I can use for med orders (in CNMOs), for something like "patient can keep their nebulizer at bedside" - like an ongoing thing. Otherwise if you put communication order in there, it's there and you don't want it to keep happening and you want it to happen once; the orders sits there once it's there. So I try to use it for ongoing things, not critical*".

Using a CNMO can also delay a time critical medication because nurses are not immediately aware of the updates to medications. One participant noted that "*I find when you use communication orders, it doesn't happen immediately. For most med things I have to call*".

Interestingly, this is also true for other types of orders in the EHR. Unless a nurse is with the computer and they physically refresh the specific order screen, they would not be aware of any order updates. The onus is on the nurses to expect an update and get the details of the update or new order from the EHR. One participant stated that "*Providers didn't plan on being in front of screen like nurses and doctors today, we didn't train on being in a computer job. We just ended up there. I feel all these tasks and all these electronic cues are just a lot. So if there is* *something actually important I try to talk to the person rather than rely on they are going to see the comment in the field*".

To summarize, one of the participants stated that "*I would not use CMNO for communicating anything that requires specific timing or dose changes and upcoming events and status change - critical to patient scenario- to be reliable"*

Participants responded to a Likert scale question on the perceived risk of communicating medication information pertaining to the six case scenarios using CNMOs. Figure 34 shows their overall risk perception, when medication information is communicated using CNMOs. 13 of the 48 responses indicated that using CNMO for communication is a 'major' or 'severe' risk.

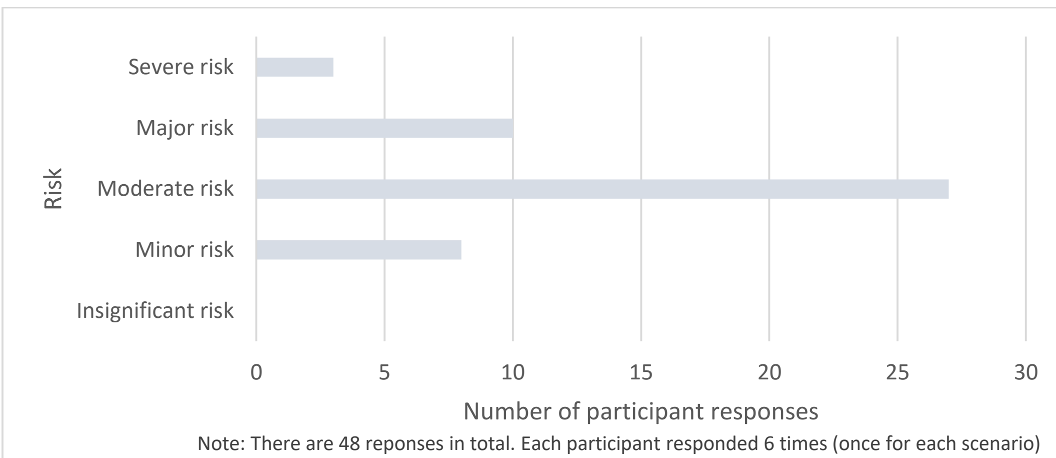

Figure 34: Physician perception of the risk of using CNMOs

Figure 35 shows the participants' perception of risks for the individual case scenarios, when information is communicated using CNMOs. For all the cases, participants indicated that communicating medication information using CNMOs is risky. Cases 1 and 4 were considered the riskiest scenarios. 3 out of 8 participants rated the use of CNMOs to be a major or severe risk in these case scenarios.

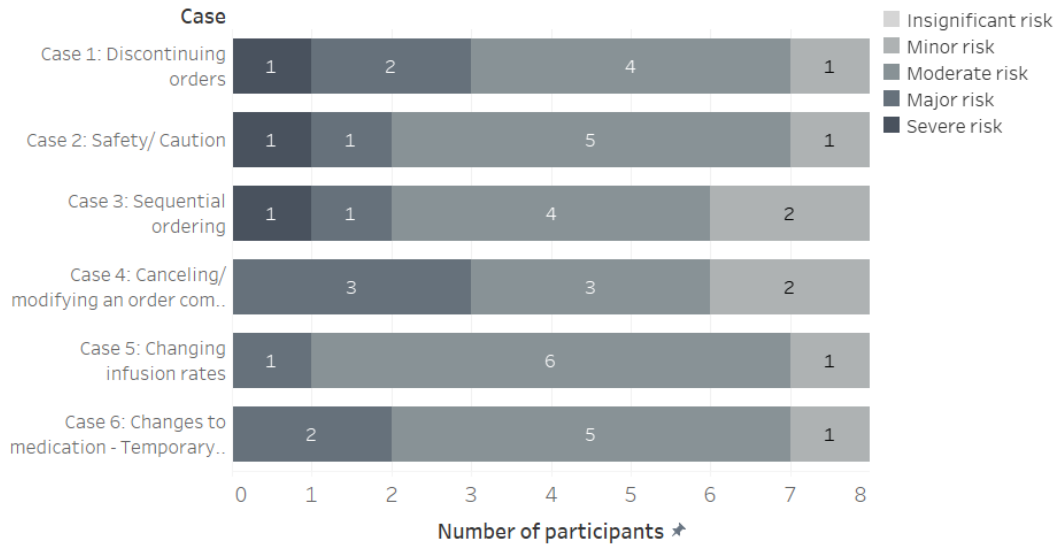

Figure 35: Physician perception of the risk of using CNMOs by case scenario

5.4.5 Challenges in Communicating Medication Information in the EHR

Participants were specifically asked if there was anything challenging about communicating medication information in the EHR. The challenges are summarized below, with representative quotes from participants. Because the question asked about the EHR in total, participants conveyed challenges on many areas of the EHR, including CPOE medication ordering, communication orders generally, and CNMOs specifically. Of note, these challenges may be specific to the vendor system used at the hospital.

1) It may take too many clicks for physicians to write an order in the EHR. One participant said "*You want to minimize the number of clicks. For like drips and for some of these specific medications, I don't actually know the underlying reason. Because I cancel the order, that doesn't go through. And then you have to redo all that information and then it's like a bunch of - you really have to fill out a drip order which isn't that much but it will take like at least 30 seconds for something like changing rate from 10 to 12. Sometimes you can and sometimes you can't. I don't know why*".

2) There may be uncertainty in the information displayed by the system or received by the nurses. Physicians may not be sure what parts of the order a nurse can see and what a nurse cannot see. Or, nurses may not notice the orders in their screen. One participant noted "*I think its special instructions vs. comments, I think its comments that nurses can't see and special instruction like pops up right next to their order and so just clarifying that. I use that a lot and I always follow through with it often because if I am using it, it is something that I want to use if I want to communicate. Clarifying those two sections - I think that is bad".* They also noted that "*Communication orders are hit or miss as far as being received*".

3) Searching for orders is often not intuitive and physicians need to rely on their experience and memory to know exactly what to search for certain orders. For example, there are more than 30 types of communication orders in the EHR system used in this hospital. However, when physicians search "communication," only 4 order types show up. So, physicians may select order types they can easily find, not necessarily the ideal order types. One participant noted "*You have to know what you have to write, then the order will pop up. Like for example if you have to do X-ray. So if a new person comes, he will type X-ray from different angles like small x or capital, things like that. But it's not going to help! Because you have to write, like if you have to get X-ray you have to write abdomen and then things related to abdomen will appear. And there is like X-ray abdomen 1 view or 2 view will appear. Then you have to write find. This is like when you get used to the system you will know how you have to order it. But for a new person, if you don't know much then he will be stuck. Like for example "HbA1C". You keep on typing "HbA1C". But you have to write hemoglobin. Then you are able to find. So there*

is something like that, the words, you have to remember particular word. So there is something that is little challenging"

4) Specifying timing of medications may be hard because the system design does not always reflect actual workflow. There may also be lack of flexibility with default time options in the medication orders, so physicians can inadvertently choose incorrect default values. This can result in nurses getting incorrect information communicated to them. One participant stated that "*Nurses don't like when we schedule medicines for 8, sometimes they give at 8:35, sometimes at 8:15. If we have to keep this 30 minutes accurate time between one drug and another drug, I am not able to find a way in the EMR that can tell them that you have to give at exact timing. In ICU mostly everything is on time. If on floors, if you have to keep 30 minutes timings then you need to be in front of the nurse and patient".* Another noted that "*Whenever you put in the order the default time auto gets setup. There should be a better way. What mostly happens, the med given at 8pm the patient already got it in the morning for 8am! Whenever we put in an order it auto puts in time, maybe they should ask us the time as well. First dose now vs. later, then second later. Then by accident if resident doesn't select STAT or now then it defaults to 8hours later. After signing the order it should ask you again to confirm a time to be given*".

5) Physicians often get feedback from nurses about medication administration through the MAR (Medication Administration Record). However, MARs can be non-comprehensive, erroneous, or delayed because the nurses must manually update some portions in the system. One participant noted that "*Medication wise it may appear that the medication wasn't given but if it was so you have to talk to nurse to double check*"

6) Parameter setting within the medication order can be challenging. One participant stated *"It would be nice to have even more nurse driven protocols. Because, then we have to change things constantly and then get a phone call you know basically parameter setting that a physician can do within meds would be super nice. Sometimes I put those in the comments sections and they get ignored. Or instead you still get a call or something. But this is fine because it's not formalized and nurses don't feel empowered to do it".*

7) EHRs are built in silos, so the information in one location is not necessarily available in another. There is often no dynamic communication between the MAR and the actual order. One participant noted that "*If for example the patient is in a med and the dose is going to change today, if they are on 20mg of Lasix and I want to change them to 40 technology should work for us. We should be able to say increase Lasix to 20 mg and, computer should talk to the medical record and should be able to say that the patient has already got the Lasix today do you want to give the extra 20 today to bring them up to 40 or do you want to start the 40 tomorrow or do you want them to have extra 40 today? The computer should be able to pull that information from itself and prompt you. It shouldn't be that you enter order for Lasix and then the pharmacy calls and says hey the dose is already given today do you want to give any extra dose? Or do you want to start tomorrow. I think the technology should take care of that. The computer already had that information .This is all promise right? That this EMR is going to work for us and that it was going to make medicine better. Instead this is like a duplication of paper and just more cumbersome*".

5.4.6 Potential Changes to Improve Communication of Medication Information

5.4.6.1 Support Medication Specific Communication in the EHR

Since providers frequently use CNMOs for varied types of nurse communication, a special order for communicating medication information with nurses would be helpful. This would make sure that the relevant communication orders are at least linked with medication orders, and less likely to be missed. One participant stated that *"It is challenging for that communication order to go as planned. Several times, these communication orders get lost or the nurse never reviewed them, or a nurse reviewed but forgot. Other times residents might feel that the nurses don't read these orders anyway*"

Another option is to change the title of the CNMO order type. All participants who mentioned that they would use CNMOs in the case scenarios were cognizant that the name CNMO does not fit the intended purpose. Some physicians also felt that the title gave the impression that the content in CNMOs is not important. Changing the order type title could change provider perception of the importance of these orders. One participant stated that "*I think it should be called 'communication to nurses' or even something more direct so it doesn't seem like 'miscellaneous'*".

5.4.6.2 Develop CDS for CNMO Orders

To make sure that nurses read CNMOs, it is important to have the information be in correct place. It may be helpful for the ordering physicians if the system intervenes when they enter something medication related in the CNMO. One participant noted that "*you can analyze the text and you can do whatever you do to intervene before it goes through, Are you sure you want to do? This is a med order and then you go immediately to the actual med order*"

5.4.6.3 Make CNMOs a Two-Way Communication Tool

One of the challenges using CNMOs is that these orders are a one-way communication tool. Providers who write CNMOs get no feedback about whether the information was viewed or acted on. "*I don't know why I am making the order if it is a non-communicable order, I don't know how much is done*"

Like medication orders, providing an option for nurses to sign off on a CNMO, or mark a CNMO as done would make these a true communication order. One participant stated that "*If we can be assured that the nurses are reviewing our orders and seeing them to completion. That would solve all problems and be a lot safer for the patients. I don't want providers (nurses/ residents/ physicians/ etc.) to get bogged down with the complicated order set as there are so many clicks already in EHR. But something as simple as a "free text box" or even a "check mark" for the nurses to enter right after they complete the communication order task. This way as residents and physicians we will be reassured that the order was met*".

Moreover, providers who access CNMOs do not have ways to ask questions or get clarifications on orders. One participant noted that "*Nurses should have the ability to put in a response or note edit function to CNMO so we can see what nurses did. CNMOs address nurses, so they should be able to address us back as simple as signing order or type free text back so we know everyone is on the same page*".

5.4.6.4 Improved Interface Design

A well designed EHR interface can improve accessibility and visibility of information. These design changes should target navigation aspects of the CNMO components. From the conversations with participants, it was evident that EHR interfaces do not always adhere to many known principles of design such as visibility, feedback, or affordances. One participant noted that "*we sometimes go into non-med orders or comments in medication orders, and then special instructions. I always get confused which one the nurses can see and which ones they don't see. Or it's like harder to see, it take an extra click to see. So it's much harder*".

The visual layout and display of information contained in the orders could be improved by adopting principles of interface design. The CNMO orders are found on the bottom of the screen and providers must scroll down to see these orders. As these orders are not easily visible, they can get lost in the list of other orders. One participant stated that "*I have heard nurses say they prefer we don't use it, because apparently they don't see it on their screen. Which I find kind of funny, because if the order is on our end as a communication order, the whole point of that is for them to read it. But I have had nurses come and tell me that they can don't it on their end or it does not flash as a priority for them*"

Information display design changes should be made based on principles of visual perception. For example, changes made to an order after order modifications are not apparent to providers. This issue could be improved by highlighting the specific order components that were modified. One participant noted that "*If there is something in the software that would let them know about the change that would be great".*

5.4.6.5 Influence User Behavior through Design

Sometimes, providers choose order types that they are most familiar with or those that are easily accessible in the system. We could support providers by allowing them to access medication orders easily when they try to search for non-med communication orders. One participant stated that "*You can have both non–med (CNMO) and the med order come up simultaneous and you choose one. For non-med, a quick way for you to do is to just type in* *'non'. So you have to make sure that you connect it in the beginning where it is easy for providers to choose*".

5.4.6.6 Provide Necessary Functionalities

As seen in previous section, not all functions or order types that participants expected to find were available in the EHR. A requirement analysis focusing on orders types that need to be built into the system can be done to help providers communicate better. One participant stated that *"To be honest I would want all the orders to be in there, I do not know much of the use of the non-med orders. Sometime I just think why is there no order to say "okay to use central line", so we can just click and sign it instead of putting a non-med order".* To avoid paper persistence all orders should be available in the EHR. This would also help to have all medication records in same place. "*We still use the insulin drip on paper but changed a few weeks ago, we are no longer on paper. There are somethings that do not have orders in the system that we have to hand write. For example, we do use patient has fluid in lungs we want to tap when we do send for analysis. We see most things in the EMR but some things we still record by hand on paper. Doesn't really have a cytology don't have something in the system*".

Apart from having new orders, systems must be built and integrated with providers' workflows so that providers are notified of a new order or an update to an order. EHRs should have the capability for auto refresh and provide pop up notifications when providers are logged into the system. When providers are away from the system, they could be provided notifications via mobile devices such as smart watches. These changes could help the communicated information reach the intended provider.

5.5 Discussion

This study identified and grouped into themes several reasons for physicians' use of CNMOs for communicating medication information. The influence of each of the themes on physician's use of CNMOs depends to a great extent on physician perspectives. Some participants appeared unaware of the risks of using CNMOs as a workaround. Even when participants knew that there were some risks, they wanted to use CNMOs to communicate medication information because of their perceived usefulness, lack of other support systems for communication and insufficient statistics on actual patient safety events due to this workaround. We hypothesized several reasons due to which physicians might use CNMO as a workaround. While these negative factors or drawbacks were mentioned by physicians during the interviews, several positive aspects and useful features of CNMOs came up during the interviews. These positive factors should be included in future research. The perceived positive aspects of CNMOs such as help with documentation, reminders and improved team awareness should be built into alternatives that we develop in place of CNMOs. Some approaches to address the issues raised by participants are detailed below:

Missing EHR system functionality: EHR systems can lack order types and functionalities that physicians require to carry out their clinical tasks. Designers and developers should carry out detailed and clear requirement analyses. Even if the requirement analyses are done before initial implementation, with changing workflows, policy, standards of care some of the requirements may change or evolve over time. Hence, requirement analyses must be carried out on a regular basis to update ordering systems.

Poor EHR system usability: Physicians often adopt to workarounds because of poor EHR usability, which often arise due to poor interface design. Issues such as lack of cognitive cues to medication changes and complex navigation can be addressed by adopting human factors and interface design principles. A user centered design approach should be adopted for design and development of the EHR. Due to hospital specific requirements, EHR systems may be different from the initial vendor design. Design changes can happen during and after implementation. Hence, usability testing and evaluation carried out after implementing any changes and before actual system use by physicians can help address this issue.

Difficulty in verbal communication: Given busy working conditions, physicians often find it difficult to contact nurses. While EHRs are helping them in such situations, use of CNMOs to achieve this goal may not be ideal. By providing a communication order for medication that gets linked with medication orders, we can better avoid unintended consequences. Also, verbal communication is usually preferred because with the EHR, physicians are not sure if nurses read the communication orders and nurses are not aware when there are new orders.[68] Because of lack of feedback, providers may adopt ad hoc verification approaches and workarounds to check order correctness and get clarification.[74,75] The use of CNMOs is one such workaround which could be avoided by 1) allowing two way communication orders, 2) Enabling auto refresh and updating of orders list and 3) Alerting providers about new orders when they are away from the EHR.

Need for flexibility: When dealing with complex scenarios, providers want flexibility with handling orders. CNMOs are often preferred when existing workflows are not supported. Research should focus on identifying and addressing mismatches between workflows imagined by EHR developers and those used in practice.

Need for redundancy: It is important to recognize that some aspects of communication can never be fulfilled by electronic orders. Having face to face or verbal communication in addition to electronic order is helpful, because it allows providers to get feedback and clarification. While redundancy is required to allow some level of safety, having multiple order types that providers can use to convey similar information can be confusing to both who write the orders and receive order information. Information can get fragmented across the EHR, resulting in unintended consequences.[9,10] Allowing providers to link similar orders can help address this issue.

Some physicians consider CNMOs to be more effective and easier to use compared to EHRs. It is not surprising to learn that CNMOs are considered easier to use as they allow physicians to use free text, avoiding complex navigation and tedious ordering / modification process associated with CPOE medication orders. However, it is surprising to learn that CNMOs are considered more effective even though they are not associated with CPOE medication orders. This may not be universally true, because some physicians shared that the nurses have requested them not to use CNMOs. Physicians who found CNMOs to be effective may not know these nurses' perspectives.

Physicians have very contrasting perspectives on the use of CNMOs. While some physicians said that they were useful for communicating medication information, others thought they should never be used to communicate medication information. Though their perspectives are in opposite sides of the spectrum, the underlying beliefs seem to be same - patient safety. Physicians who said CNMOs are useful seemed to feel that CNMOs reassure them that the information is communicated reliably. They felt nurses would not miss any required actions, thus avoiding error. On the other hand, physicians who didn't want to use CNMOs to communicate medication information have felt that if the information was not associated with the medication order itself, it could be missed by the nurses, thus contributing to error. Though physicians had different views on the use of CMNOs, all agreed that there is a need for system redundancy. All of them generally used more than one avenue to communicate medication information. Irrespective of using CNMOs or medication orders, physicians either talked to nurses over the phone or in person, because they did not receive enough feedback through the EHR. They lacked trust with the EHR, especially for critical, timely, urgent and/ complex situations. Future research should focus on addressing these aspects of communication. This study generated many challenges and potential solutions from physician's perspective. Future research should include nurses' perspectives, as they are the primary consumers of the medication information. Their perspectives will allow for a more holistic view when designing solutions to improve provider communication.

CHAPTER 6

DEVELOPING MODELS FOR CLASSIFYING FREE TEXT COMMUNICATION ORDERS

6.1 Introduction

The results from Chapter 3 showed that a large proportion of CNMOs contained medication information. These workarounds are risky and have a high potential for patient harm. To mitigate this risk, we could change EHR design to better accommodate clinical and usability needs of the providers. However, a large-scale study analyzing workflow interactions, changes in policies & procedures, and training would be required. Alternatively, we could develop trigger tools to alert providers about potential medication information in CNMOs. This trigger tool could be used 1) at the point of CNMO order entry, by alerting ordering providers whenever medication information is entered and directing them to write the information in another EHR location or 2) at the point of information retrieval, by alerting providers who need to act on the medication information. With this end goal, the objective of this phase of the study was to develop a model that could identify whether a CNMO contained medication information.

6.2 Methods

6.2.1 Training and Testing Dataset

The coded data from the initial analysis (Chapter 3) were used for training and testing. 80% of the data were randomly sampled for training and the remaining 20% of the data were used for evaluation. The testing of various model alternatives, termed an experiment in this field, is described in the following sections.

6.2.2 Experimental Setup

The classification of the CNMOs is a binary class problem; the string is considered either medication related or not. There are multiple modeling approaches for binary class problems. In the context of our medication related text, it was unclear which approach would yield the best results. An overview of the experimental workflow to the problem is shown in Figure 36. The first step involves *data preparation,* after which the free text strings were processed for information representation via *feature extraction techniques*. Next, binary classification models were *trained and validated* using 5-fold cross validation on the training data set (80% of the tagged data set). Finally, the model performance was *evaluated*. Each step is detailed below.

6.2.2.1 Data Preparation

The three CNMO free text fields (i.e., Verbatim, Special Instructions and Comments) were concatenated into a single string. Each CNMO was considered a document. The document was converted to lower case and punctuations were removed. An optional step of word replacement using dictionaries was performed in one of the experiments. In this step, medication names were replaced with a placeholder name so that any generic / brand medication name was identified as a medication. The full list of medication names and phrases used in the dictionary is shown in Appendix H. After initial data preparation, various text pre-processing techniques including removal of stop words, stemming and lemmatization were applied to enhance the quality of features that could be extracted.[108] Stop words are common words used in English language such as “the”, “an”, “a”, “is”. These were removed from the document as they generally do not add to the quality of information. Stemming and Lemmatization are methods that try to obtain the root form of the words, so that words in document can be normalized. This normalization helps to reduce inflectional and derived forms of words to a common base form.

For example, *am*, *are*, or *is* would be converted to *be* and *play*, *plays*, *playing*, or *played* would be converted to *play*.

Stemming uses a crude heuristic process that chops off the ends of words and often includes the removal of derivational affixes, while Lemmatization uses of a vocabulary and morphological analysis of words to remove inflectional endings only and to return the base or dictionary form of a word, which is known as the *lemma*.[109] When using stemming on text “the nurse saw the patient falling down” the stemming function could output “the nurse s the patient fall down” while lemmatization could result in “the nurse saw the patient fall” or “ the nurse see patient fall” depending on the usage of the word token ‘saw’ as noun or verb. There are multiple stemming and lemmatization algorithms. The Porter stemming algorithm[110] and Lemmatization based on WordNet lexical database[111] were used for preprocessing texts.

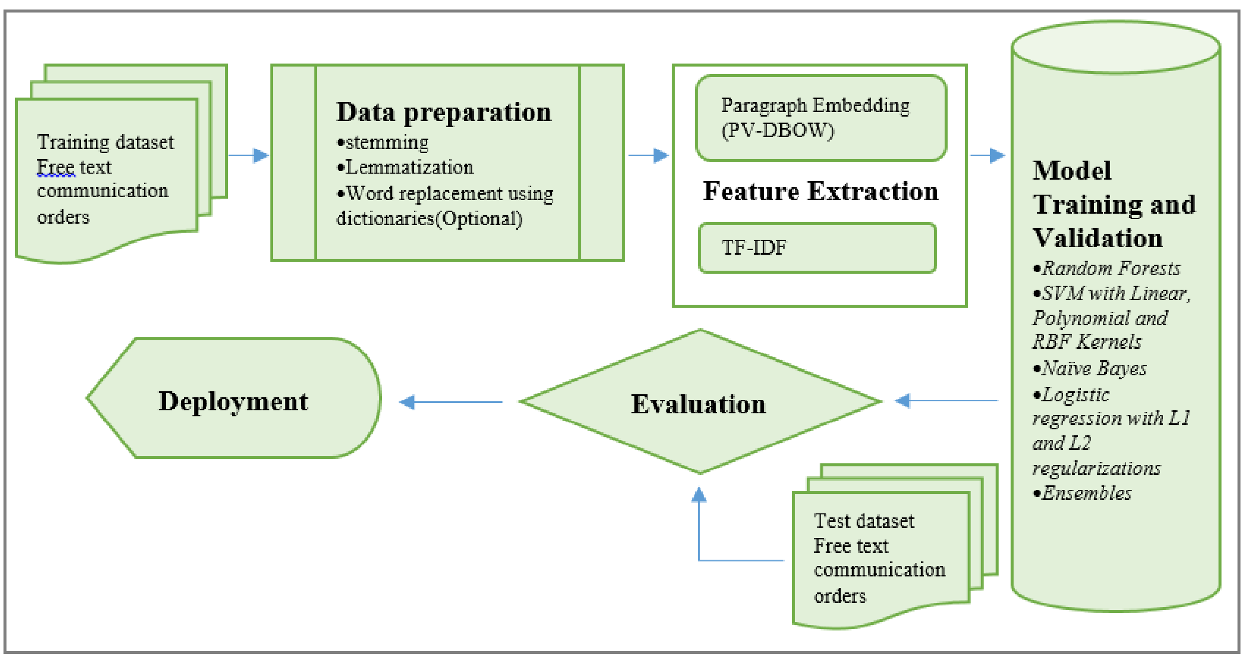

Figure 36: Experimental workflow

6.2.2.2 Feature Extraction

Feature extraction converts the free text data to a numerical representation that a classifier model can interpret. Two approaches were used for feature extraction: 1) frequency-based word embedding: TF-IDF (term frequency–inverse document frequency), and 2) neural embedding: Doc2Vec.

6.2.2.2.1 Frequency-Based Word Embedding: TF-IDF

The first step in the feature extraction process is tokenization. Tokens are unit representation of texts, which can be a single character, word or sentence. A unigram model would consider one token at a time, while bi-gram model would consider two tokens at a time and an n-gram model would consider n tokens at a time for feature representation. A unigram tokenization model was used.

A bag-of-words is a commonly used model for feature extraction, where the occurrence of each token is used as feature for training a classifier model.[112] Irrespective of grammar and occurrence order in the documents, the set of unique words (tokens) are represented as features. A simplest bag-of-words model is a binary count representation. Binary count representation transforms documents into 1 or 0 for each word (token) within the document. However, this does not represent much about the importance of words. The term frequency–inverse document frequency (TF-IDF), is a numerical statistic that is intended to reflect how important a word is to a document.[113] TF-IDF is a product of term frequency (TF) and inverse document frequency (IDF). Term frequency for term *t* in document *d* is simply the number of occurrences of the term *t* within document *d*. (1) The inverse document frequency is the logarithmic inverse fraction of the documents that contain the term *t* (2). Scikit-learn implementation of TF-IDF using TfidfVectorizer was used for feature extraction.[114]

$$\boldsymbol{TF(t,d) = f_{t,d}} \tag{1}$$

$$IDF(t,D) = log\frac{N}{1 + |\{d\epsilon D : t\epsilon d\}|} \tag{2}$$

$$TFIDF = TF(t,d).IDF(t,D) \tag{3}$$

Where D is the corpus representation collection of all documents *d*
N is the total number of documents in corpus D
$|\{d\epsilon D:t\epsilon d\}|$ is the number of documents *d* where the term *t* occurs

6.2.2.2.2 Neural Embedding: Doc2Vec

One of the disadvantages of using TF-IDF is that the features extracted do not represent semantic and syntactic relationships between the words in the document. To address this, multiple neural-network based models that provide high quality vector representations of words were proposed.[115–117] These vector representations are referred as word embedding. More recently, Continuous-Bag-of-Words (CBOW) and Continuous Skip-Gram (Skip-Gram) have been proposed as two efficient neural network model architectures for estimation of word representations (word2vec).[118] The architecture for these two models is shown in Figure 37. The objective of the CBOW model is to predict a current word given a window of context words, while the objective of Skip-Gram is to predict surrounding words within a window given a central word. Formally, given a sequence of words $w_1, w_2, w_3,..., w_T$; the objective of CBOW is to maximize the log likelihood of a word given a set of context. (4)

$$\text{Maximize} \log p(w_O|w_I) \tag{4}$$

Where w_O is the current word (or output word)
w_I is the set of context words w_O represented as w_{t+j} where $-c \leq j \leq c\ ; j \neq 0$
c is the size of context/ window size

The objective of the skip-gram model is to maximize the average log probability given current word w_o(5)

$$\text{Maximize} \frac{1}{\text{T}} \sum_{t=1}^{T} \sum_{-c \leq j \leq c} log\, p\left(w_{t+j} | w_t\right) \tag{5}$$

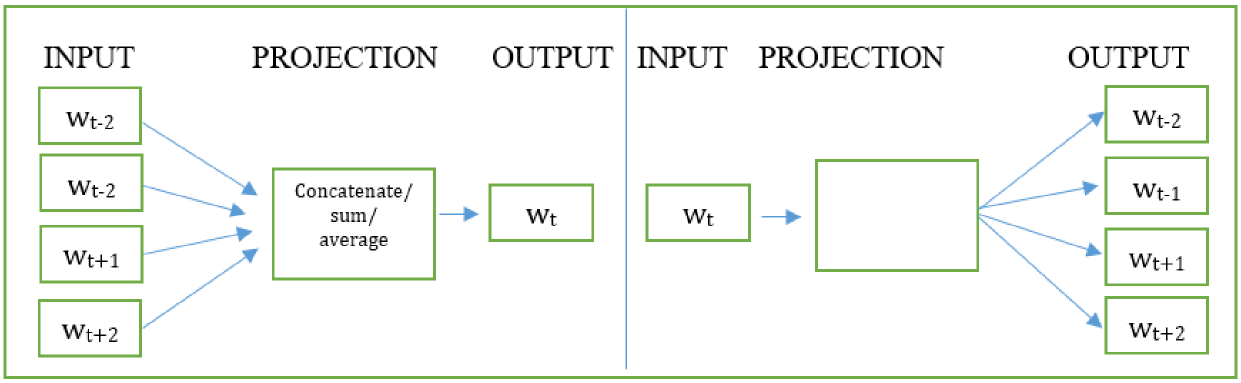

Figure 37: CBOW (Left) and Skip-gram (Right) model architectures

The basic formulation defines $\log p\,(w_{t+j}|w_t)$ for a Skip-gram model or $\log p\,(w_t|w_{t+j})$ for CBOW i.e $\log p\,(w_O|w_I)$ using softmax function as:

$$\log p(w_O|w_I) = \frac{\exp\left(v'_{w_O}{}^{T} v_{w_I}\right)}{\sum_{w=1}^{W} \exp\left(v'_{w_O}{}^{T} v_{w_I}\right)} \tag{6}$$

Where v_w is the input vector representation for w
v'_w is the output vector representation for w
W is the total number of words in the vocabulary

The softmax function used in (6) is computationally expensive. As an alternative to using softmax in word2vec, Mikolov et al. proposed negative sampling.[119] The idea is that a good model should be able to differentiate between data and noise using a simple logistic regression. In context of word embeddings this means we want to maximize the dot product between Input word vector(s) w_I and Output word vector(s) w_O while minimizing the dot product between vector(s) of input word(s) and randomly sampled “negative” words. Consequently, the objective with negative sampling is given by (7)

$$\log \sigma \left({v'}_{w_O} T_{v_{w_I}} \right) + \sum_{i=1}^{k} \mathbb{E}_{w_I \sim P_n(w)} \left[\log \sigma \left(- {v'}_{w_i} T_{v_{w_I}} \right) \right] \quad (7)$$

Where v_w is the input vector representation for w
v'_w is the output vector representation for w
k is the number of negative sample words
$P_n(w)$ is the noise distribution
σ is the sigmoid function $\sigma(x) = \frac{1}{1+\exp(-x)}$

The neural network model was trained using stochastic gradient descent where the gradient was obtained using back-propagation.[120] The word embeddings from the above models have been found to carry syntactic and semantic information.[118,119] One way to use the word embeddings at the document level is to aggregate the word vectors of all the words in a given document using simple techniques such as averaging of vectors. However, such averaging can make the embeddings lose context. To retain some context of the documents while obtaining embeddings at a document level, Le and Mikolov extended representation of words and phrases to representation of sentences and documents (Doc2Vec).[121] There are two frameworks, namely Distributed Memory Model of Paragraph Vectors (PV-DM) and Distributed Continuous Bag of Words (PV-DBOW). The frameworks for PV-DM and PV-DBOW are shown in Figure 38.

In the PV-DM framework, every paragraph (or document) is mapped to a unique vector and every word is mapped to a unique vector. The vectors are concatenated or averaged to predict the next word in the context similar to CBOW discussed earlier. The only change to the CBOW in our model was the addition of a paragraph token. This paragraph token can be considered as another word; but is unique to each paragraph. The paragraph vectors were shared across the context for words from the same paragraph but are not shared across paragraphs (i.e., the paragraph vectors are unique for each paragraph.) The word vectors were shared across paragraphs. The word and paragraph vectors were initiated randomly and then trained using stochastic gradient descent.[120] For each iteration of the training, a fixed length of context words were sampled randomly from a random paragraph. The error gradient was computed and used to update model parameters (i.e., the document and word vectors.)

$$\text{Maximize } \log p(w_O | w_I, D_I) \quad (8)$$

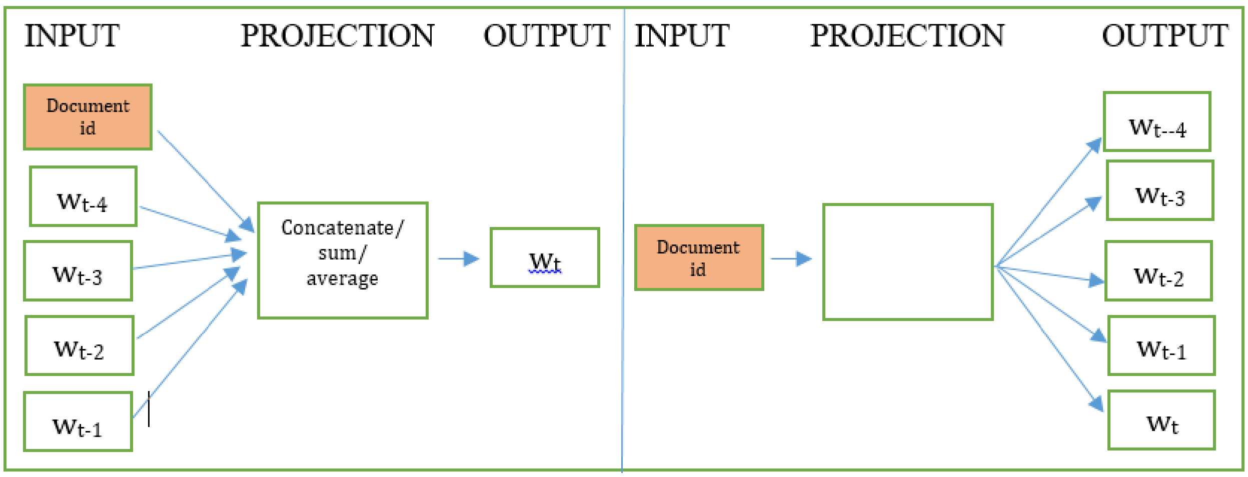

Figure 38: PV-DM (Left) and PV-DBOW (Right) model architectures

As an alternative to PV-DM, the PV-DBOW framework ignores the context words in the input but considers only randomly sampled paragraph ID to predict words in the sampled paragraph. This is very similar to the skip-gram model where the model objective is to predict context words. The only difference is that the input for PV-DBOW is paragraph ID instead of center word. The optimization function / model objective is same as in (7), except that v_{w_I} is vector representation for the paragraph. When inferring vectors for a new document the model parameters for word vectors, weights for the output hidden layer are kept constant. The weights for input hidden layer were learned using stochastic gradient decent. The neural network model described above has multiple options for parameter setting. We had to make multiple choices including using PV-DBOW or PV-DM, the number of hidden layers (vector size for embedding), the type of aggregation (sum, average, concatenation), the window size for context words (number of words to consider left/right from the center word), the type of activation function (Hierarchical soft max, negative sampling), the number of model iterations, and the learning rate for stochastic decent. Choosing correct hyper parameter settings is essential for getting good embeddings. However, this process requires a robust evaluation data set, more computational power, and time to do grid search on multiple parameter settings. Han Lau and Baldwin conducted an empirical evaluation of the performance of Doc2Vec and provided recommendations for hyper parameter settings.[122] The Doc2Vec model was developed using 544,829 unique documents (CNMOs). I used the recommendations from their study for parameter setting to train the Doc2Vec model using genism[123] (v3.4.0) for feature extraction.

6.2.2.3 Model Training and Validation

The extracted features were used for training the binary classifier models. Several models including Random Forests[124], Support Vector Machine (SVM) with Linear, Polynomial and Radial Basis Function (RBF) Kernels[125,126], Logistic Regression with L1 and L2 regularization functions[127–129], Gaussian Naïve Bayes[130] were trained on the training dataset (n = 4428 examples.) A five-fold cross validation was used for selecting model hyper-parameters. An additional ensemble model[131] was also trained using trained Random Forest, SVM with RBF and Logistic Regression with L2 regularization. All model training was done using scikit-learn.[114]

6.2.2.4 Evaluation

The models were evaluated using the test dataset (n = 1,146 samples.) Precision is the number of true positives divided by the number of positives returned by the model. Recall is the number of true positives divided by number of positives in the sample. F1score is the harmonic mean of precision and recall. These performance metrics, along with Area under the Curve (AUC), were used to evaluate the models. In total, these measures can evaluate the model performance comprehensively. The FDA(Food and Drug Administration) authorized list of medications was used for identifying baseline performance.[132]

6.3 Results

The baseline precision was 0.74 and recall was 0.67. Tables 4, 5, and 6 show the model performance metrics using the three feature extraction approaches. Of the models trained using TF-IDF without medication name replacement, the Random Forests model had the best performance in terms of precision (0.92) and AUC (0.94), but the recall (0.61) and F1 score (0.73) were much lower than other models. Of the models trained using TF-IDF without medication name replacement, the Ensemble model using TF-IDF with medication name replacement had the best scores on all four performance measures (precision = 0.90, recall = 0.92, F1 = 0.91, AUC = 0.98). Of the models trained using Doc2Vec, the SVM RBF model provided the best precision (0.92), recall (0.87), and F1 score (0.89), though the AUC was slightly higher with the Ensemble model (0.99 vs. 0.98). Overall, the models trained using TF-IDF features without medication name replacement performed more poorly than other two feature extraction approaches.

Table 4: Model performances using TF-IDF without replacement

Model	Precision	Recall	F1 Score	AUC
Random Forest	**0.92**	**0.61**	**0.73**	**0.94**
Gaussian Naïve Bayes	0.39	0.93	0.54	0.76
Logistic Regression with L1 Regularization	0.87	0.70	0.78	0.94
Logistic Regression with L2 Regularization	0.88	0.70	0.78	0.94
SVM Linear	0.91	0.66	0.77	0.93
SVM RBF	0.90	0.68	0.78	0.93
SVM Polynomial	0.82	0.73	0.77	0.92
Ensemble	0.91	0.66	0.76	0.94

Table 5: Model Performances using TF-IDF with replacement

Model	Precision	Recall	F1 Score	AUC
Random Forest	0.88	0.89	0.88	0.98
Gaussian Naïve Bayes	0.37	0.92	0.53	0.75
Logistic Regression with L1 Regularization	0.89	0.87	0.88	0.98
Logistic Regression with L2 Regularization	0.89	0.87	0.88	0.98
SVM Linear	0.89	0.91	0.90	0.98
SVM RBF	0.89	0.92	0.90	0.98
SVM Polynomial	0.84	0.86	0.85	0.96
Ensemble	**0.90**	**0.92**	**0.91**	**0.98**

Table 6: Model Performances using Doc2Vec

Model	Precision	Recall	F1 Score	AUC
Random Forest	0.91	0.56	0.69	0.96
Gaussian Naïve Bayes	0.51	0.56	0.53	0.81
Logistic Regression with L1 Regularization	0.85	0.86	0.86	0.97
Logistic Regression with L2 Regularization	0.84	0.87	0.86	0.97
SVM Linear	0.90	0.82	0.86	0.97
SVM RBF	**0.92**	**0.87**	**0.89**	**0.98**
SVM Polynomial	0.90	0.87	0.88	0.97
Ensemble	0.91	0.86	0.88	0.99

The brier score is measure of accuracy of probabilistic prediction and measures the mean squared difference between the predicted probability assigned to the possible outcomes and the actual outcome. If the model predicts that a CNMO is medication related with probability p = 1 and the CNMO is medication related, then the Brier Score is 0, the best score achievable. If the model predicts that CNMO is medication related with probability p = 0 (i.e. the CNMO is not medication related) and the CNMO is medication related, then the Brier Score is 1, the worst score achievable. If the model predicts that the CNMO is medication related with probability p = 0.70 and the CNMO is medication related, then the Brier Score is $(0.70-1)^2 = 0.09$.

Shown in Table 7, the SVM RBF model trained using all feature extraction techniques had the lowest (better) Brier scores. The SVM RBF model using TF-IDF features with medication name replacements had the best Brier score (0.037), followed by the slightly higher Doc2Vec (0.038). These low scores indicate very good accuracy for the probability predictions when using these models.

Table 7: Brier Scores

Classifier	TF-IDF without replacement	TF-IDF with replacement	Doc2Vec
Random Forest	0.082	0.052	0.084
Gaussian Naïve Bayes	0.354	0.378	0.219
Logistic Regression with L1 Regularization	0.071	0.040	0.051
Logistic Regression with L2 Regularization	0.071	0.041	0.053
SVM Linear	0.073	0.039	0.047
SVM RBF	**0.071**	**0.037**	**0.038**
SVM Polynomial	0.077	0.054	0.043
Ensemble	0.073	0.039	0.043

6.4 Discussion

The model performance with TF-IDF features is limited by the frequency of medication names in the corpus. If certain medication names are missing from the TF-IDF vocabulary, they are not considered as features and the classifier model misses that key information. This explains high precision and lower recall performance metrics for the models shown in Table 4. The model performance using TF-IDF with replacement and Doc2Vec feature extraction are comparable. However, generating a list of medication names (generic, brand names) can take a lot of manual effort. Also, the list can still be not exhaustive due to the use of acronyms, misspellings, etc. Feature extraction with Doc2Vec can learn semantic relationship for new words and understand context, so the use of word dictionaries is not required when using Doc2Vec extraction. Table 8 shows a list of examples that were identified using the Doc2Vec model but were missed by the TF-IDF model.

Table 8: Example CNMOs where Doc2Vec is better suited compared to TF-IDF

Example CNMO	**Challenge Type**	**Detailed Reason**
Pls stop *hearpin*	Mis-spelling	"Heparin" misspelled as "hearpin"
Pls give *packed unit of red blood cell*	Unknown phrase / Acronym	"PRBC" is usually used as an acronym for packed unit of red blood cell
Please discontinue *Xanax*	Unknown medication name/ Brand Name	"Xanax" is a brand name for alprazolam

The ability of the Doc2Vec model to infer semantic relationships makes the trained model more generalizable than TF-IDF approach. In some cases, the Doc2Vec model provides false positives when context is very similar. For example, if the free text is "pls hold food" the model classifies it as medication related. However, if there is more context to the order say, "pls hold food as pt might be NPO" the model classifies it correctly. Providing more example CNMOs for developing the Doc2Vec feature extraction model or adding an additional rule-based model to complement the existing model can improve performance. When comparing the various binary classifiers, the discriminative models such as SVM and Random Forests perform much better than Gaussian Naïve Bayes as found in other text classification tasks.[133]

The approach can be used for determining if a CNMO contains medication related information. This can be used both prospectively and retrospectively. Figure 39 shows a screenshot of a web application showcasing the use of the model for prospective use. Users can provide input by either using the free text input box to type a free text CNMO or, select input from the list of example CNMO text. The model will give the prediction and probability that the CNMO contains medication information.

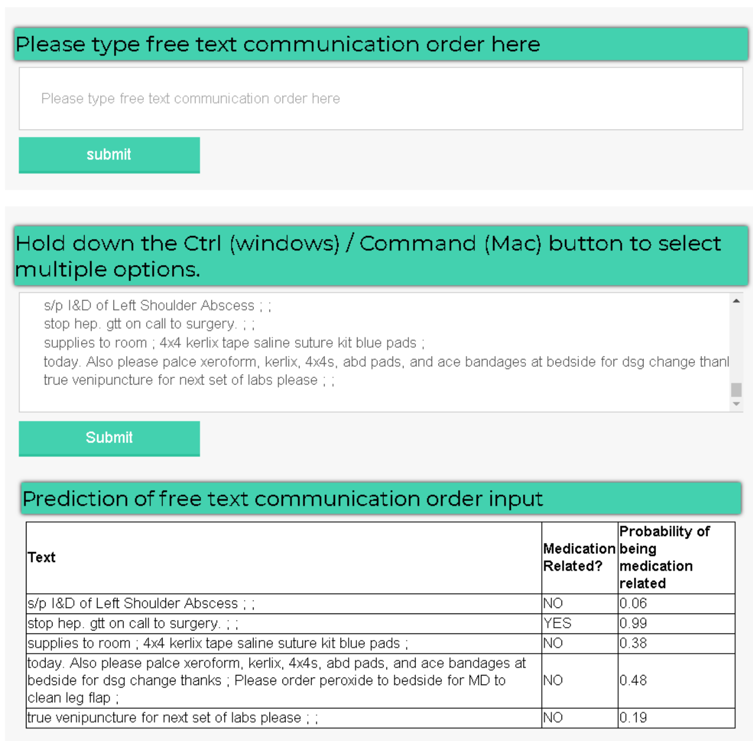

Figure 39: Screen capture of web application

This stand-alone application could be integrated into the EHR and be used as a trigger tool to alert ordering providers, requesting that they consider writing this text as part of a medication order or within another area of the EHR. The same tool could also be used to either highlight a CNMO or link it with medication orders if it contains medication related information. This could improve nurse awareness and provide context to the nurses while looking at medication orders. Another use case for the model is to link it to the MAR (Medication

Administration Record). Whenever a provider sees a patient chart to get information about medications to be given, a passive content box containing CNMOs with potential medication information could be displayed. This would serve as another way of helping nurses to direct their attention to medication information. Figure 40 shows the Receiver Operating Characteristic curve for the classifier model. We can vary the prediction thresholds to control the true positive and false positive rates. For the CDS application, if we want to ensure that most of the CNMOs with medication information are captured for nurses to act on, then we can set the probability threshold to 0.1 and expect a true positive rate of 99%. However, the false positive rate would go up to 40%. Alternatively, if our aim is to reduce alarm fatigue, we could use a threshold of 0.75. This would enable us to have a true positive rate at least 75% and reduce the false positive rate to less than 1%.

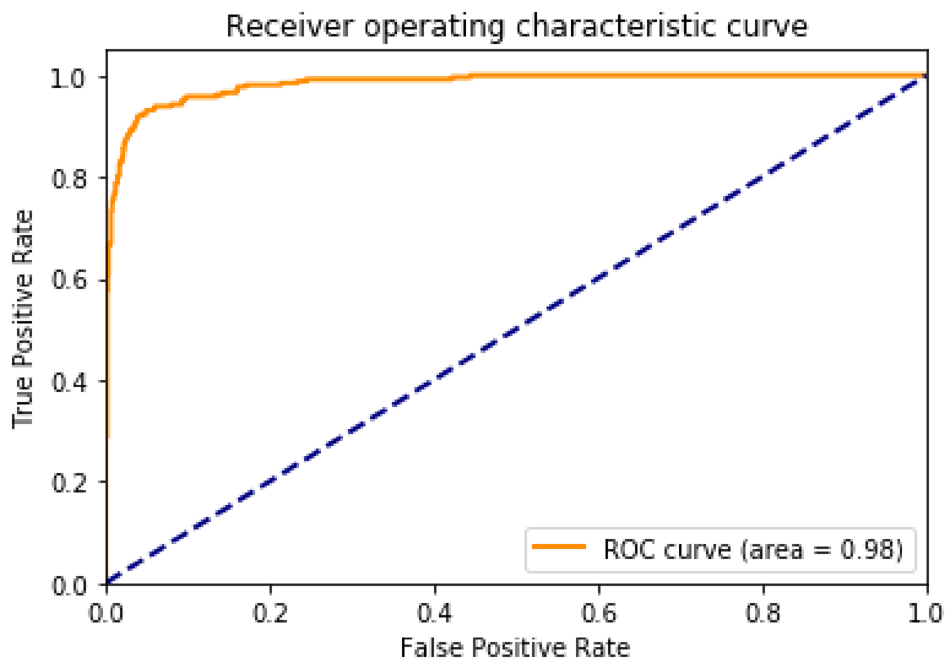

Figure 40: ROC Curve for SVM RBF using Doc2Vec

When used retrospectively, the application could be used to find patterns of CNMO usage over time across multiple locations. As an example, this model was applied to all the orders written within the hospital system during the five-year period (3.2 million orders). The overall proportion of CNMOs containing medication information was 29%, lower than the 42% obtained from our manual analysis of a sample of CNMOs. This difference may be due to the following reasons 1) The model recall was only 0.87, so the model could have missed many CNMOs that are medication related. 2) The manual estimate was based on a sample from 2017. The rates of use of CNMOs in the previous years may be comparatively lower. 3) Some of the texts are repeated in CNMOs, so a classification error in one text would affect all CNMOs having the same text, thus resulting in lower number of positives.

The results show that we can get high classification performance when identifying CNMOs containing medication information, regardless of the methods. The performance measures indicate that we can solve this classification problem in a reasonable way using machine learning.

This modelling approach could be extended to information types other than medications. For example, a classifier model could be built to identify diet related orders. This could be integrated to a trigger tool to alert providers to write the order as part of diet order. The tool could also be used to direct attention of nurses to CNMOs by linking them to diet orders. Specific diet related CNMOs such as NPO status and restrictions on amounts of food could be identified and sent to the pantry, as the pantry does not have access to the communication orders. The tool should be tested for scalability and usefulness in actual practice.

CHAPTER 7

CONCLUSION

Communication is a critical component of safe health care delivery, with CPOE now being ubiquitously used for communicating medication information through various order types. Prior studies have looked at the use of free text within medication orders, but the inclusion of medication related information in communication for non-med orders (CNMOs) has not been adequately studied. In this dissertation, we explored providers' use of CNMOs by analyzing orders placed at six hospitals in a Mid-Atlantic health system. In Chapter 3, we found that over 42% of the CNMOs are used for communicating medication information. We then analyzed the contents of the CNMOs and identified 16 uses of CNMOs. Four of the sixteen uses (i.e., Medication, ADT (Admission, Discharge, and Transfer), Labs, and Diet) were associated with standard CPOE order types. The use of CNMOs to communicate information about these four uses could be potentially risky as other providers may not expect the information to be in CNMOs and hence miss the information. The results highlight the severity of the issue and need for addressing the problem.

In Chapter 4, we analyzed overall prevalence of CNMOs and CNMOs containing medication information across factors such as hospital location (even though these hospitals were a part of the same healthcare system), patient setting, and provider type. We found large variation in the frequency of CNMO use across all of these factors and the usage of CNMOs for communicating medication information. Differences in usage exist across and within hospitals. Understanding these differences by analyzing usage patterns across hospitals can help decision makers learn from other hospitals, especially in a multi-hospital healthcare system. These differential policies may be problematic for providers who practice at multiple hospitals.

The analysis also showed nuanced differences in two types of providers: action and ordering. Residents were ordering providers for approximately 5500 CNMOs and action providers for 4500 CNMOs, whereas Anesthesiologists were ordering providers for approximately 5000 CNMOs and action providers less than 50 CNMOs. This disparity indicates that physicians may be relegating ordering work to nurse. The disparity might also be due to differences in workflow and communication needs specific to the provider types. We can target interventions to specific user groups by understanding such differences.

We also identified the frequency of medication names and medication classes contained in CNMOs. Naloxone, Heparin, Flumazenil and Dextrose were the most frequently mentioned medication names in CNMOs. Order sets, Antidotes, Analgesics, and Anticoagulants were the most common medication classes mentioned in CNMOs. The prevalence of different medication classes was unique to certain hospitals. For example, Anticonvulsants were prevalent only at Hospital 3. This suggest that hospitals may have unique challenges with respect to the use of different medication classes, meaning they may require different solutions related to the use of CNMOs.

We discovered action specifications for which CNMOs were used. Discontinuation of medications was the most common action specification for which providers used this workaround. Discontinuing medications is known to be a challenge for providers when using CPOE systems.[9] By analyzing the free text CNMOs, we were able to identify challenges specific to hospitals, patient settings, and provider types. We were able to discover challenging medications, and types of actions for which providers use this workaround.

In this dissertation, we used quantitative analysis to inform the design of our qualitative research. At present, the standard practice is typically to design a qualitative study using data from literature, and from formative or preliminary observations or interviews. Our unique methodology can be used in future studies.

The case scenarios in our qualitative study were developed based on the analysis of CNMO usage patterns. Based on usage rates of CNMOs, we targeted physicians in the inpatient setting. We used results from action requirements in CNMOs, namely discontinuation, holding, order modifications to inform development of the interview questions. Because the interviews were being conducted at Hospital 5, the case scenarios focused more on anticoagulant medications, the most common medication class in CNMOs Hospital 5. Also, because CNMOs at Hospital 5 contained a lot of high-risk medications, we included scenarios reflecting use of the high-risk medications potassium and insulin. This was a unique way of identifying key areas to explore and user groups to target for doing qualitative analysis.

The reasons for using CNMOs fell into ten themes. Some of these issues, such as missing system functionality and the need for other documentation avenues can be directly addressed by system developers. To address other issues, such as poor system usability with respect to communicating medication information, further research is needed. Reasons such as better reminders and team situation awareness reinforce key requirements we need to satisfy when designing systems.

Physicians reported using multiple avenues to ensure that nurses receive information correctly and act on the information in a timely manner. For all case scenarios, physicians used verbal communication, even if they also used the EHR to communicate the medication information. They specifically mentioned that EHRs were not reliable when they wanted to communicate something that was either critical, timely, urgent and/or complex. These findings provide important direction for future research.

This study also identified specific challenges within the EHR for communicating medication information. The challenges cannot be generalized to other EHR systems. However, it is plausible for some pattern of the challenges to be common across systems. For example, a study by Ratwani et al. found that the general pattern of usability challenges and medication errors were the same across the three sites in their study.[134] They found that the most common usability challenge was associated with system feedback. The same issue was also reported by multiple participants in our study. Future research should focus on this key challenge to improve communication.

As a potential solution to help provider communication, we developed classifier models to identify CNMOs that contained medication information. When developing the classifier models, we explored two feature extraction techniques (TF-IDF and Doc2Vec) and compared performance across all combinations of classifier models and feature extraction techniques. The SVM Classifier model with RBF kernel using Doc2Vec features gave the best performance. The potential applications of such modeling techniques to help provider communication were discussed.

Overall, we explored prevalence of a specific workaround across hospitals in a health system that uses a prominent EHR vendor system and analyzed variation across hospitals, provider types, and patient settings. We also identified specific medications and medication classes for which providers tend to use CNMOs more frequently. The reasons for workarounds, challenges with using EHR for communicating medication information, and potential solutions were identified. To address one of the challenges, a prototype application using natural language processing was developed and its potential uses were discussed. Future research could adopt similar methods to identify issues related to provider communication. One of the critical findings of this work is the types of information for which providers do not trust using the EHR for communication. Future work can focus on addressing these issues to support provider communication.

This dissertation was limited by its analysis of data from one hospital system using the same EHR vendor product, though the EHR is used by a large portion of US hospitals. Challenges with the EHR for communicating medication information and the reasons for the use of CNMOs were qualitatively analyzed via a small sample of physicians. The analysis can be supplemented with interviews with more types of physicians and with perspectives from nurses who are the primary consumers of the information. These additional participants would provide a more holistic view into the use of CNMOs in provider workflows. Finally, the NLP tool should be analyzed in actual practice to validate its usefulness and scalability.

APPENDIX A

LITERATURE REVIEW SUMMARY

S NO	Citation	Year	Study type	Study details	Key Point(s)
1	Joint Commission. Sentinel Event Statistics Data–Root Causes by Event Type (2004–2015). *Sentinel event data- root causes by event type*. 2016.	2016	JC report	JC report	Communication failures contribute to a majority of sentinel events that occur in hospitals during 2004–2015
2	*Medical Malpractice in America*. Boston: CRICO; 2018:28.	2018	Quantitative study	Report based on analysis of medical professional liability cases from 2007 to2016	38% of malpractice incident claims involve miscommunication between providers
3	Agarwal R, Sands DZ, Schneider JD. Quantifying the economic impact of communication inefficiencies in U.S. hospitals. *J Healthc Manag*. 2010;55(4):265-281; discussion 281-282.	2010	Quantitative study	Study uses data collected from interviews in seven hospitals as primary data and secondary data from a literature review, the Bureau of Labor Statistics (BLS), and the Agency for Healthcare Research and Quality (AHRQ) to estimate the economic impact caused by communication inefficiencies across all U.S. hospitals.	Communication inefficiencies among care providers cost US hospitals $12 billion annually
4	*Hospital: 2019 National Patient Safety Goals*. The Joint Commission; 2018. https://www.jointcommission.org/assets/1/6/NPSG_Chapter_HAP_Jan2019.pdf. Accessed March 19, 2019.	2018	JC report	JC report	Improving provider to provider communication is a national patient safety goal for 2019
5	Office of the National Coordinator for Health Information Technology. Office-based Physician Electronic Health Record Adoption. Health IT Quick-Stat #50. dashboard.healthit.gov/quickstats/pages/physician-ehr-adoption-trends.php. Published January 2019.	2019	ONC statistics	ONC statistics	99% of large hospitals are now using a certified EHR
6	Taylor SP, Ledford R, Palmer V, Abel E. We need to talk: An observational study of the impact of electronic medical record implementation on hospital communication. *BMJ Qual Saf*. 2014;23(7):584-588. doi:10.1136/bmjqs-2013-002436	2014	Qualitative study	Pre-Post CPOE implementation study assessing impact of CPOE on communication. Study involved 75 patient-nurse-physician triads prior to the introduction and 123 triads after the introduction of CPOE	CPOE was associated with a decrease in face to face interaction between physician and nurses, and worsened overall agreement about plans of care. "Face-to-face communication was significantly reduced (67% vs 51%, p=0.03). Total Agreement Score was significantly lower after the implementation of EMR (p=0.03). Additionally, fewer patients accurately predicted their expected length of stay after EMR (34% vs 26%, p=0.001)".
7	Walsh C, Siegler EL, Cheston E, et al. Provider-to-provider electronic communication in the era of meaningful use: A review of the evidence. *Journal of Hospital Medicine*. 2013;8(10):589-597. doi:10.1002/jhm.2082	2013	Literature review	Review based on 25 studies, to assess the impact of provider-to-provider electronic communication tools on communication	"The principal findings of the literature review underline the paucity of quantitative data surrounding provider-to-provider communication" It is unclear which types of communications would be best served within the EHR and which should remain external to it".

S NO	Citation	Year	Study type	Study details	Key Point(s)
8	Tan T-C, Zhou H, Kelly M. Nurse–physician communication – An integrated review. *Journal of Clinical Nursing*. 2017;26(23-24):3974-3989. doi:10.1111/jocn.13832	2017	Literature review	Literature-based on 22 studies during period Jan 2005 to April 2016.	Review suggests that nurse-physician communication still remains ineffective.
9	Koppel R, JP M, Cohen A, Al et. Role of computerized physician order entry systems in facilitating medication errors. *JAMA*. 2005;293(10):1197–1203.	2005	Mixed methods study	"We performed a qualitative and quantitative study of house staff interaction with a CPOE system at a tertiary-care teaching hospital (2002-2004). We surveyed house staff (N = 261; 88% of CPOE users); conducted 5 focus groups and 32 intensive one-on-one interviews with house staff, information technology leaders, pharmacy leaders, attending physicians, and nurses; shadowed house staff and nurses; and observed them using CPOE".	CPOE system facilitated 22 types of medication error risks. More than 90% of the respondents had difficulty specifying medications and problems ordering off-formulary medications at least once in the past three months, pointing to the aforementioned inflexibility of CPOE. CPOE lacks certain features such as dosing calculations. CPOE has also been found to be inflexible with ordering, for example by a patient to be admitted into the department or hospital before placing orders, thus causing delays in care. CPOE also removes asynchronous steps and informal mechanisms such as checks by pharmacists, and notes or clarifications for complex orders that help with decision making, order review, and error checking, thus increasing the risk of errors
10	Howe JL, Adams KT, Hettinger AZ, Ratwani RM. Electronic Health Record Usability Issues and Potential Contribution to Patient Harm. *JAMA*. 2018;319(12):1276-1278. doi:10.1001/jama.2018.117 1	2018	Qualitative study	"Patient safety reports, which are free-text descriptions of safety events, were analyzed from 2013 through 2016. Reports were retrieved from the Pennsylvania Patient Safety Authority database, which collects reports from 571 health care facilities in Pennsylvania, and from a large multihospital academic health care system in the mid-Atlantic, outside of Pennsylvania"	"Of 1.735 million reported safety events, 1956 (0.11%) explicitly mentioned an EHR vendor or product and were reported as possible patient harm and 557 (0.03%) had language explicitly suggesting EHR usability contributed to possible patient harm".
11	Ash, J.S., Berg, M., Coiera E. Some Unintended Consequences of Information Technology in Health Care: The Nature of Patient Care Information System-related Errors. *J Am Med Inform Assoc*. 2004;11(2):104–112. doi:10.1197/jamia.M1471. Medical	2004	Literature Review	"Reflections are based on U.S. data about CPOE from four hospitals, including 340 hours of observation and 59 formal interviews, Australian data about CPOE from 18 semi structured interviews with stakeholders at several public hospital sites, and Dutch data from electronic medical records, CPOE, and medication system studies involving participant observations and interviews from two hospitals and other settings in The Netherlands".	CPOE can cause cognitive overload because it over emphasizes structured data entry. Providers resort to workarounds due to poor user interfaces and cumbersome data entry processes. Orders are entered in an environment away from patients, outside the context in which patient order was discussed and away from those who could correct misinterpretations, order entry in CPOE can be prone to errors.
12	Campbell EM, Sittig DF, Ash JS, Guappone KP, Dykstra RH. Types of unintended consequences related to computerized provider order entry. *Journal of the American Medical Informatics Association*. 2006;13(5):547–556.	2006	Qualitative study	390 hours of observation of 95 clinicians, and 32 interviews at five hospitals	Misinformation and errors occur due to problematic electronic data presentations; confusing order option presentations and selection methods; inappropriate text entries

S NO	Citation	Year	Study type	Study details	Key Point(s)
13	Baron JM, Dighe AS. Computerized provider order entry in the clinical laboratory. *Journal of pathology informatics*. 2011;2.	2011	Literature Review	Review of reported CPOE benefits and drawbacks. Discussion on barriers to the implementation of CPOE systems	CPOE can help check for duplicate therapies and medications, can lack system support
14	Sittig DF, Krall M, Kaalaas-Sittig J, Ash JS. Emotional aspects of computer-based provider order entry: A qualitative study. *Journal of the American Medical Informatics Association*. 2005;12(5):561–567.	2005	Qualitative study	Secondary analysis of data collected in precious research involving observations, interviews and focus groups, conducted to describe the perceptions of diverse professionals involved in computerized physician order at 3 hospitals. The original study included a total of 19 observations, 19 informal interviews, 14 formal interviews, 3 focus groups.	Negative emotions such as guilt, shame, anger, anxiety and frustration associated with the use of CPOE
15	McDonald CJ, Callaghan FM, Weissman A, Goodwin RM, Mundkur M, Kuhn T. Use of internist's free time by ambulatory care Electronic Medical Record systems. *JAMA Intern Med*. 2014;174(11):1860-1863. doi:10.1001/jamainternmed. 2014.4506	2014	Qualitative study	"On December 12, 2012, the ACP mailed a 19-question survey to its panelists (900 ACP member and 102 nonmember internists at that time) who provided ambulatory care, and left it in the field for 10 days. Of 845 invitees, 485 opened the e-mail (a 62.5% contact rate). We removed 69 who reported no EMR use or no ambulatory practice (a 53.6% response rate [416 of 776])"	CPOE system is inconvenient to use. " 89.8% reported that at least 1 data management function was slower post-EMR adoption, and 63.9% reported that note writing took longer. Surprisingly, a third (33.9%) reported that it took longer to find and review medical record data with the EMR than without, and a similar proportion, 32.2%, that it was slower to read other clinicians' notes. The mean time loss for attending physicians was −48 minutes per clinic day ($P < .001$), or 4 hours per 5-day clinic week. The mean loss for trainees was −18 minutes per day, less than that of attending physicians ($P < .001$). For the 59.4% of all respondents who did lose time, the mean loss was −78 minutes per clinic day, or 6.5 hours per 5-day clinic week".
16	Sittig DF, Ash JS, Guappone KP, Campbell EM, Dykstra RH. Assessing the Anticipated Consequences of Computer-based Provider Order Entry at Three Community Hospitals Using an Open-ended, Semi-structured Survey Instrument. *Int J Med Inform*. 2008;77(7):440-447. doi:10.1016/j.ijmedinf.2007.08.005	2008	Qualitative study	Qualitative analysis to determine what "average" clinicians in organizations that were about to implement Computer-based Provider Order Entry (CPOE) were expecting to occur .Study interviewed a total of 83 clinicians: 31 physicians, 31 nurses, and 21 allied health professionals at the three community hospitals.	Clinicians are often unaware of the unintended consequences or errors associated with using CPOE in ways it was not designed for

S NO	Citation	Year	Study type	Study details	Key Point(s)
17	Zhou L, Mahoney LM, Shakurova a, et al. How many medication orders are entered through free-text in EHRs?–a study on hypoglycemic agents. *AMIA Annu Symp Proc*. 2012;2012:1079–1088.	2012	Quantitative study	Analysis of free-text medication order entries involving hypoglycemic agents in an ambulatory electronic health record (EHR) system with CPOE during 2010.	"Overall, 2,412 hypoglycemic drugs were entered using free-text for 2,091 patients". "Our results showed that free-text order entry continues to be frequent. During 2010, 9.3% of hypoglycemic agents were entered as free-text for 2,091 patients. 17.4% of the entries contained misspellings. The highest proportion of free-text entries were found in urgent care clinics (49.4%) and among registered nurses (31.5%). Additionally, 92 drug-drug interaction alerts were not triggered due to free-text entries. Only 25.9% of the patients had diabetes recorded in their problem list".
18	Singh H, Mani S, Espadas D, Petersen N, Franklin V, Petersen LA. Prescription errors and outcomes related to inconsistent information transmitted through computerized order entry: A prospective study. *Arch Intern Med*. 2009;169(10):982-989. doi:10.1001/archinternmed. 2009.102	2009	Quantitative study	Pharmacists reported prescriptions containing inconsistent communication(mismatch between the structured template and the associated free-text field) over a 4-month period at a tertiary care facility	Of 55 992 new prescriptions, 532 (0.95%) were reported to contain inconsistent communication. The most common inconsistent element across reported prescriptions was drug dosage (239 or 44.9%)
19	Palchuk MB, Fang EA, Cygielnik JM, et al. An unintended consequence of electronic prescriptions: Prevalence and impact of internal discrepancies. *Journal of the American Medical Informatics Association: JAMIA*. 2010;17(4):472-476. doi:10.1136/jamia.2010.003335	2010	Quantitative study	Analysis and review of 2914 electronic prescriptions that contained free-text fields	Internal discrepancies were found in 16.1% of the prescriptions. Most (83.8%) of the discrepancies could potentially lead to adverse events and many (16.8%) to severe adverse events, involving a hospital admission or death.
20	Radley DC, Wasserman MR, Olsho LEW, Shoemaker SJ, Spranca MD, Bradshaw B. Reduction in medication errors in hospitals due to adoption of computerized provider order entry systems. *Journal of the American Medical Informatics Association*. 2013;20(3):470–476. doi:10.1136/amiajnl-2012-001241	2013	Literature review, Meta-analysis	Review based on 9 studies that were conducted between 1999 and 2008	CPOE reduced medication errors by approximately 17.4 million (bounds 0.09–27.1 million) over a 1-year period
21	Aarts J, Ash J, Berg M. Extending the understanding of computerized physician order entry: Implications for professional collaboration, workflow and quality of care. *Int J Med Inform*. 2007;76 Suppl 1:S4-13. doi:10.1016/j.ijmedinf.2006.05.009	2007	Qualitative study	Semi-structured interviews with 17 experts involved in the design, implementation and evaluation of computerized physician order systems in the United States	Providers opt to use paper as an aid to keep track of information when using CPOE

S NO	Citation	Year	Study type	Study details	Key Point(s)
22	Kim MO, Coiera E, Magrabi F. Problems with health information technology and their effects on care delivery and patient outcomes: A systematic review. *Journal of the American Medical Informatics Association*. 2017;24(2):246-250. doi:10.1093/jamia/ocw154	2017	Literature review	Systemic review based on studies reporting problems with IT and their effects. Study period January 2004 to December 2015.Study included 13 of 34 studies that met criteria	"Use errors and poor user interfaces interfered with the receipt of information and led to errors of commission when making decisions. Clinical errors involving medications were well characterized. Issues with system functionality, including poor user interfaces and fragmented displays, delayed care delivery. Issues with system access, system configuration, and software updates also delayed care. In 18 studies (53%), IT problems were linked to patient harm and death".
23	Kuperman GJ, Teich JM, Gandhi TK, Bates DW. Patient safety and computerized medication ordering at Brigham and Women's Hospital. *The Joint Commission journal on quality improvement*. 2001;27(10):509–521.	2001	Meta-Analysis	Analysis of CPOE at BWH and analysis of studies that measured the impact of CPOE at BWH on the safety and quality of the medication process	"CPOE can serve as a form of checklist; clinical decision support targeted at increasing patient safety have substantially decreased the frequency of serious medication errors and have had an even bigger impact on the overall medication error rate"
24	Mekhjian HS, Kumar RR, Kuehn L, et al. Immediate benefits realized following implementation of physician order entry at an academic medical center. *Journal of the American Medical Informatics Association*. 2002;9(5):529–539.	2002	Quantitative study	Pre-Post CPOE implementation study at 2 hospitals over 10 month period	CPOE reduced transcription error
25	Shulman R, Singer M, Goldstone J, Bellingan G. Medication errors: A prospective cohort study of hand-written and computerised physician order entry in the intensive care unit. *Critical Care*. 2005;9(5):R516.	2005	Quantitative study	Pre-Post CPOE implementation study at ICU, 28 weeks before and 2, 10, 25 and 37 weeks after introduction of CPOE.	Introduction of CPOE was associated with a reduction in the proportion of medical errors
26	Aronsky D, Johnston PE, Jenkins G, et al. The effect of implementing computerized provider order entry on medication prescribing errors in an emergency department. *AMIA Annu Symp Proc*. October 2007:863.	2007	Quantitative study	Pre-Post CPOE implementation study at ED, during two 10-day periods before and during one 9-day period after introduction of CPOE.	Introduction of CPOE was associated with a reduction in prescribing errors
27	Wright A, Feblowitz JC, Pang JE, et al. Use of order sets in inpatient computerized provider order entry systems: A comparative analysis of usage patterns at seven sites. *International journal of medical informatics*. 2012;81(11):733–745.	2012	Quantitative study	Analysis of order set usage logs from a purposive sample of seven sites during 1 year period	Order sets serve as checklist. Personalized order sets can lead to non-standard care practices.

S NO	Citation	Year	Study type	Study details	Key Point(s)
28	Adam TJ, Waitman R, Jones I, Aronsky D. The effect of computerized provider order entry (CPOE) on ordering patterns for chest pain patients in the emergency department. In: *AMIA Annual Symposium Proceedings*. Vol 2011. American Medical Informatics Association; 2011:38.	2011	Quantitative study	Post CPOE implementation study on order data from 300 randomly selected, time matched patients in an Emergency department	CPOE implementation is associated with improved clinical documentation, Order completeness , compliance to guidelines
29	Nanji KC, Rothschild JM, Salzberg C, et al. Errors associated with outpatient computerized prescribing systems. *J Am Med Inform Assoc*. 2011;18(6):767-773. doi:10.1136/amiajnl-2011-000205	2011	Quantitative study	Retrospective cohort study of 3850 computer-generated prescriptions received by a commercial outpatient pharmacy chain across three states over 4 weeks in 2008	Of 3850 prescriptions, 452 (11.7%) contained 466 total errors. The most common error was omitted information (60.7% of all errors).
30	Odukoya OK, Stone JA, Chui MA. E-prescribing errors in community pharmacies: Exploring consequences and contributing factors. *Int J Med Inform*. 2014;83(6):427-437. doi:10.1016/j.ijmedinf.2014.02.004	2014	Qualitative study	Direct observations in five pharmacies for 45 hours. Follow-up interviews were conducted with 20 study participants.	Wrong or missing data result in additional work for pharmacists, increase frustration and can delay patient care
31	Horsky J, Kuperman GJ, Patel VL. Comprehensive analysis of a medication dosing error related to CPOE. *Journal of the American Medical Informatics Association*. 2005;12(4):377–382. doi:10.1197/jamia.M1740	2005	Case study	Analysis of a dosing error related to computer-based ordering of potassium chloride	Missing critical information in CPOE order and several usability issues with CPOE contributed to error
32	Magrabi F, Ong M, Runciman W, Coiera E. Patient Safety Problems Associated with Heathcare Information Technology: An Analysis of Adverse Events Reported to the US Food and Drug Administration. *AMIA Annual Symposium Proceedings*. 2011;2011:853-857.	2011	Meta Analysis	Analysis of 46 patient safety events submitted to Manufacturer and User Facility Device Experience (MAUDE) database from January 2008 to July 2010	Medication overdose attributed to missing information in CPOE due to mismatches of the system with clinical workflow
33	Ahmed A, Chandra S, Herasevich V, Gajic O, Pickering BW. The effect of two different electronic health record user interfaces on intensive care provider task load, errors of cognition, and performance*: *Critical Care Medicine*. 2011;39(7):1626-1634. doi:10.1097/CCM.0b013e31821858a0	2011	Quantitative study	Randomized crossover study, Comparison of EHR interface with novel interface with 20 participants completing the task on eight patients(total of 160patient provider encounters)	Standard electronic health record interfaces make it hard for the providers to integrate information available across multiple screens. NASA-task load index values were 38.8 (32-45) and 58 (45-65) for the novel user interface compared with the standard electronic medical record (p < .001)

S NO	Citation	Year	Study type	Study details	Key Point(s)
34	Pelayo S, Leroy N, Guerlinger S, Degoulet P, Meaux J-J, Beuscart-Zéphir M-C. Cognitive analysis of physicians' medication ordering activity. *Stud Health Technol Inform*. 2005;116:929-934.	2005	Qualitative study	Comparison of paper based on CPOE systems involving interviews and observations at 3 hospitals. For paper based system, 10 physicians were interviewed, 20 medical rounds were observed. For CPOE systems 4 physicians were interviewed, 7 medical rounds were observed.	The most important requirement from the physician's perspective would be an efficient display of relevant information provided first in the form of a summarized view of the patient's current treatment, followed by in a more detailed focused display of those items pertinent to the current situation. The CPOE system examined obviously failed to provide the physicians this critical summarized view.
35	Ballard DJ, Ogola G, Fleming NS, et al. The impact of standardized order sets on quality and financial outcomes. 2008;Vol. 2: Culture and Redesign. http://www.ahrq.gov/downloads/pub/advances2/vol2/Advances-Ballard_12.pdf.	2008	Quantitative study	Study involving 8 acute care hospitals, to examine order set use by hospital, discharge month, severity of illness and risk of mortality for pneumonia patients between March 2006 and September 2007	Over 19 months, order set use increased by 55 percent. Order set use significantly improved in-hospital mortality [hazard ratio (95 percent confidence interval (CI): 0.66 (0.45; 0.97) or 0.67 (0.46; 0.98); and Core Measures compliance (relative risk, 95 percent CI: 1.24 (1.04; 1.48) or 1.22 (1.02; 1.45)] following covariate or propensity score risk adjustment. Evidence-based pneumonia order sets can reduce inpatient mortality and increase delivery of important care processes.
36	Fleming NS, Ogola G, Ballard DJ. Implementing a standardized order set for community-acquired pneumonia: Impact on mortality and cost. *Joint Commission journal on quality and patient safety*. 2009;35(8):AP1–AP5.	2009	Quantitative study	Analysis of outcomes involving adult patients admitted with community-acquired pneumonia at 8 hospitals over 30 month period(4,454 patients)	Unadjusted analysis showed significant reductions in in hospital mortality, 30-day mortality, and direct cost and a significant increase in core measures compliance. Following risk adjustment, the difference in core measures compliance was retained (relative risk [95% confidence interval (C.I.)] 1.08 [1.03, 1.12]). In hospital mortality and 30-day mortality reductions both approached significance (hazard ratios [95% C.I.] of 0.73 [0.51,1.02] and 0.79 [0.62, 1.00], respectively). Mean (standard error) benefits of order set use in in-hospital mortality and costs were estimated at 1.67 (0.62)% and $383 (207). The incremental cost-effectiveness ratio point estimate was -$22,882 per life saved, with an upper 95% confidence limit of$1,278 per life saved.

S NO	Citation	Year	Study type	Study details	Key Point(s)
37	Fishbane S, Niederman MS, Daly C, et al. The impact of standardized order sets and intensive clinical case management on outcomes in community-acquired pneumonia. *Archives of internal medicine*. 2007;167(15):1664–1669.	2009	Quantitative study	Analysis of interventions using of order sets and intensive clinical case management for treatment of pneumonia at single hospital. Patients were studied in 3 sequential blocks at a single hospital from November 2002 to February 2005. Block 1 patients (n = 110) were given conventional treatment. For block 2 (n = 119), guidelines and/or standardized order sets (SOSs) were used supported by intensive clinical case management (ICCM) (full variance tracking with concurrent feedback and reminders). The ICCM interventions were conducted by resident physicians. For block 3 (n = 115), all orders were written with guidelines and/or SOSs but without ICCM.	The mean Length of Stay was significantly lower in block 2 (5.3 +/- 3.5 days) than in blocks 1 (8.8 +/- 4.4 days) (P<.001) and 3 (7.3 +/- 3.9 days) (P<.01) and significantly lower in block 3 than in block 1 (P = .05).
38	Micek ST, Roubinian N, Heuring T, et al. Before–after study of a standardized hospital order set for the management of septic shock*. *Critical Care Medicine*. 2006;34:2707-2713. doi:10.1097/01.ccm.0000241151.25426.d7	2006	Quantitative study	Pre-post implementation analysis of order sets at Emergency department in one academic medical center	Sixty patients (50.0%) were managed before the implementation of the standardized order set, constituting the before group, and 60 (50.0%) were evaluated after the implementation of the standardized order set, making up the after group. Patients in the after group were less likely to require vasopressor administration at the time of transfer to the intensive care unit (100.0% vs. 71.7%, p < .001), had a shorter hospital length of stay (12.1 +/- 9.2 days vs. 8.9 +/- 7.2 days, p = .038), and a lower risk for 28-day mortality (48.3% vs. 30.0%, p = .040).
39	Santolin CJ, Boyer LS. Change of care for patients with acute myocardial infarctions through algorithm and standardized physician order sets. *Crit Pathw Cardiol*. 2004;3(2):79-82. doi:10.1097/01.hpc.0000128715.42953.78	2004	Qualitative study	Review of charts at a hospital to assess medications ordered within the first 24 hours of hospitalization	Patients were more likely to receive aspirin, β-blockers, and ACE inhibitor therapy when standardized (preprinted) orders were used as opposed to de novo orders constructed by the physicians for that particular admission.
40	Bobb AM, Payne TH, Gross PA. Viewpoint: Controversies Surrounding Use of Order Sets for Clinical Decision Support in Computerized Provider Order Entry. *Journal of the American Medical Informatics Association: JAMIA*. 2007;14(1):41-47. doi:10.1197/jamia.M2184	2007	Viewpoint paper	Discussion on use of order sets based on literature	The presence of order sets in a system does not guarantee that clinicians will use them, in which case the increased morbidity and mortality due to “lack of order sets” occurs functionally
41	Grissinger M. Guidelines for Standard Order Sets. *P T*. 2014;39(1):10-50.	2014	Viewpoint paper	Discussion on use of order sets based on literature	Problems with order sets included use of outdated order sets that do not reflect current evidence-based or best practices

S NO	Citation	Year	Study type	Study details	Key Point(s)
42	John D. McGreevey III. Unexpected Drawbacks of Electronic Order Sets | AHRQ Patient Safety Network. https://psnet.ahrq.gov/webmm/case/390/unexpected-drawbacks-of-electronic-order-sets. Published November 2016. Accessed June 12, 2019.	2016	Case study	Study of fatal arrhythmia	The transition to electronic order sets contributed to mismanagement of the patient's low magnesium and potassium levels because, magnesium and potassium guidance were linked on the prior paper order set, but were not linked in the electronic version. This resulted in a fatal arrhythmia.
43	GM C, Lee J, GJ K, Al et. Guided medication dosing for inpatients with renal insufficiency. *JAMA*. 2001;286(22):2839–2844.	2001	Quantitative study	Outcome assessment of decision support application over 8 month period involving sample of 17,828 adults admitted to an urban tertiary care teaching hospital.	CDS helps providers in dosage calculation. "A total of 7490 patients were found to have some degree of renal insufficiency. In this group, 97,151 orders were written on renally cleared or nephrotoxic medications, of which 14 440 (15%) had at least 1 dosing parameter modified by the computer based on renal function. The fraction of prescriptions deemed appropriate during the intervention vs control periods by dose was 67% vs 54% (P<.001) and by frequency was 59% vs 35% (P<.001). Mean (SD) length of stay was 4.3 (4.5) days vs 4.5 (4.8) days in the intervention vs control periods, respectively (P =.009)".
44	Netherton SJ, Lonergan K, Wang D, McRae A, Lang E. Computerized physician order entry and decision support improves ED analgesic ordering for renal colic. *The American journal of emergency medicine*. 2014;32(9):958–961.	2014	Quantitative study	Pre-Post CPOE implementation study at three tertiary hospitals	The proportion of patients receiving ketorolac significantly increased after CPOE implementation (65.6% pre-CPOE vs 76.5% post-CPOE, P = .015), as did the proportion of patients receiving fentanyl (pre, 9.7%; post, 16.7%; P = .047). Computerized physician order entry implementation with condition-specific electronic order sets and decision support may improve evidence-based practice
45	Teich JM, Merchia PR, Schmiz JL, Kuperman GJ, Spurr CD, Bates DW. Effects of Computerized Physician Order Entry on Prescribing Practices. *Archives of Internal Medicine*. 2000;160:2741-2747. doi:10.1001/archinte.160.18.2741	2000	Quantitative study	Pre-post implementation analysis of all orders entered through a computerized system at an urban academic medical center over 2 year period	For medication selection, use of a computerized guideline resulted in a change in use of the recommended drug (nizatidine) from 15.6% of all histamine(2)-blocker orders to 81.3% (P<.001). Implementation of dose selection menus resulted in a decrease in the SD of drug doses by 11% (P<.001). The proportion of doses that exceeded the recommended maximum decreased from 2.1% before order entry to 0.6% afterward (P<.001). Display of a recommended frequency for ondansetron hydrochloride administration resulted in an increase in the use of the approved frequency from 6% of all ondansetron orders to 75% (P<.001). The use of subcutaneous heparin sodium to prevent thrombosis in patients at bed rest increased from 24% to 47% when the computer suggested this option (P<.001). All these changes persisted at 1- and 2-year follow-up analyses.

S NO	Citation	Year	Study type	Study details	Key Point(s)
46	Sanders DL, Miller RA. The effects on clinician ordering patterns of a computerized decision support system for neuroradiology imaging studies. In: *Proceedings of the AMIA Symposium*. American Medical Informatics Association; 2001:583.	2001	Quantitative study	Pre-post implementation study of decision support system with a 9-week control period followed by an 8-week intervention period	Decision support systems may aid in improving appropriate selection of test orders. 742 tests were ordered in the pre-intervention period, while 704 studies were ordered after the intervention. A significant change in the distribution of tests ordered resulted from the intervention (p=0.048). Changes trended toward the guideline recommendations for all tests considered. 60% of users receiving a recommendation ordered the suggested study.
47	Shojania KG, Yokoe D, Platt R, Fiskio J, Ma'Luf N, Bates DW. Reducing vancomycin use utilizing a computer guideline: Results of a randomized controlled trial. *Journal of the American Medical Informatics Association*. 1998;5(6):554–562.	1998	Quantitative study	Pre-post intervention study of decision support system, at urban university-affiliated public hospital, involving 78 house staff rotating on the 6 general medicine services.	Decision support systems may aid in improving appropriate selection of orders. "Compared with the control group, intervention physicians wrote 32 percent fewer orders (11.3 versus 16.7 orders per physician; P = 0.04) and had 28 percent fewer patients for whom they either initiated or renewed an order for vancomycin (7.4 versus 10.3 orders per physician; P = 0.02). In addition, the duration of vancomycin therapy attributable to physicians in the intervention group was 36 percent lower than the duration of therapy prescribed by control physicians (26.5 versus 41.2 days; P = 0.05). Analysis of pharmacy data confirmed a decrease in the overall hospital use of intravenous vancomycin during the study period".
48	Overhage JM, Tierney WM, Zhou X-H, McDonald CJ. A randomized trial of "corollary orders" to prevent errors of omission. *Journal of the American Medical Informatics Association*. 1997;4(5):364–375.	1997	Quantitative study	Randomized control study of a reminding decision support system, for a period of 6 months. Reminders about corollary orders were presented to 48 intervention physicians and withheld from 41 control physicians.	Decision support systems can decrease errors of omissions and improve adherence to practice guidelines. "Intervention physicians ordered the suggested corollary orders in 46.3% of instances when they received a reminder, compared with 21.9% compliance by control physicians (p < 0.0001)".
49	Dexter PR, Perkins S, Overhage JM, Maharry K, Kohler RB, McDonald CJ. A computerized reminder system to increase the use of preventive care for hospitalized patients. *New England Journal of Medicine*. 2001;345(13):965–970.	2001	Quantitative study	Pre-post intervention study of decision support system, assessing the effects of computerized reminders on the rates at which four preventive therapies were ordered for inpatients during an 18-month study period involving 6371 patients admitted to a general-medicine service (for a total of 10,065 hospitalizations)	Decision support systems can improve rate of delivery of therapies. "The reminder system identified 3416 patients (53.6 percent) as eligible for preventive measures that had not been ordered by the admitting physician. For patients with at least one indication, computerized reminders resulted in higher adjusted ordering rates for pneumococcal vaccination (35.8 percent of the patients in the intervention group vs. 0.8 percent of those in the control group, P<0.001), influenza vaccination (51.4 percent vs. 1.0 percent, P< 0.001), prophylactic heparin (32.2 percent vs. 18.9 percent, P<0.001), and prophylactic aspirin at discharge (36.4 percent vs. 27.6 percent, P<0.001)".

S NO	Citation	Year	Study type	Study details	Key Point(s)
50	Mattison ML, Afonso KA, Ngo L, Mukamal KJ. Preventing Potentially Inappropriate Medication Use in Hospitalized Elders with a Computerized Provider Order Entry Warning System. *Archives of internal medicine*. 2010;170(15):1331-1336. doi:10.1001/archinternmed. 2010.244	2010	Quantitative study	Pre-post intervention study of decision support system, assessing its use to prevent potentially inappropriate medication use among patients 65 years or older admitted to a large, urban academic medical center in Boston, Massachusetts, from June 1, 2004, through November 29, 2004 (for patients admitted before the warning system was added), and from March 17, 2005, through August 30, 2008 (patients admitted after the warning system was added	The mean (SE) rate of ordering medications that were not recommended dropped from 11.56 (0.36) to 9.94 (0.12) orders per day after the implementation of a CPOE warning system (difference, 1.62 [0.33]; P<.001)
51	Kuperman GJ, Bobb A, Payne TH, et al. Medication-related clinical decision support in computerized provider order entry systems: A review. *Journal of the American Medical Informatics Association*. 2007;14(1):29–40.	2007	Literature review	Literature-based summary and discussion of the papers that illustrate the limitations of CPOE technology , which can help point the way forward for future developments in the field	CPOE helps in identifying duplicate therapy, duplicate medications, and drug-drug and drug-allergy interactions. Substantial reductions in potential medication errors in studies of both CPOE and CDSS systems
52	Kaushal R, Bates DW. *Computerized Physician Order Entry (CPOE) with Clinical Decision Support Systems (CDSS).* Agency for Healthcare Research and Quality; 2013. https://psnet.ahrq.gov/primers/primer/6. Accessed February 13, 2018.	2013	Literature review, Meta-analysis	A systemic review on effects of computerized physician order entry and clinical decision support systems on medication safety. The review evaluated 7 studies that met the criteria	CPOE helps in identifying drug-drug and drug-allergy interactions
53	Charles K, Cannon M, Hall R, Coustasse A. Can utilizing a computerized provider order entry (CPOE) system prevent hospital medical errors and adverse drug events? *Perspectives in health information management*. 2014;11(Fall).	2014	Literature review, Meta-analysis	Systemic review of 51 articles published from 2005 to 2014 that met review criteria	Multiple benefits can be gained from adopting and implementing CPOE systems, including reduction of medication errors, identification of drug-drug, drug-allergy interactions, and duplicate tests.
54	Bates DW, Kuperman GJ, Rittenberg E, et al. A randomized trial of a computer-based intervention to reduce utilization of redundant laboratory tests. *Am J Med*. 1999;106(2):144-150.	1999	Quantitative study	Randomized controlled trial that included all inpatients at a large teaching hospital during a 15-week period.	CPOE can help identify duplicate tests. "There were 939 apparently redundant laboratory tests among the 77,609 study tests that were ordered among the intervention (n = 5,700 patients) and control (n = 5,886 patients) groups. In the intervention group, 69% (300 of 437) of tests were canceled in response to reminders. Of 137 overrides, 41% appeared to be justified based on chart review. In the control group, 51% of ordered redundant tests were performed, whereas in the intervention group only 27% of ordered redundant tests were performed (P <0.001)".

S NO	Citation	Year	Study type	Study details	Key Point(s)
55	Levick DL, Stern G, Meyerhoefer CD, Levick A, Pucklavage D. "Reducing unnecessary testing in a CPOE system through implementation of a targeted CDS intervention". *BMC Medical Informatics and Decision Making*. 2013;13(1):43. doi:10.1186/1472-6947-13-43	2013	Quantitative study	Multiple regression analysis on a sample of 41,306 patient admissions with at least one B-Type Natriuretic Peptide (BNP) test at LVHN between January, 2008 and September, 2011.	CPOE can help identify duplicate tests. CDS intervention reduced BNP orders by 21% relative to the mean
56	Procop GW, Yerian LM, Wyllie R, Harrison AM, Kottke-Marchant K. Duplicate laboratory test reduction using a clinical decision support tool. *American journal of clinical pathology*. 2014;141(5):718–723.	2014	Quantitative study	Assessment of reduction of duplicate tests after implementation of CDS	The Clinical decision support blocked 11,790 unnecessary duplicate test orders in 2 years, which resulted in a cost savings of $183,586
57	Campbell EM, Sittig DF, Guappone KP, Dykstra RH, Ash JS. Overdependence on technology: An unintended adverse consequence of computerized provider order entry. In: *AMIA Annual Symposium Proceedings*. Vol 2007. American Medical Informatics Association; 2007:94.	2007	Qualitative study	Expert panel conference with 19 experts in April of 2004 followed by 390 hours of observation of 95 clinicians, and 32 interviews at five hospitals	Three themes among the unintended adverse consequences related to overdependence on technology. Overdependence on decision and cognitive support can make it hard or impossible for providers to work on a COPE systems using different decision or cognitive support features, or during instances without access to technology
58	Wears RL, Berg M. Computer technology and clinical work: Still waiting for godot. *JAMA*. 2005;293(10):1261-1263. doi:10.1001/jama.293.10.1261	2005	JAMA Editorial	Editorial	"Clinical work, especially in hospitals, is fundamentally interpretative, interruptive, multitasking, collaborative, distributed, opportunistic, and reactive. In contrast, CPOE systems and decision support systems are based on a different model of work: one that is objective, rationalized, linear, normative, localized (in the clinician's mind), solitary, and single-minded". "The misleading theory about technology is that technical problems require technical solutions; ie, a narrowly technical view of the important issues involved that leads to a focus on optimizing the technology. In contrast, a more useful approach views the clinical workplace as a complex system in which technologies, people, and organizational routines dynamically interact".
59	Niazkhani Z, Pirnejad H, Berg M, Aarts J. The impact of computerized provider order entry systems on inpatient clinical workflow: A literature review. *J Am Med Inform Assoc*. 2009;16(4):539-549. doi:10.1197/jamia.M2419	2009	Literature review	Review based on a literature search for CPOE evaluations between 1990 and June 2007,. Total of 51 studies included.	CPOE often fails to address this need for collective cognition

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60	Henneman PL, Fisher DL, Henneman EA, et al. Providers do not verify patient identity during computer order entry. *Academic emergency medicine*. 2008;15(7):641–648.	2008	Simulation study	"Prospective study using simulated scenarios with an eye-tracking device. Medical providers were asked to review 10 charts (scenarios), select the patient from a computer alphabetical list, and order tests. Two scenarios had embedded ID errors compared to the computer (incorrect DOB or misspelled last name), and a third had a potential error (second patient on alphabetical list with same last name)".	"Twenty-five of 25 providers (100%; 95% confidence interval [CI] = 86% to 100%) selected the correct patient when there was a second patient with the same last name. Two of 25 (8%; 95% CI = 1% to 26%) noted the DOB error; the remaining 23 ordered tests on an incorrect patient. One of 25 (4%, 95% CI = 0% to 20%) noted the last name error; 12 ordered tests on an incorrect patient. No participant (0%, 0/107; 95% CI = 0% to 3%) verified patient ID by looking at MRN prior to selecting a patient from the alphabetical list. Twenty-three percent (45/200; 95% CI = 17% to 29%) verified patient ID prior to ordering tests".
61	Eslami S, de Keizer NF, Abu-Hanna A. The impact of computerized physician medication order entry in hospitalized patients—a systematic review. *International journal of medical informatics*. 2008;77(6):365–376.	2008	Literature review	Evaluation of the effect of CPOE on outcomes pertaining to the medication process in inpatients were electronically searched in MEDLINE (1966 to August 2006), EMBASE (1980 to August 2006) and the Cochrane library	Clinicians ignore alerts, reminders, warning due to alert fatigue. CPOE often does not take into context the social requirements of the system
62	Zhan C, Hicks RW, Blanchette CM, Keyes MA, Cousins DD. Potential benefits and problems with computerized prescriber order entry: Analysis of a voluntary medication error-reporting database. *American Journal of Health-System Pharmacy*. 2006;63(4):353–358. doi:10.2146/ajhp050379	2006	Quantitative study	"A national voluntary medication error-reporting database, Medmarx, was used to compare facilities that had CPOE with those that did not have CPOE"	CPOE can misrepresent data and fail to alert providers due to missing functionalities, poor interface
63	Bates DW, Teich JM, Lee J, et al. The impact of computerized physician order entry on medication error prevention. Journal of the American Medical Informatics Association. 1999;6(4):313–321.	1999	Quantitative study	Pre-post intervention study of CPOE, assessing decision support features such as drug allergy and drug-drug interaction warnings. All patients admitted to three medical units were studied for seven to ten-week periods in four different years. The baseline period was before implementation of POE, and the remaining three were after	Increase in preventable ADEs due to software bugs; "The rate of intercepted potential ADEs climbed substantially from baseline to periods 1 and 2; it rose from 15.8 per 1,000 patient-days at baseline to 31.3 in period 1 and 59.4 in period 2 (P = 0.15) before falling to 0.5 in period 3 . These increases in errors were largely related to POE's initial structure for potassium chloride orders, which made it easy to order large doses of intravenous potassium without explicitly specifying that it be given in divided doses (i.e., not more than 20 milliequivalents at a time)".
64	Ash JS, Sittig DF, Campbell EM, Guappone KP, Dykstra RH. Some unintended consequences of clinical decision support systems. In: *AMIA Annual Symposium Proceedings*. Vol 2007. American Medical Informatics Association; 2007:26.	2007	Qualitative study	Expert panel conference with 19 experts in April of 2004 followed by 390 hours of observation of 95 clinicians, and 32 interviews at five hospitals	Clinicians feel that there are too many alerts. Fixing an alert from CPOE can cause errors as providers are unsure of changes that happen to the order while fixing

S NO	Citation	Year	Study type	Study details	Key Point(s)
65	Nam HS, Han SW, Ahn SH, et al. Improved Time Intervals by Implementation of Computerized Physician Order Entry-Based Stroke Team Approach. *Cerebrovascular Diseases*. 2007;23:289-293. doi:10.1159/000098329	2007	Quantitative study	Pre-post intervention study of CPOE, assessing time to time from a patient's arrival at the emergency department to thrombolysis, during 1 year period.	"Among 379 consecutive patients who were screened as potential candidates for thrombolysis, 25 patients (6.6%) received tPA during a 1-year period after initiation of the program. Fourteen patients were treated with tPA in the previous year. After program implementation, time from arrival to computed tomography scan was reduced from 34 to 19 min (p = 0.01). Time to report of complete blood count was also shortened from 52 to 33 min (p < 0.01). Finally, time from arrival to tPA treatment was reduced by 23 min (from 79 to 56 min; p < 0.01). Onset-to-door time tended to be longer after the program implementation (from 41 to 60 min; p = 0.14). "
66	Han YY, Carcillo JA, Venkataraman ST, et al. Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. *Pediatrics*. 2005;116(6):1506-1512. doi:10.1542/peds.2005-1287	2005	Quantitative study	Pre-post intervention retrospective study of CPOE, assessing impact on mortality	"Among 1942 children who were referred and admitted for specialized care during the study period, 75 died, accounting for an overall mortality rate of 3.86%. Univariate analysis revealed that mortality rate significantly increased from 2.80% (39 of 1394) before CPOE implementation to 6.57% (36 of 548) after CPOE implementation. Multivariate analysis revealed that CPOE remained independently associated with increased odds of mortality (odds ratio: 3.28; 95% confidence interval: 1.94 – 5.55) after adjustment for other mortality covariables". "Diminished opprtunities for face to face communication and lack of feedback after implementation of CPOE"
67	Pirnejad H, Niazkhani Z, van der Sijs H, Berg M, Bal R. Impact of a computerized physician order entry system on nurse-physician collaboration in the medication process. *International Journal of Medical Informatics*. 2008;77(11):735–744. doi:10.1016/j.ijmedinf.2008.04.001	2008	Qualitative study	Pre-post CPOE implementation study at Six internal medicine wards at the Erasmus Medical Centre. Methods include questionnaire to record nurses' attitudes towards the effectiveness of the former paper-based system and CPOE system that replaced the paper-based system, followed by interviews with physicians and nurses.	CPOE separates the work of physicians from that of nurses. "Response rates for the analyzed questions in the pre- and post-implementation questionnaires were 54.3% (76/140) and 52.14% (73/140)".. "A comparison of supportive features of the paper-based system with non-supportive features of the CPOE system showed that synchronization and feedback mechanisms in nurse-physician collaborations have been impaired after the CPOE system was introduced"
68	Dykstra R. Computerized physician order entry and communication: Reciprocal impacts. In: *Proceedings of the AMIA Symposium.* American Medical Informatics Association; 2002:230.	2002	Qualitative study	Reexamination of observation, focus group and oral history data from four different sites to understand how CPOE alters communication	CPOE promotes asynchronous communication between providers, Reduced face to face communication was found to adversely affect team relationships, undermine team spirit, cohesion and rework. Writing orders off-floor is problematic because the nurse does not always know that a new order has been placed, which can delay time sensitive medications.

S NO	Citation	Year	Study type	Study details	Key Point(s)
69	Beuscart-Zéphir MC, Pelayo S, Anceaux F, Meaux JJ, Degroisse M, Degoulet P. Impact of CPOE on doctor-nurse cooperation for the medication ordering and administration process. *International Journal of Medical Informatics*. 2005;74(7-8):629–641. doi:10.1016/j.ijmedinf.2005.01.004	2005	Qualitative study	Analysis of the impact of medication ordering and administration functions of CPOE on doctor-nurse communications and cooperation in several departments of three different hospitals. At hospitals 1 and 2 paper based system was evaluated , while at hospital 3 CPOE system was evaluated	"The paper-based situation is characterized by a synchronous cooperation with a distributed decision-making where physicians and nurses rely mostly on verbal communications to coordinate their actions; paper order sheets are weakly structured and poorly support the documentation task. In the computer situation, physicians and nurses work in an asynchronous mode, and leave to the system the coordination of their actions. Orders are exhaustively documented but some data may be misinterpreted. Some of these problems are due to usability flaws of the Human Computer Interface".
70	Shu K, Boyle D, Spurr C, et al. Comparison of time spent writing orders on paper with computerized physician order entry. *Stud Health Technol Inform*. 2001;84(Pt 2):1207-1211.	2001	Qualitative study	Pre-Post CPOE implementation study comparing time spent by physicians doing various activities. In pre implementation, 43 interns participated and recorded a total of 1729 observations over 1554 hours. In post implementation, 29 interns participated and recorded a total of 953 observations over 962 hours	Participants spent more time pre implementation (50%) compared to post implementation (39%)
71	Saddik B, Al-Mansour S. Does CPOE support nurse-physician communication in the medication order process? A nursing perspective. *Stud Health Technol Inform*. 2014;204:149-155.	2014	Qualitative study	Measurement of nurse perceptions of CPOE features on workflow and nurse physician communication using survey questionnaire. 146 of the 173 nurses participated in the study	Nurses reported additional work was required for follow up of physicians.
72	Fields W, Jacoby J, McCullough S. Effect of computerized physician order entry on nurses and nurses' work. Presented at the: AMIA 2009 Symposium; San Francisco, CA.	2009	Qualitative study	Interview to analyze effect of CPOE on nurse	Nurses felt the need to seek out the physician to better understand the care plan and the nurses needed additional information with regard to medications because physicians had entered orders off-floor
73	Campbell EM, Guappone KP, Sittig DF, Dykstra RH, Ash JS. Computerized Provider Order Entry Adoption: Implications for Clinical Workflow. *Journal of General Internal Medicine*. 2009;24(1):21-26. doi:10.1007/s11606-008-0857-9	2009	Qualitative study	390 hours of observation of 95 clinicians, and 32 interviews at five hospitals	"CPOE systems, because they allow orders to be entered at any time by providers located outside of the hospital, can contribute to loss of situation awareness". Sometimes only a part of the clinical workflow is supported by CPOE
74	Cheng CH, Goldstein MK, Geller E, Levitt RE. The effects of CPOE on ICU workflow: An observational study. In: *AMIA Annual Symposium Proceedings*. Vol 2003. American Medical Informatics Association; 2003:150.	2003	Qualitative study	Observation of work patterns of 50 individuals on the ICU care team, including the physicians (attendings, fellows, residents, interns, medical students), the nursing staff (day and evening nurses, charge nurses, resource nurses, unit clerks), two pharmacists, and one respiratory therapist (RT) for 86 hours.	CPOE changed workflows and led to new forms of communication such as frequent ad hoc verification tasks to check for an order's existence and correctness. CPOE systems are built assuming idealized workflows that often do not reflect actual clinical practice

S NO	Citation	Year	Study type	Study details	Key Point(s)
75	Khajouei R, Wierenga PC, Hasman A, Jaspers MWM. Clinicians satisfaction with CPOE ease of use and effect on clinicians' workflow, efficiency and medication safety. *Int J Med Inform*. 2011;80(5):297-309. doi:10.1016/j.ijmedinf.2011.02.009	2011	Qualitative study	Survey questionnaires were used to understand satisfaction of end-users of a computerized physician order entry (CPOE) system concerning ease of use and the effect on users' workflow, efficiency, and medication safety 49% of 217 physicians and 56% of 587 nurses working in inpatient departments of a university hospital participated in the study.	Clinicians used workarounds to communicate information and restored the feedback loops by using paper artifacts. When responding to the question "How do you usually coordinate medication ordering activities with other nurses?" 194/292 i.e 66.4% participants responded positively to using "By printout labels of Medicator"
76	Ash JS, Gorman PN, Lavelle M, et al. A Cross-site Qualitative Study of Physician Order Entry. *J Am Med Inform Assoc*. 2003;10(2):188-200. doi:10.1197/jamia.M770	2003	Qualitative study	Observations, interviews and focus groups were conducted to describe the perceptions of diverse professionals involved in computerized physician order at 3 hospitals. A total of 19 observations, 19 informal interviews, 14 formal interviews, 3 focus groups were conducted	Providers can inadvertently write order on wrong patient thus providing wrong information
77	Hatfield MD, Cox R, Mhatre SK, Flowers WP, Sansgiry SS. Impact of computerized provider order entry on pharmacist productivity. *Hospital pharmacy*. 2014;49(5):458–465.	2014	Qualitative study	To examine the impact of computerized provider order entry (CPOE) implementation on average time spent on medication order entry and the number of order actions processed, an observational time and motion study was conducted from March 1 to March 17, 2011. Two similar community hospital pharmacies were compared: one without CPOE implementation and the other with CPOE implementation	"The implementation of CPOE facilitated pharmacists to allocate more time to clinical and administrative functions and increased the number of order actions processed per hour, thus enhancing workflow efficiency and productivity of the pharmacy department". "The mean ± SD time spent by pharmacists per hour in the CPOE pharmacy was significantly less than the non-CPOE pharmacy for distributive activities (43.37 ± 7.75 vs 48.07 ± 8.61) and significantly greater than the non-CPOE pharmacy for administrative (8.58 ± 5.59 vs 5.72 ± 6.99) and clinical (7.38 ± 4.27 vs 4.22 ± 3.26) activities. The CPOE pharmacy was associated with a significantly higher number of order actions per hour (191.00 ± 82.52 vs 111.63 ± 25.66) and significantly less time spent (in minutes per hour) on order entry and order verification combined (28.30 ± 9.25 vs 36.56 ± 9.14) than the non-CPOE pharmacy. "
78	Ash JS, Sittig DF, Campbell E, Guappone K, Dykstra R. An unintended consequence of CPOE implementation: Shifts in power, control, and autonomy. In: *AMIA Annual Symposium Proceedings*. Vol 2006. American Medical Informatics Association; 2006:11.	2006	Qualitative study	390 hours of observation of 95 clinicians, and 32 interviews at five hospitals	CPOE implementation caused shifts in power structure due to forced work redistribution and changes to workflow. These changes in power structures caused perceived loss of control and autonomy amongst clinicians, and increased power of nurses and information technology specialists and the formation of coalition

S NO	Citation	Year	Study type	Study details	Key Point(s)
79	Ash JS, Sittig DF, Dykstra R, Campbell E, Guappone K. The unintended consequences of computerized provider order entry: Findings from a mixed methods exploration. International Journal of Medical Informatics. 2009;78:S69-S76. doi:10.1016/j.ijmedinf.2008.07.015	2007	Mixed methods study	390 hours of observation of 95 clinicians, and 32 interviews at five hospitals	Study identified and categorized into nine types 380 examples of the unintended consequences of CPOE
80	Ash JS, Sittig DF, Dykstra R, Campbell E, Guappone K. Exploring the unintended consequences of computerized physician order entry. *Studies in health technology and informatics*. 2007;129(1):198.	2007	Mixed methods study	390 hours of observation of 95 clinicians, and 32 interviews at five hospitals	The highest proportion of unintended consequences were due to the decision support features within CPOE

APPENDIX B

CNMO CODEBOOK

Code	Description	Example
Medication	Information related to medication(s) **INCLUSION:** Medication name, modifying medication attribute, confirming/documenting medication administration or intake **EXCLUSION:** None	• *hold heparin* • *give ceFAZolin* • *Confirm if pt took meds*
ADT (Admission/ Discharge/Transfer)	Instructions or information related to admitting, transferring or discharging patients **INCLUSION:** Terms such as “discharge”, “d/c”, “transfer”, “go back to floor”, or “leave ICU” **EXCLUSION:** Phrases referring to movement to or from scans, procedures, etc.	• *"Patient can be discharge home after PT/OT.* • *Please give patient one time dose IV morphine 2 mg an hour prior to d/c or when doing PT, and than regular scheduled dose 8 mg dilaudid prior to leaving so comfortable when traveling. Thank you”.* • *Pt to be discharged with indwelling foley catheter* • *The patient can go back to the floor once he meet the PACU discharge criteria*
Protocol	Information about a protocol to be followed **INCLUSION:** Phrases such as “as per XYZ protocol”, “follow XYZ procedure” or “as per XYZ rule” **EXCLUSION:** None	• *Initiate hypoglycemia protocol*
Documentation	Request for information or documentation, recording/changing information in the patient’s chart/EHR, or note instructions **INCLUSION: Phrases referring to** asking or informing about status post procedure/therapy, requesting information from the patient, or requesting documentation or confirmation **EXCLUSION:** None	• *Pls get records from xxx hospital* • *pls confirm allergy* • *pls document all episodes of hemostatis* • *Confirm if pt took meds*

Code	Description	Example
Transport	Introductions, clarification, and requests for patient transportation **INCLUSION:** Terms related to actual patient movement such as “pt to xray”, “pt to OR”, “pt can go off floor”, “pt to be discharged/meets d/c criteria” **EXCLUSION:** None	• *Move pt to xray* • *pt can go off the floor without tele*
Other Clinical Tasks	Permission or Instructions for clinical procedures (not covered by L/T/D; Labs; Imaging; Medication; Transportation; Medical Device) **INCLUSION:** References to activities such as dressing wounds, neuro checks, observations, or terms related to patient care activities such as “walking pt”, “cleaning pt”, etc. **EXCLUSION:** None	• *Please clean forehead* • *Pls walk patient* • *Bladder scan* • *pt to wear mask out of room* • *transfer 1 uprbc* • *read chart* • *no q1hr neuro checks* •
Procedure	Information about procedures or instruction before a procedure **INCLUSION:** References to blood transfusions, PT/OT evals, colonoscopies, surgeries, or therapies (OT, speech, etc) **EXCLUSION:** None	• *going for colonoscopy* • *pt ok for PT/OT eval* •
Lines/Tubes/Drains	Information about Lines, tubes, or drains **INCLUSION:** Terms such as **“**IV”, ”IV Meds”, “NG Tubes”, Other tubes, “Foley”, “drains”, “drips”, “arterial/central/peripheral lines”, etc… **EXCLUSION:** None	• *Ok to use central line* • *D/C aterial* • *Restart insulin drip* • *NG tube to suction prior to starting CPAP*
Vitals	Information about patient vitals, instructions to skip taking vitals or discontinue monitoring **INCLUSION:** References to taking or skipping vital sign(s), including terms such as “weight”, “blood pressure” or “height” **EXCLUSION:** None	• *rectal temp* • *daily wt* • *pt can go off the floor without tele*

Code	Description	Example
Devices	References to medical devices, patient aides that are internal/external to the patient **INCLUSION:** References to tele-monitoring, pace makers, pumps, pulse-ox, walkers, or wheelchairs **EXCLUSION:** None	• *LVAD Speed changed from 9200 RPM to 9400 PRM at the bedside by Dr. XXXX at XXXX* • *OK to go to dialysis, off tele* • *Platform walker*
Labs	Clarification or instructions related to lab tests or imaging **INCLUSION:** Terms such as **"**Xray", "radiology", "CT/MRI", "Echo/EKG", "BNP", "CBC", "blood draws", "blood sugar (accu check)", or just labs **EXCLUSION:** None	• *Please clean forehead and do accuxheck* • *Move pt to xray*
Contact	Information about contacting or calling another provider, or asking for information from patient **INCLUSION:** Terms such as "page", "phone", "call", "contact" or any other terms implying a communication from one person to another. Includes phone number, email, etc. **EXCLUSION:** Terms such as "as per Dr. X said this…"	• *page DR XXX XXX* • *call MD*
Goal	References to clinical goals for the patient **INCLUSION:** Explicitly states a numerical value or patient status to be achieved and/or includes the terms "goal", "target" etc. **EXCLUSION:** Reference to abnormal values (e.g., hypertension)	• *Goal oxygen sat >88%*
Diet	References to patient food, fluid, diet **INCLUSION:** Terms related to "PO", "NPO" or "Diet" or items surrounding food, fluid intake. Or, "diet related" activities such as an "order snacks" **EXCLUSION:** Information about lines/tubes/drains pertaining to diet but does not explicitly mention diet; code only as "Lines/Tubes/Drains". Example: "NG tube to suction prior to starting CPAP"	• *small sips of liquid* • *PO challenge*

Code	Description	Example
Education	Information about patient education or requesting patent education **INCLUSION:** Terms such as “educate”, “inform patient”, “teach”, etc. in reference to the patient **EXCLUSION:** Terms above but directed towards clinical staff	• *pls teach pt about diabetics*
Non Clinical Task	Permission or instruction about issues outside of direct patient care **INCLUSION:** confirmation/ permission for tasks outside patient care **EXCLUSION:** None	• *Spouse can meet pt outside visiting hours* • *pt can use own shoes* • *Ok to wear sweater*

APPENDIX C

LIST OF ALL MEDICATION NAMES AND THEIR COUNTS

MEDICATION NAME	COUNT
NALOXONE	923
HEPARIN	901
FLUMAZENIL	656
DEXTROSE	369
GLUCAGON HYDROCHLORIDE	319
SALINE	270
INSULIN	203
ENOXAPARIN	169
CEFAZOLIN	144
FONDAPARINUX	139
CHLORHEXIDINE	138
DABIGATRAN	135
BLOOD	118
RIVAROXABA	114
LIDOCAINE	91
EPINEPHRINE	90
PHENYTOIN	89
VALPROIC ACID	89
CARBAMAZEPINE	88
INSULIN GLARGINE	84
ARGATROBAN	77
EPTIFIBATIDE	73
DIGOXIN	72
IVF	71
ENOXAPARIN SODIUM	65
SUCROSE	56
METOPROLOL	44
WARFARIN	40
NOREPINEPHRINE	39
DOBUTAMINE	27
HYDRALAZINE	27
DIPHENHYDRAMINE	26
EPIDURAL	26
DOPAMINE	25
NICARDIPINE	25
ASPIRIN	23
LABETALOL	20
FUROSEMIDE	19

VANCOMYCINE	19
CLOPIDOGREL	18
PROPOFOL	17
SCOPOLAMINE	16
METFORMIN	14
MILRINONE	14
POTASSIUM	14
NOAC	13
APIXABAN	12
ERYTHROMYCIN	12
INSULIN LISPRO	10
AMIODARONE HYDROCHOLORIDE	9
MORPHINE	9
NITROGLYCERIN	9
VACCINE	9
ALTEPLASE	8
DIHYDROERGOTAMINE	8
DOCUSATE SODIUM	8
HYDROMORPHONE	8
MAGNESIUM CITRATE	8
POLYETHYLENE GLYCOL 3350	8
CLINDAMYCIN	7
POLYETHYLENE GLYCOL	7
LISINOPRIL	6
METRONIDAZOLE	6
OXYCODONE	6
RITUXIMAB	6
ACETAMINOPHEN	5
CALCIUM	5
CARDIZEM	5
CARVEDILOL	5
PETROLEUM DRESSING	5
PIPERACILLIN	5
TACROLIMUS	5
AMLODIPINE	4
DEXMEDETOMIDINE	4
DILTIAZAM	4
FENTANYL	4
GENTAMICIN	4
IBUPROFEN	4
ONDANSETRON	4
ACETAMINOPHEN	3
AQUACEL SILVER	3

ATROPINE	3
BACITRACIN	3
BUMETANIDE	3
CLONIDINE	3
COLLAGENASE	3
DEXAMETHASONE	3
OLANZAPINE	3
TRAMADOL	3
ALBUMIN HUMAN	2
AMLODIPINE BESYLATE	2
AMPICILLIN	2
ANICOAGULANT	2
CEFTRIAXONE	2
CYCLOSPORINE	2
ENEMA	2
ERYTHROPOIETIN	2
GLUCAN	2
KETOROLAC	2
LORAZEPAM	2
MIDODRIN	2
MIRTAZAPINE	2
NUTRIONAL SUPPLEMENT	2
OCTREOTIDE	2
ORDER SET	2
PANTOPRAZOLE	2
POVIDONE-IODINE	2
QUETIAPINE	2
RINGERS LACTATE SOLUTION	2
SILVER SULFADIAZINE	2
STATIN	2
THIAMINE	2
TRAZODONE	2
TREPROSTINIL	2
ACETAMINOPHEN/BUTALBITAL/CAFFEINE	1
ACETAMINOPHEN/OXYCODONE	1
ACETAZOLAMIDE	1
ACETYLSALICYLIC ACID	1
ACYCLOVIR	1
AGRATROBAN	1
ALBUTEROL	1
ARIPIPRAZOLE	1
ATENOLOL	1
AZITHROMYCIN	1

BARIUM	1
BARRIER CREAM	1
BENZALKONIUM CHLORIDE	1
BICARBONATE	1
BIVALIRUDIN	1
BLEOMYCIN	1
BUSPIRONE	1
CADEXOMER IODINE	1
CEFEPIME	1
CEFOXITIN	1
CEFTAZIDIME	1
CIPROFLOXACIN	1
CLONAZEPAM	1
COSYNTROPIN	1
CYANOACRYLATE	1
DEMEBORO	1
DEXTRIN?	1
DIALYSATE	1
EPOPROSTENOL	1
FILGRASTIM	1
GABAPENTIN	1
GLYCOPYRROLATE	1
GUAIFENESIN	1
HALOPERIDOL	1
HETASTARCH	1
HYDROCORTISONE	1
HYDROGENPEROXIDE	1
HYDROXYZINE	1
IMMUNE GLOBULIN	1
INDAPAMIDE	1
IODOFORM	1
KETAMINE	1
KETOROLAC TROMETHAMINE	1
LACTATE RINGERS	1
LACTULOSE	1
LEDIPASVIR /SOFOSBUVIR	1
LEVALBUTEROL	1
LEVETIRACETAM	1
LEVOTHYROXINE	1
LITHIUM	1
LOSARTAN	1
MAGNESIUM	1
MEDIHONEY	1

MEROPENEM	1
MESNA	1
METHIMAZOLE	1
METHYLNALTREXONE	1
METHYLPREDNISOLONE	1
MIDAZOLAM	1
MULTIPLE INGREDIENTS	1
MYCOPHENOLIC ACID	1
NATURE THYROID	1
NICOTINE	1
NIFEDIPINE	1
OXCARBAZEPINE	1
OXYGEN	1
PACU ORDERSET	1
PANCRELIPASE	1
PATIENT CONTROLLED ANALGESIA	1
PEDIALYTE	1
PENICILLIN	1
PETROLEUM JELLY	1
PHENAZOPYRIDINE	1
PHENOBARBITAL	1
PHENYLEPHRINE	1
POMALIDOMIDE	1
PREDNISONE	1
PROCHLORPERAZINE	1
REGULAR HUMAN INSULIN	1
ROSUVASTATIN	1
SILVER	1
SILVER SULFADIAZINE	1
SODIUM HYPOCHLORITE	1
SULFAMETHOXAZOLE	1
TICAGRELOR	1
TRIAMCINOLONE	1
VALSARTAN	1
VASOPRESSIN	1
ZINC SULFATE	1

APPENDIX D

LIST OF ALL MEDICATION CLASSES AND THEIR COUNTS

CLASS	**COUNT**
ORDER SET	4,918
ANTIDOTE	1,579
ANALGESIC	1,472
ANTICOAGULANT	1,351
ENDOCRINE METABOLIC AGENT	695
NUTRITIVE AGENT	395
ANTIDIABETIC	312
ANTIBIOTIC	279
ANTICONVULSANT	273
ANTISEPTIC	142
BLOOD PRODUCT	118
ANTIARRHYTHMIC	106
NITRATES	97
ANESTHETIC	91
ADRENERGIC AGONIST	90
PLATELET AGGREGATION INHIBITOR	90
ANTIHYPERTENSIVE	84
HYPOGLYCEMIC	49
INOTROPIC AGENT	41
SEDATIVE	38
VASOPRESSOR	37
VASODILATOR	36
ELECTROLYTE	28
LAXATIVE	28
NARCOTIC	28
ADERNERGIC	27
ANTIHISTAMINE	27
ANTIPLATELET	24
DIURETIC	24
CNS AGENT	21
ANTICHOLINERGIC	17
NONSTEROIDAL ANTI-INFLAMMATORY DRUG	16
BLOOD PRESSURE SUPPORT	14
BETA BLOCKER	11
ANTI-EMETIC	10

WOUND DRESSING	10
VACCINE	9
ANTIANXIETY	8
ANTIMIGRAINE	8
THROMBOLYTIC	8
ANTIPSYCHOTIC	7
ACE INHIBITOR	6
ANTIBACTERIAL	6
MONOCLONAL ANTIBODIES	6
ANTIEMETIC	5
ANTIPSORIATIC	5
CALCIUM CHANNEL BLOCKER	5
AMINO	4
ANTIBIOTICS	4
CHEMOTHERAPHY	4
CORTICOSTEROID	4
PRESSORS	4
TRANSDERMAL PATCH	4
ANTBACTERIAL	3
ANTIDEPRESSION	3
ANTIMUSCARINIC	3
BRONCHODILATOR	3
DEBRIDING AGENT	3
IVF	3
WOUND CARE	3
ALPHA ADRENERGIC AGENT	2
ANTIBACTERIAL CLEANSING AGENT	2
ANTIDEPRESSANT	2
ANTIFUNGAL	2
ANTINEOPLASTIC AGENT	2
ANTIVIRAL	2
BLOOD MODIFIER AGENT	2
CALCINEURIN INHIBITOR	2
HEMATOPOIETIC AGENT	2
HMG COA REDUCTASE INHIBITOR	2
NUTRIONAL SUPPLEMENT	2
PROTON PUMP INHIBITOR	2
STEROID	2
TOPICAL AGENT	2
VITAMIN	2
ADP INDUCED AGGREGATION INHIBITOR	1

ANALGESICS	1
ANESTHETIC ADJUNCT	1
ANGIOTENSIN II RECEPTOR ANTAGONIST	1
ANTI-INFLAMMATORY	1
ANTIBODY	1
ANTIHYPERLIPIDEMIC	1
ANTIHYPERTIENSIVE	1
ANTIMANIC AGENTS	1
ANTITHYROID AGENT	1
ASTRINGENT	1
BENZODIAZEPINE	1
BIRTH CONTROL	1
CHOLINERGIC	1
COLONY STIMULATING FACTOR	1
CYTOPROTECTANT AGENT	1
DIAGNOSTIC AGENT	1
EXPECTORANT	1
GASTROINTESTIONAL AGENT	1
HARMONE	1
HYPERTENSIVE	1
IMMUNOSUPPRESSANT	1
MINERAL	1
OXYGEN	1
PACU ORDERSET	1
PITUITARY HORMONE	1
VOLUME EXPANDER	1

APPENDIX E

LIST OF WORDS USED TO DESCRIBE CNMO ACTION

CNMO Action	**List of word used to describe the action**
Discontinue	Discontinue, D/C, discontinuation, discontinued
Give	Give, given, apply, transfuse, infuse, irrigate, start, initiate, replete, re-dose, re-administer, titrate, run, put
Hold	Hold, standby
Modify	Modify, early, late, increase, decrease, reschedule, reduce, switch, retime, extra dose, up titrate, titrate down, half dose, half rate
Resume	Restart, resume
Stop	Stop, turn off, titrate off, wean off
Continue	Continue, continuously, cont., keep, maintain
Do not give	Do not give, do not administer, do not apply, do not infuse, do not transfuse, do not irrigate, do not start
Do not modify	Do not modify, do not adjust
Do not resume	Do not resume
Do not hold	Do not hold
Other action	CNMOs not categorized by the above

APPENDIX F

INTERVIEW GUIDE

Thank you for offering your time today! I am Swaminathan Kandaswamy, a graduate student at the University of Massachusetts Amherst. Bear with me, as I tend to read from the script to make sure everyone receives the same information. This interview is about understanding how the current Electronic Health Record system supports communication of medication information. The questions are only to understand the usability of the Electronic Health Record and not to test your knowledge. The responses will be used to understand how the Electronic Health Record fits or does not fit clinical and usability needs to guide future research. I will now read through the informed consent document. Please feel free to ask questions if you want any clarification.

[READ INFORMED CONSENT DOCUMENT]

By participating in the study you are giving consent to record the conversation during the interview. This audio recording will be transcribed and then destroyed. This study required only verbal consent.

Do you have any questions before we continue?
Do you consent to taking part in the study?

[HAND PARTICIPANT PAYMENT SHEET]

Expect to receive compensation, in the form of a paper check, for this study within 4-6 weeks from today in the mail. If you do not receive anything, please let me know and I can check the status of your reimbursement.

You will be given six clinical scenarios, and asked questions following each scenario. I will then ask you a series of questions about specific aspects of the Electronic Health Record. At the end of the session, you will be asked to fill out a questionnaire. (For phone interviews) At end of session, you will receive an email questionnaire. Please fill and send them back as soon as possible after you receive them.

Do you have any questions before we begin?

[Hand the participants the descriptions of the scenarios/ Share it via email]

I will now begin the audio recording
[Start audio recording]
[Read Case Scenario]

1) ***Discontinuing orders:*** *Ms. Gonzales has a surgery scheduled for tomorrow. She is on the anticoagulation medication enoxaparin (lovenox) and you want her off the medication 12 hrs prior to the surgery.*

   What steps would you take in the Electronic Health Record to communicate this information to nurses?
   How do you track the completion of this task communicated to the nurses?

2) ***Safety/ Caution:*** *MR. Smith is on an insulin protocol and may have a procedure in the afternoon requiring NPO (Nothing Per Oral) status. You want to let nursing know to hold insulin if MR. Smith is NPO for the procedure and doesn't eat lunch.*

   What steps would you take in the Electronic Health Record to communicate this information to nurses?
   How do you track the completion of this task communicated to the nurses?

3) ***Sequential ordering:*** *MR. Williams is on anticoagulation medication heparin drip. You want to move him from heparin to eliquis. Specifically, you want to stop the heparin drip 30 minutes before giving the first dose of Eliquis*

   What steps would you take in the Electronic Health Record to communicate this information to nurses?
   How do you track the completion of this task communicated to the nurses?

4) ***Canceling/ modifying an order component:*** Ms. Jones is on IV potassium. She has received first two doses from the Potassium Chloride 10meq IV Q1hr X4 doses order and her level has normalized. Now, you want to cancel the third and fourth doses of potassium, from the Potassium Chloride 10meq IV Q1hr X4 doses.

   What steps would you take in the Electronic Health Record to communicate this information to nurses? How do you track the completion of this task communicated to the nurses?

5) ***Changing infusion rates:*** *MR. Lee is on diltiazem drip, and you want to increase the rate from 10mg/hr to 12mg/hr.*

   What steps would you take in the Electronic Health Record to communicate this information to nurses? How do you track the completion of this task communicated to the nurses?

6) ***Changes to medication - Temporary State:*** *Your patient Ms. Garcia with hypertensive emergency has improved substantially. Her blood pressure is currently 140/80 on a rate of 0.5mg/hr and she will be getting switched to oral medications. You are unsure if she will need nicardipine drip so you want to keep nicardipine on standby in case her condition worsens.*

   What steps would you take in the Electronic Health Record to communicate this information to nurses? How do you track the completion of this task communicated to the nurses?

[Questions after Discussing All Scenarios]

Thank you for your response to the scenarios. I would like to ask you some specific questions regarding the Electronic Health Record and its usage for the scenarios we discussed

1. Have you heard of
   a. Communication orders in the Electronic Health Record? (*Communication orders are free text orders available in Electronic Health Record*)
   b. Non-Medication Communication orders in the Electronic Health Record (*Non-medication communication orders are a specific type of communication order available in Electronic Health Record)?*
2. Describe a couple of instances of when you would use a communication order and when you would use a Non-medication Communication Orders?
3. Do you know if other providers use Non-medication Communication Orders for communicating medication related information?
   a. If yes, describe a few examples for which they have used Non-medication Communication Orders?
4. Some providers opt to use Non-medication Communication Orders in the scenarios we discussed

Ask for each scenario

For discontinuing orders due to scheduled surgery:
To give a safety message or warn about dosage based on condition:
To ensure medication is given specific order (stopping heparin 30 min before eliquis):
For canceling/ modifying an order component due to change in patient status (cancelling3rd,4th runs of potassium):
For changing infusion rates:
Changes to medication (keeping nicardipine drip on hold):

   a. Why do you think providers might opt to use Non-medication Communication Orders in the scenarios?

5.
   a. Do you know where the Non Medication Communication Orders appear for Nurses in your Electronic Health Record?
      If No, - (*It appears on the orders page under communications the tab - below other orders such as medication and lab*)

b. Do you know if the Non-Medication Communication Orders requires nurses to signoff for task completion? (*No, After the nurse initially views the Non-medication communication order there is no pending task alert to follow up on the order*)
   i. If you knew where and how a Non Medication Communication Order appears to a nurse would you change your usage of Non Medication Communication Orders?
   ii. If so what changes would you make?

6. Is there anything you would change about the Electronic Health Record to support entry of the information you **ideally do not want to include** in Non-medication Communication Orders/ communication order but include in Non-medication Communication Orders?
   a. What are the changes/ recommendations?
7. Are there circumstances when you would use something other than the Electronic Health Record to communicate medication information?
   a. When / why?
8. Have you heard of safety issues due to use of Non-medication Communication Orders?
   a. If yes, please elaborate
9. Is there anything about the Electronic Health Record that makes entering or updating medication information difficult?
   a. What are the challenges?
   b. What suggestions do you have on how to handle medication communication in Electronic Health Record?

Please let me know if you have any additional comments regarding what we discussed in the interview

[***End of interview questions.]***

Thanks so much for your time! Your feedback and perspective are invaluable! If you have any colleagues who may be interested in participating in this study please feel free to let them know.

[Stop audio recording]

[Administer the survey questionnaire and ask participant to complete questionnaire]
This questionnaire has a few questions about your background and the scenarios we discussed
[If survey administered in person]
Please circle the options for Q 3,4,5.
Please indicate "x" on the relevant cell(s) for all other questions .
[If survey is sent by email]
Please highlight/ bold the option text for Q 3,4,5.
Please enter "x" on the relevant cell(s) for all other questions
Thank you! Hope you have a wonderful rest of the day!

APPENDIX G

SURVEY QUESTIONS

Participant ID _____________

Please fill in the following, if applicable

Your Role (e.g., RN, Resident, Attending, etc.): _____________________________________

Your Specialty: _______________________________

1. How many years of clinical experience do you have?

    a. Resident _____________years

    b. Attending _____________years

2. Electronic Health Record vendors that you have used and the number of years you have used them including years used as a Medical Student, Resident, and Attending. (Cerner, Epic, AllScripts, etc)

Electronic Health Record Vendor	**Years of Experience**

3. How often do you use communication orders?
    a. More than 15 times a shift
    b. 11-15 times a shift
    c. 6-10 times a shift
    d. 1-5 times a shift
    e. Once every 2-5 shifts
    f. Never
4. How often do you use Non-medication Communication Orders?
    a. More than 15 times a shift
    b. 11-15 times a shift
    c. 6-10 times a shift
    d. 1-5 times a shift
    e. Once every 2-5 shifts
    f. Never

5. For each factor mentioned below, please rate the factors due to which physicians are **likely** to use Non-medication Communication Orders in the Electronic Health Record

Factor	Extremely Unlikely	Unlikely	Neutral	Likely	Extremely Likely
To record a verbal order in Electronic Health Record					
High patient load does not allow easy communication, so want to update through Electronic Health Record					
The physical environment and unit layout does not allow for easy communication, making it hard to access nurses and other staff involved in patient care. I use communication orders as a way to give updates through Electronic Health Record					
No other place in Electronic Health Record to update this information					
Other places in Electronic Health Record can be used, but they opt to use Non-medication Communication Orders due to usability and navigation issues with Electronic Health Record					
It is easier to update/communicate via the Electronic Health Record than in person					
Provider Preference					
Other? Please specify					

6. For each scenario we discussed in the interview, how **easy** is it to communicate the information to the nurse through the Electronic Health Record?

Scenario	**Extremely easy**	**Very easy**	**Moderately easy**	**Slightly easy**	**Not at all easy**
For discontinuing orders due to scheduled surgery: (Discontinue Lovnox 12 hrs before surgery)					
To give a safety message or warn about dosage based on condition: (Hold insulin if patient is NPO)					
To ensure medication is given specific order: (stopping heparin 30 min before eliquis)					
For canceling/ modifying an order component due to change in patient status: (cancelling 3rd & 4th runs of potassium)					
For changing infusion rates: (increase diltiazem drip to 12mg/hr)					
Changes to medication order (nicardipine drip on hold)					

7. For each scenario we discussed in the interview, how **easy** is it to communicate the information to the nurse if a physician used the Non-medication communication Order in the Electronic Health Record?

Scenario	**Extremely easy**	**Very easy**	**Moderately easy**	**Slightly easy**	**Not at all easy**
For discontinuing orders due to scheduled surgery: (Discontinue Lovnox 12 hrs before surgery)					
To give a safety message or warn about dosage based on condition: (Hold insulin if patient is NPO)					
To ensure medication is given specific order: (stopping heparin 30 min before eliquis)					
For canceling/ modifying an order component due to change in patient status: (cancelling 3rd & 4th runs of potassium)					
For changing infusion rates: (increase diltiazem drip to 12mg/hr)					
Changes to medication order (nicardipine drip on hold)					

8. For each scenario we discussed in the interview, is the Electronic Health Record **effective** in updating the information for the nurses to act on? By effective, I mean does it help in ensuring that the clinical task is completed correctly

Scenario	Extremely effective	Very effective	Moderately effective	Slightly effective	Not at all effective
For discontinuing orders due to scheduled surgery: (Discontinue Lovnox 12 hrs before surgery)					
To give a safety message or warn about dosage based on condition: (Hold insulin if patient is NPO)					
To ensure medication is given specific order: (stopping heparin 30 min before eliquis)					
For canceling/ modifying an order component due to change in patient status: (cancelling 3rd & 4th runs of potassium)					
For changing infusion rates: (increase diltiazem drip to 12mg/hr)					
Changes to medication order (nicardipine drip on hold)					

9. For each scenario we discussed in the interview, how **effective** is it to communicate the information to the nurse if a physician used the Non-medication communication Order in the Electronic Health Record?

Scenario	Extremely effective	Very effective	Moderately effective	Slightly effective	Not at all effective
For discontinuing orders due to scheduled surgery: (Discontinue Lovnox 12 hrs before surgery)					
To give a safety message or warn about dosage based on condition: (Hold insulin if patient is NPO)					
To ensure medication is given specific order: (stopping heparin 30 min before eliquis)					
For canceling/ modifying an order component due to change in patient status: (cancelling 3rd & 4th runs of potassium)					
For changing infusion rates: (increase diltiazem drip to 12mg/hr)					
Changes to medication order (nicardipine drip on hold)					

10. For each scenario we discussed in the interview, how **risky** is it to communicate the information to the nurse if a physician used **communication orders** in terms of potential patient safety issues?

Scenario	**Insignificant risk**	**Minor risk**	**Moderate risk**	**Major risk**	**Severe risk**
For discontinuing orders due to scheduled surgery: (Discontinue Lovnox 12 hrs before surgery)					
To give a safety message or warn about dosage based on condition: (Hold insulin if patient is NPO)					
To ensure medication is given specific order: (stopping heparin 30 min before eliquis)					
For canceling/ modifying an order component due to change in patient status: (cancelling 3rd & 4th runs of potassium)					
For changing infusion rates: (increase diltiazem drip to 12mg/hr)					
Changes to medication order (nicardipine drip on hold)					

11. For each scenario we discussed in the interview, how **risky** is it to communicate the information to the nurse if a physician used the **non-medication communication** orders in terms of potential patient safety issues?

Scenario	**Insignificant risk**	**Minor risk**	**Moderate risk**	**Major risk**	**Severe risk**
For discontinuing orders due to scheduled surgery: (Discontinue Lovnox 12 hrs before surgery)					
To give a safety message or warn about dosage based on condition: (Hold insulin if patient is NPO)					
To ensure medication is given specific order: (stopping heparin 30 min before eliquis)					
For canceling/ modifying an order component due to change in patient status: (cancelling 3rd & 4th runs of potassium)					
For changing infusion rates: (increase diltiazem drip to 12mg/hr)					
Changes to medication order (nicardipine drip on hold)					

12. For each Electronic Health Record function, please indicate how **helpful** it is to communicate medication information to the nurse using the specific function, in terms of avoiding/minimizing the potential of a patient safety?

Electronic Health Record Function	Extremely helpful	Very helpful	Moderately helpful	Slightly helpful	Not at all helpful
Free text box in medication orders					
Non-medication Communication Order					
Communication Order					
Others- Please Specify					

Please feel free to add comments about challenges with communication of medication information in EHR.

APPENDIX H

LIST OF MEDICATION NAMES AND PHRASES REPLACED IN CNMO TEXTS FOR DATA PREPARATION

MEDICATION NAMES
NITRATE
NITRATES
NITROPASTE
VANCO
HYPOGLYCEMICS
SCOPOLAMINE
PREMEDICATION
TPA
STEROID
STEROIDS
ORDER SET
ORDERSET
PACU ORDER
PACU ORDERS
BETA BLOCKER
PREOP ORDERS
PREOP ORDER
ANTICOAGULANTS
ANTICOAGULANT
ANTICOAGULATION
IVFS
IVF
DEXTROSE
ANTIEMETIC
MEDICINE
NSS
LEVO
MEQ
HEPARINGTT
PRESSORS
PRESSORS
GLYCOPYRRHOLATE
HEPLOCK
EPO
DOSE
LIDO

NSAID
LAXATIVE
LAXATIVES
IV
IVS
TACROLIMUS
BOLUS
BOLUSES
AQUACEL
TRANSDERMAL PATCH
TRANSDERMAL PATCHES
NNS
IVPB
SALINE
LISPRO
DEX
PHENYLEPRINE
NSAIDS
NSAID
HEP
ANTIBIOTICS
PRBCS
PRBC
SALINE
NS
ANTIBIOTIC
IV FLUID
IV FLUIDS
LIDODERM
PCA
PATIENT CONTROLLED ANALGESIC
IV
RIVAC
PACU ANALGESIA
ANALGECIS
ANALGESIC
ABX
ACETAMINOPHEN
ACETAZOLAMIDE
ACETYLSALICYLIC ACID
ACYCLOVIR
AGRATROBAN
ALBUMIN

ALBUMIN HUMAN
ALBUTEROL
ALTEPLASE
ALUMINUM SULFATE TETRADECAHYDRATE
AMIODARONE
AMIODARONE HYDROCHOLORIDE
AMLODIPINE
AMLODIPINE BESYLATE
AMPICILLIN
ANCEF
ANGIOMAX
APIXABAN
AQUACEL SILVER
ARGATROBAN
ARIPIPRAZOLE
ASA
ASPIRIN
ATENOLOL
ATENONOL
ATIVAN
ATROPINE
AZITHROMYCIN
BACITRACIN
BACTRIM DS
BARIUM
BARRIER CREAM
BENEDRYL
BENZALKONIUM CHLORIDE
BETADINE
BICARBONATE
BIVALIRUDIN
BLEOMYCIN
BRILINTA
BUMETANIDE
BUMEX
BUSPIRONE
BUTALBITAL
CADEXOMER IODINE
CALCIUM
CARBAMAZEPINE
CARDIZEM
CARVEDILOL

CEFAZOLIN
CEFEPIME
CEFOXITIN
CEFTAZIDIME
CEFTRIAXONE
CHLORHEXIDINE
CIPROFLOXACIN
CLINDAMYCIN
CLONAZEPAM
CLONIDINE
CLOPIDOGREL
COLLAGENASE
COMPAZINE
COREG
COSYNTROPIN
COUMADIN
CREON
CRESTOR
CYANOACRYLATE
CYCLOSPORINE
DABIGATRAN
DAKIN SOLUTION
DECADRON
DEMEBORO
DEPAKOTE
DEXAMETHASONE
DEXMEDETOMIDINE
DEXTRIN
DEXTROSE
DIALYSATE
DIAMOX
DIGOXIN
DIHYDROERGOTAMINE
DILANTIN
DILAUDID
DILTIAZAM
DIPHENHYDRAMINE
DOBUTAMINE
DOCUSATE SODIUM
DOMEBOROS
DOPAMINE
ELIQUIS
ENEMA

ENOXAPARIN
ENOXAPARIN SODIUM
ENTRESTO
EPIDURAL
EPINEPHRINE
EPOPROSTENOL
EPTIFIBATIDE
ERYTHROMYCIN
ERYTHROPOIETIN
FENTANYL
FILGRASTIM
FIORICET
FLUMAZENIL
FONDAPARINUX
FUROSEMIDE
GABAPENTIN
GENTAMICIN
GLUCAGON HYDROCHLORIDE
GLUCAN
GLUCOGON
GLYCOPYRROLATE
GOLYTELY
GUAIFENESIN
HALDOL
HALOPERIDOL
HARVONI
HEPARIN
HESPAN
HETASTARCH
HUMALOG
HUMULIN
HYDRALAZINE
HYDROCORTISONE
HYDROGENPEROXIDE
HYDROMORPHONE
HYDROXYZINE
IBUPROFEN
IMMUNE GLOBULIN
INDAPAMIDE
INSULIN
INSULIN GLARGINE
INSULIN LISPRO
INTEGRILIN

INTERDRY
IODOFORM
IODOSORB
IVF
KETAMINE
KETOROLAC
KETOROLAC TROMETHAMINE
LABETALOL
LACTATE RINGERS
LACTULOSE
LANTUS
LASIX
LEDIPASVIR
LEVALBUTEROL
LEVETIRACETAM
LEVOPHED
LEVOTHYROXINE
LIDOCAINE
LIPIDS
LISINOPRIL
LITHIUM
LOPRESSOR
LORAZEPAM
LOSARTAN
LOVENOX
MAGNESIUM
MAGNESIUM CITRATE
MARATHON
MEDIHONEY
MEPILEX
MEROPENEM
MESNA
METFORMIN
METHIMAZOLE
METHLYPREDNISOLONE
METHYLNALTREXONE
METHYLPREDNISOLONE
METOPROLOL
METRONIDAZOLE
MIDAZOLAM
MIDODRIN
MILRINONE
MIRALAX

MIRTAZAPINE
MORPHINE
MORPHINE SULPHATE
MOTRIN
MSCONTIN
MUCINEX
MYCOPHENOLATE
MYCOPHENOLIC ACID
NALOXONE
NATURE THYROID
NEB
NICARDIPINE
NICOTINE
NIFEDIPINE
NITROGLYCERIN
NOAC
NOREPINEPHRINE
NORVASC
NOVOLOG
OCTREOTIDE
OLANZAPINE
ONDANSETRON
ORDER SET
OXCARBAZEPINE
OXYCODONE
OXYGEN
PACU ORDERSET
PANCRELIPASE
PANTOPRAZOLE
PATIENT CONTROLLED ANALGESIA
PEDIALYTE
PENICILLIN
PERCOCET
PERI-COLACE
PETROLEUM DRESSING
PETROLEUM JELLY
PHENAZOPYRIDINE
PHENOBARBITAL
PHENYLEPHRINE
PHENYTOIN
PIPERACILLIN
PLAVIX
POLYETHYLENE GLYCOL

POMALIDOMIDE
POMALYST
POVIDONE-IODINE
PRECEDEX
PREDNISONE
PROCHLORPERAZINE
PROPOFOL
PROTONIX
PYRIDIUM
QUETIAPINE
REGULAR HUMAN INSULIN
RELISTOR
REMODULIN
RHI
RINGERS LACTATE SOLUTION
RITUXIMAB
RIVAROXABA
ROCEPHINE
ROSUVASTATIN
SALINE
SANTYL
SCOPOLAMINE
SEROQUEL
SILVADENE
SILVER SULFADIAZINE
SODIUM HYPOCHLORITE
SOFOSBUVIR
SSI
STATIN
SULFAMETHOXAZOLE
TACROLIMUS
TEGRETOL
THIAMINE
TICAGRELOR
TORADOL
TRAMADOL
TRAZODONE
TREPROSTINIL
TRIAMCINOLONE
TRILEPTAL
TYLENOL
VACCINE
VALPROIC ACID

VALSARTAN
VANCOMYCIN
VANCOMYCINE
VASOPRESSIN
VELETRI
VERSED
WARFARIN
XARELTO
XEROFORM
XOPENEX
ZINC SULFATE
ZOFRAN
ZOSYN
ZYPREXA

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