System-related errors associated with the long-term use of electronic medication management

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Statement of Originality

This is to certify that to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

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Madaline Kinlay 28 June 2023

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‘*Teamwork makes the dream work’* - John C. Maxwell

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Dedication

I dedicate this thesis to my mother, Anita Kornmehl.

My eternal sunshine.

Abstract

Background

Electronic medication management (EMM) systems have been shown to improve medication safety in hospitals yet simultaneously facilitate new system-related errors; errors that were less likely or not possible with the use of paper-based medication charts. Research has explored system-related errors that emerge immediately following EMM system implementation, however little is known about the types of system-related errors that persist or emerge once system use becomes routine. This program of research aimed to 1) identify and classify system-related errors associated with long-term use of EMM systems, 2) determine the factors (i.e., design, user or organisational factors) contributing to these long-term errors and 3) compare long-term system-related errors with short-term errors with respect to types contributing factors and mitigation strategies.

Methods

This research was conducted at three hospitals in a Local Health District in Sydney, Australia. The hospitals used the same EMM system but had the system in place for different lengths of time. A narrative review was initially undertaken to scope the existing literature on the occurrence of system-related errors over time. Mixed methods were then employed to explore system-related errors, including an analysis of EMM-related incident reports, interviews with key stakeholders and a review of documents detailing EMM system enhancements at the three sites. Long-term system-related errors were examined in terms of error types, contributing factors, consequences, and strategies for detection and mitigation. Importantly, the analysis

of each data source considered the element of time since EMM system implementation to compare long-term system-related errors with short- and medium-term errors.

Results

Overall, system-related errors were found to persist with long-term EMM system use. Factors related to the EMM system design, user and organisation led to system-related errors in varying degrees over time. However, certain factors were consistently associated with system-related errors, irrespective of time since EMM system implementation, including user unfamiliarity with the EMM system and the use of hybrid systems. System-related errors not only resulted in medication errors, but also impacted the user, and documentation within the EMM system. Detection of system-related errors was found to rely heavily on clinicians, while mitigation strategies targeted the EMM system and the context in which the system was used.

Conclusion

This program of research identified and classified long-term system-related errors, highlighting how errors develop and change over time. The findings emphasise that system-related errors result from a combination of different factors, and therefore mitigation strategies should be multilayered. Organisations should remain vigilant to factors that increase vulnerability to system-related errors. Future research should investigate the effectiveness of interventions aimed at minimising system-related errors, particularly as EMM systems are increasingly updated and improved.

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List of Abbreviations

ASCQHC	Australian Commission for Safety and Quality in Health Care
CDS	Clinical decision support
CPOE	Computerised provider order entry OR computerised prescriber order entry
EMM	Electronic medication management
eMM	Electronic medication management
EMMS	Electronic medication management system/s
EMR	Electronic medical record
eMR	Electronic medical record
HREC	Human Research Ethics Committee
ICT	Information and Communications Technology
ICU	Intensive Care Unit
IIMS	Incident Information Management System
IM&TD	Information Management and Technology Division
JCAHO	Joint Commission on Accreditation of Healthcare Organizations
LHD	Local Health District
MAR	Medication administration record
NCC MERP	National Coordinating Council for Medication Error Reporting and Prevention
NSW	New South Wales
UK	United Kingdom
US / USA	United States / United States of America
WHO	World Health Organization

List of Publications

Authorship attribution statement included at the beginning of each chapter.

Peer-review publications

Kinlay M, Zheng WY, Burke R, Juraskova I, Moles R, Baysari M. Medication errors related to computerized provider order entry systems in hospitals and how they change over time: A narrative review. *Res Social Adm Pharm*. 2021;17(9):1546-1552. doi:10.1016/j.sapharm.2020.12.004

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Under review

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Presentations

Kinlay M, Zheng WY, Juraskova I, Moles R, Baysari M. Optimizing electronic medication management to minimize medication errors and streamline workflow: An ongoing journey. *AIDH Young Talent Time 2021.*

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Posters

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Kinlay M, Zheng WY, Burke R, Juraskova I, Ho LMR, Turton H, Trinh J, Baysari M. Use it or lose it: The role user unfamiliarity with electronic medication systems plays in medication errors. *Digital Health Week 2023.*

Chapter 1: Introduction

Medications are the most frequently used intervention in healthcare, and when used appropriately, can significantly improve the health of individuals and populations, by treating illness and preventing disease.[1] Healthcare providers play a crucial role in supporting consumers throughout the medication management process, ensuring optimal medication use and minimising potential harm.[2,3] During each episode of care in hospitals, the medication management process involves a series of essential steps that precede the delivery of medications to the consumer.[4] Classified by the World Health Organization (WHO), these steps fall under four key stages of medication use: prescribing, dispensing, administering and monitoring (see Figure 1).[1,5,6] In Australian hospitals, doctors prescribe most medications, which are then verified and dispensed by pharmacists, and finally administered by nurses. Throughout the medication management process, all healthcare providers, as well as the patient, are responsible for monitoring medication use, ensuring patient safety and preventing medication errors.[7]

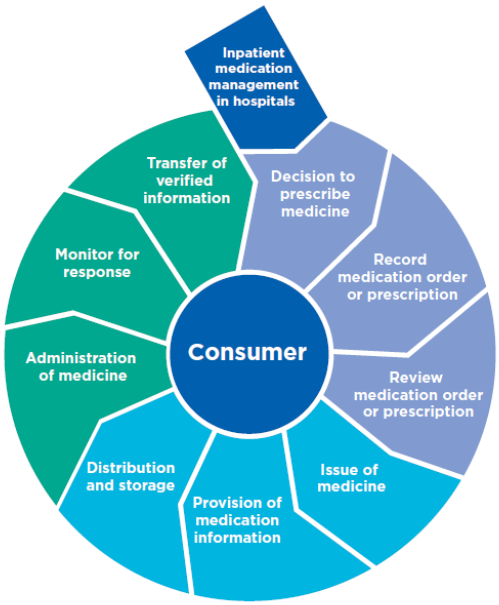

Figure 1: The medication management cycle.[6] Clockwise from the top, the first three segments refer to prescribing and associated activities; the next three segments refer to dispensing and associated activities; and the final three segments refer to medication administration and monitoring.

MEDICATION ERRORS

Medication errors are defined as "*any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of*

the health care professional, patient, or consumer" (see Box 1).[8-10] This definition is endorsed by the National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP) of the United States (US),[8,11] however, variability in terms and definitions used to describe medication errors is an ongoing challenge for healthcare providers and researchers.[11,12] In one review, 26 variations in wording and content of medication errors were identified, reaffirming these inconsistencies.[9]

A key point of difference is in scope. Some definitions describe medication errors as errors that occur at one stage of the medication management process (i.e. typically during prescribing),[13,14] while other definitions describe medication errors as those occurring at all stages of the medication management process (i.e. prescribing, dispensing, administering, and monitoring).[15-17] In the definition endorsed by the NCC MERP, it is further clarified that *"such events may be related to professional practice, health care products, procedures, and systems, including prescribing, order communication, product labelling, packaging, nomenclature, compounding, dispensing, distribution, administration, education, monitoring, and use",* highlighting the broad range of errors that are possible.[8]

Box 1: Key terms associated with medication errors.

Medication error: any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer.[8]
Adverse drug event: a medication error that results in any unintentional harm to the patient.[10]
Near-miss: a medication error that had the potential to cause harm to the patient, but did not, as a result of chance, prevention or mitigation.[10]

Most definitions of a medication error refer to a failure, error or deviation from a treatment process or planned action, and traditionally have not included details on the relationship between process and outcome.[9,18] However, in more recent research, there has been a shift away from solely determining what went wrong, to also describing whether there was harm to the patient as a result of the medication error.[19] Most commonly, a medication error is described as leading to, or having the potential to lead to, harm to the patient.[20] In an early paper, Hofer et al. (2000) recommended redefining error as a failure clearly linked to an outcome, specifically an adverse drug event.[18] However, a medication error can occur regardless of whether injury or harm occurred to the patient.[13,21] Although medication errors can increase the probability of harm to the patient, errors and harm can also occur independently of one another, which is why most definitions of medication error do not imply causation.[3,9,13,17,22]

How are medications errors identified?

Error detection is the first step for organisations seeking to reduce medication errors and minimise their potential harm. Once detected, medication errors can be analysed to determine the underlying causes of the error and establish preventative measures.[23,24] Clinicians act as the frontline defence against medication errors in hospitals; their professional roles include detecting, reporting and rectifying errors.[25] In particular, Australian clinical pharmacists evaluate medication orders for accuracy, assess potential drug interactions, verify dosages for appropriateness, and reconcile patients' medication regimens.[26] Through these essential pharmacy functions, various medication errors can be detected prior to reaching the patient.

In addition to frontline detection, medication errors in hospitals are identified through several methods, including voluntary reports, medication chart review, direct observations and computer monitoring.[23,27] Voluntary reporting platforms allow clinicians, and in some cases patients, to confidentially disclose incidents, near misses, and potential risks through a dedicated portal.[28] Reports are then escalated to senior staff for review and analysis.[29] Medication chart review involves retrospectively examining a patient's medication chart and offers a more comprehensive approach to detecting errors than incident reports.[30] However, conducting medication reviews can be labour intensive and may not effectively capture the underlying factors that contributed to the error.[23] Direct observations, although time-consuming, offer a prospective means of error detection, and are useful for identifying administration errors. Lastly, when used for medication management, computers can monitor medication orders, alerting healthcare professionals to potential errors in real-time.[23,30]

How are medication errors classified?

Medication errors can be categorised in various ways; by the stage in which they occurred in the medication management process, the type of medication error, the cause of the medication error, or the severity of harm which resulted from the medication error. Some classifications make reference to the relationship between the type of error and the possible resulting harm (e.g. incorrect dose prescribed → increased dose of medication administered → patient experienced drowsiness), while others simply describe the characteristics of the error (e.g. the wrong dose was prescribed).[31] For the purposes of communication and reporting, attempts have been made to standardise the way medication errors are classified.[12] Several classifications have been proposed by healthcare providers, researchers and

organisations, however few have been successfully implemented or applied consistently across multiple settings.[32]

In one of the earliest attempts to classify medication error classifications, it was proposed that errors can be classified either by context, mode or in a psychological manner.[33] Contextual classifications are descriptive, describing what actions were performed and in what context. For example, how often 2mg of warfarin was prescribed for inpatients when 1mg was intended. On the other hand, a modal classification is concerned with the way in which the error occurred, whether by omission, repetition, substitution or insertion. In the warfarin example, this could be classified as a substitution error. Generally, contextual and modal taxonomies describe errors, but fail to explain their causes. Therefore, psychological classifications may be more beneficial, as they interpret events and provide explanations for what mechanisms generated errors.[32] These types of classifications are particularly useful for determining the causes of medication errors and developing prevention strategies.[33,34]

One example of a psychological classification, adapted from Reason's (1990) theory of human error, is that proposed by Ferner and Aronson (2006), which describes the cognitive processes believed to underlie medication errors. This classification includes two error categories: mistakes and skill-based errors.[31,32] Mistakes are made during the planning of an action and are errors in either knowledge or applying rules. Skill-based errors occur while undertaking a correctly planned action and are either slips or lapses. Slips occur when an action is executed not as intended, while a lapse is the failure of memory.[32,34] In another seminal classification, put forward by Reason (1997), factors contributing to errors are grouped into three categories;

organisational or systems, local workplace and unsafe acts.[35] This classification places more importance on the environmental factors in which the error occurred, such as gaps in supervision or time pressures, instead of user factors, such as cognition.[35] Although broader in scope than Reason's (1990) earlier theory of error, this classification describes how an error occurred in a particular context and so is useful for determining how it could be prevented in the future with the redesign of systems and environments.[36]

In addition to describing how and why errors occur, classifications have also been used to describe errors with respect to their outcome, or the severity of harm that may ensue.[37] For example, a commonly used error and harm classification developed by the Pharmaceutical Care Network Europe and the NCC MERP of the US, includes four broad categories; no error, no harm, harm and death.[38,39] While this classification has been shown to be applied consistently,[40] it has been noted that its use for prevention is inadequate, due to the limited insight it provides into the source of errors.[32] In another frequently used harm classification, adverse drug events are categorised by whether a medication error had occurred, if it could have been prevented, and how severe the event was.[41] By including *potential* adverse drug events, such as prescribing errors that were intercepted before being administered, it has been suggested that a more holistic prevention strategy is achievable.[32]

A recent review showed that the terms medication error, adverse drug event, adverse drug reaction and drug-related problem are often used interchangeably across classifications.[11] Furthermore, each term is defined and classified by researchers without consistency or consensus. Interestingly, Ferner and Aronson

(2006) critiqued competing definitions and classifications of a medication error, concluding that a general consensus is unnecessary and the myriad of terminology only enhances understanding.[32] However, evaluating a concept, in this case, medication errors, begins with a definition that removes ambiguity, guides the appropriate selection of measurement tools and reduces the chances of obtaining different results when collecting data.[42] Additionally, effective strategies for reducing medication errors requires accurate identification and measurement of the sources or factors contributing to these errors.[37] Therefore, for the purposes of this thesis, the definitions adopted by Westbrook et al. (2013), as described below, will be used to conceptualise and describe medication errors; deconstructing a medication error into the mechanism and the manifestation of the error, leading to the outcome (see Table 1).[43]

The mechanism of a medication error

The mechanism of a medication error can be defined as *"the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim"*.[10] The mechanism should be separated from its manifestation or consequence; it is entirely the action that was not as intended or was not executed optimally.

The manifestation of medication error

If we interpret the mechanism to be the action, then the ensuing consequence of this action is the manifestation of the medication error.[44] Adapted from the NCC MERP definition, this manifestation of a medication error can be defined as "*any preventable event, resulting from a wrongly planned or unintended action, that may cause or lead to inappropriate medication use or patient harm*".[8,32,44]

The outcome of a medication error

The outcome of a medication error is dependent upon a range of situational factors and can be classified into either an adverse drug event or a near-miss. Adapted from the US Institute of Medicine an adverse drug event is a medication error that results in any unintentional harm to the patient.[10] In this context, the use of adverse drug *event*, rather than *reaction*, signifies that the resulting harm may not necessarily be directly caused by the drug, but rather the result of using the drug inappropriately (e.g. dose reductions or drug discontinuation).[45] More often, a medication error results in a near-miss rather than an adverse drug event.[13] A near-miss can be defined as a medication error that had the potential to harm the patient, but did not, as a result of chance, prevention, protection or mitigation.[10]

Table 1: Examples of each term referenced in the medication error taxonomy.

Term		**Example**
Medication error	Mechanism	Writing an illegible script
	Manifestation	The incorrect dose was prescribed
Outcome	Adverse drug event	Patient suffers from heart palpitations and sweats after receiving incorrect dose
	Near-miss	Dose corrected by pharmacist prior to dispensing medication

Strategy	Prevention	Medication review: During the medication review process, the incorrect dose is identified and rectified
	Protection	Monitoring: After the wrong dose has been administered, the patient is regularly monitored
	Mitigation	Electronic medication management: An electronic medication management system is introduced, eliminating the illegible script of the prescription

Taxonomy of medication errors

Figure 2 presents the inter-relationship between the terms in Table 1, using an adapted classification of the US Joint Commission on Accreditation of Healthcare Organizations (JCAHO) safety event taxonomy.[46] As shown in Table 1 and Figure 2, strategies that can reduce the occurrence of errors and harm can take many forms, including prevention, protection and mitigation. Prevention of medication errors involves identifying risk factors and devising strategies to limit the occurrence of errors.[46] The medication review process is an example of a prevention strategy to reduce medication errors. Protection and mitigation strategies are implemented after a medication error has occurred; the former limiting the immediate harm to the patient and the latter seeking to alleviate future harm with corrective action.[46]

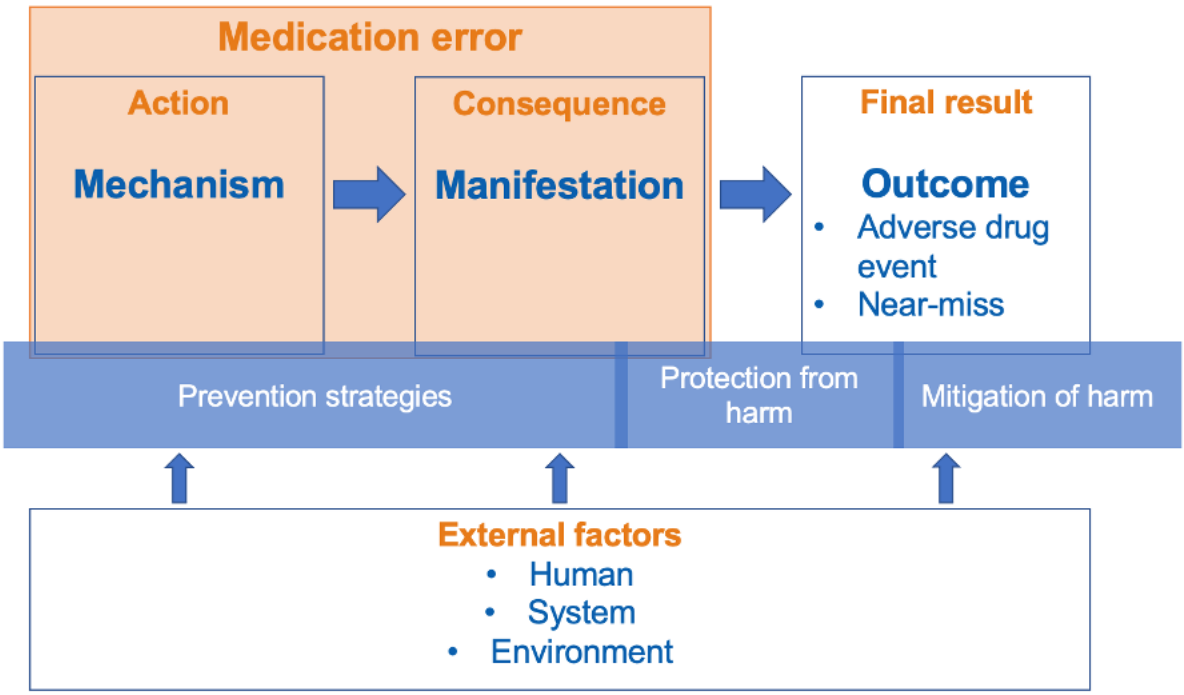

Figure 2: Classification and model of medication errors and related terms (Adapted from Jenicek[44]).

How often do medication errors occur in hospitals?

Medication error rates in hospitals are difficult to estimate due to inconsistent methods used to define, classify and measure errors.[47,48] Research suggests that in Australia, up to one error occurs per patient per hospitalisation.[48,49] In synthesising the literature, medication errors occur at each stage of a hospital stay (see Figure 3).[48] Medication errors account for around 25% of reported incidents in public hospitals, making them the second most frequently reported clinical incidents, after falls.[50] A study of 22 Australian hospitals showed that up to 85% of patient charts contained a prescribing error,[51] highlighting the high frequency with which patients are exposed to medication errors.

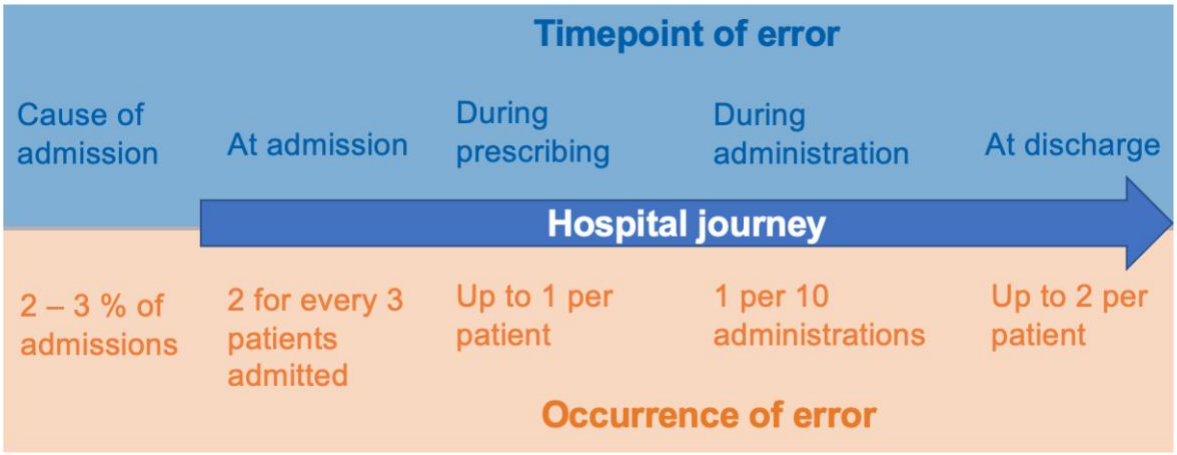

Figure 3: Medication-related incidents during the hospital journey in Australians (Taken from Roughead, Semple and Rosenfeld[48]).

Yet, as noted previously, medication errors do not necessarily result in adverse drug events. For example, a study assessing medication errors in paediatric inpatients determined that of 616 errors, 19.5% had the potential to cause harm. Further, only 0.8% of these errors resulted in an adverse drug event, highlighting the discrepancy between error rates and outcomes.[52] Despite this, error rates remain high and efforts to prevent medication errors in hospitals continue to be a priority.[4,53]

Interventions to reduce medication errors

Medication errors are typically the result of defective systems, processes and conditions, that occur irrespective of individuals' skill or knowledge.[3] As such, reducing medication errors requires a systems approach that considers the complexities of healthcare.[2,31] Following the release of *To Err is Human: Building a Safer Health System* in 2000, in which the Institute of Medicine outlined the impact and inadequacy of medication safety practices, an increase was seen in the adoption of strategies to reduce errors in healthcare settings.[54-56] In 2017, WHO's global

patient safety challenge was *'Medication without harm'*, which aimed to elicit a global response to improve medication safety.[57] In Australia, Medication Safety is included in the eight national health care standards developed by the Australian Commission for Safety and Quality in Health Care (ASCQHC), highlighting the importance of this issue.[58] Common strategies adopted by hospitals to prevent medication errors include medication review and reconciliation, standardisation, incident reporting systems and computerised systems.

Medication review and reconciliation

The process of medication review involves evaluating patients' current medications to ensure the provision of up-to-date, optimal treatment.[59] This review may be part of a formal medication reconciliation, which aims to compile a detailed and current medication list, and reconcile any discrepancies that may have occurred during admission, transitions of care, or discharge.[31,53] The process of evaluating and systematically rechecking patient medications at regular intervals provides opportunities for medication errors to be detected and corrected.

Standardisation of processes

Standardisation in healthcare involves establishing a uniform set of specifications, processes and protocols to increase the level of quality and compatibility across services, and ensure consistency of care.[5,10,60] Adopting a standardised medication management process ensures all those involved are responsible for delivering evidence-based products and services.[61] For example, the National Inpatient Medication Chart was introduced in Australia as a way of standardising medication documentation practices, resulting in a 16.6% reduction in prescribing errors per order per patient.[51] When standards of care differ between services, clinical

outcomes can vary, and patient safety is compromised.[62] Therefore, ensuring that healthcare providers abide by nationally recognised standards of medication dosing, labelling, storage and procedures, as outlined by the ACSQHC in Standard Four: Medication safety, is perceived to be critical for error reduction.[63]

Voluntary incident reporting

Routinely documenting any potential or actual errors can provide valuable information to guide improvements in patient safety.[64] Healthcare providers are encouraged to report medication errors via dedicated incident reporting platforms.[31,38] For example, the Incident Information Management System (IIMS) is used in NSW public hospitals for reporting clinical incidents, near misses and complaints.[39] Although underreporting is a significant problem,[65] in the last three decades there has been a shift away from blaming individuals for errors to a focus on the systems and processes that led to the errors, in order to encourage transparency and learning from errors.[66] The review and analysis of voluntary incident reports can provide information on how and why errors occurred, facilitating the identification of underlying contributing factors and informing the development of targeted interventions to prevent similar errors from occurring in the future.

Computerised systems

Technology in healthcare has evolved rapidly, with the introduction of clinical information systems in hospitals such as electronic medical records, electronic medication management (EMM) systems with clinical decision support (CDS), automatic medication dispensing cabinets, and barcode medication administration.[67,68] A significant technological advancement in medication management has been the shift to EMM systems from paper-based medication

charts. There is substantial evidence showing that implementation of an EMM system is associated with significant reductions in medication errors, supporting the continual development and use of these systems.[69-72]

ELECTRONIC MEDICATION MANAGEMENT SYSTEMS

All aspects of the medication management process are supported and facilitated in a digital form by EMM systems (also referred to as computerised provider order entry (CPOE) systems). In a similar fashion to paper-based charts, EMM systems allow clinicians to prescribe, review, administer and monitor medications. At the very least, introduction of an EMM system ensures prescriptions are legible, complete and uniform.[73] In addition to this, EMM systems can increase ease of access to patient records and provide real time clinical decision support (e.g. alerts, pre-defined order sets).[74] As a result of these capabilities, EMM systems have been shown to be cost-effective, improve workflow and communication between clinicians, and most importantly, increase medication safety.[6,75,76]

Improving medication safety with electronic medication management systems

Several studies have demonstrated that the transition from paper-based medication charts to EMM systems has resulted in lower rates of medication errors and adverse drug events.[69,77-79] A recent systematic review of EMM system evaluations revealed that eight out of nine studies reported a decrease in the rate of medication errors after the introduction of EMM systems, with reductions in medication errors ranging from 41% to 55%.[77] In the first controlled study to be undertaken in Australia, 3291 inpatient medication charts were reviewed before and after the introduction of two different EMM systems at two hospitals.[80] The transition to the EMM systems was associated with a 55% reduction in prescribing error rates and a 44% reduction in

serious prescribing errors, those with the potential to lead to permanent bodily damage or significant medical repercussions. Procedural errors, including unclear, incomplete and legal/procedural prescriptions were almost eliminated, decreasing by an average of 92% after the EMM systems were introduced. Interestingly, this seminal study also showed that EMM systems introduced new types of errors, errors that were not possible with paper-based charts; specifically, system-related errors.[80]

SYSTEM-RELATED ERRORS

Evaluations of EMM systems have revealed that reductions in certain types of medication errors occur simultaneously with an increase in system-related errors; errors that were unlikely or not possible with the use of paper-based medication charts.[81-83] Selecting the wrong medication from a drop-down list (e.g., loratadine instead of lorazepam) is a common example of a system-related error.[84] System-related errors directly relate to the introduction of EMM systems, and are generally attributed to a combination of sociotechnical factors, rather than a lack of clinical knowledge or skill by the end-user.[20,85,86]

Reports of system-related errors are predominantly found in studies evaluating medication error rates before and after the introduction of EMM systems.[80,87-94] For example, an observational study conducted in a geriatric ward of a United Kingdom (UK) hospital employed an interrupted time-series approach, and measured the prevalence of medication administration errors before and after the implementation of an EMM system.[88] Despite finding no significant difference in the rate of medication administration errors pre- and post-EMM implementation, the study uncovered new types of medication administration errors associated with the EMM system. The researchers identified errors involving extra doses, wrong routes and

wrong formulations, and stipulated that these errors were less likely to occur on paper medication charts due to visual cues, such as coloured ink and highlighting of relevant text.[88]

Some literature has also sought to describe and quantify system-related errors separately from other medication error types.[43,79,95-102] Notably, in a key study conducted at two Australian hospitals, three clinical pharmacists reviewed 629 inpatient admissions roughly 18 weeks following EMM system implementation.[43] After initially classifying prescribing errors into procedural or clinical errors, a classification of system-related prescribing errors was developed to compare the types and rates of these errors. System-related prescribing errors were classified according to their mechanism (e.g. errors made when selecting information from drop-down menus) and manifestation (e.g. wrong route), and accounted for approximately 42% of all prescribing errors. Timing errors were the most common manifestation of system-related errors, while selection errors, where the user made an incorrect selection from a drop-down menu, were found to be the most frequent mechanism of errors. Other reported mechanisms of system-related errors included editing errors, construction errors and new tasks required by the EMM system. It is interesting to note that selection errors were found to be more prevalent in one hospital, occurring four times more frequently following implementation of one system compared to the other. Similarly, timing errors were shown to be 13 times more frequent with one EMM system than the other. This inconsistency in error types between hospitals demonstrated that different EMM systems resulted in different types of system-related errors.[43]

Since the publication of this system-related error classification, further research has emerged categorising these errors. For example, a US study analysed over 10 thousand reported medication incidents where the EMM system was listed as a contributing cause and coded EMM-related incidents according to what went wrong, why the incident occurred and potential prevention strategies.[97] The most frequent EMM-related incidents reported included missing or erroneous label instructions, wrong dose or strength and scheduling issues. In approximately half of the EMM-related incidents, the reasons for the report were unclear, however some common issues were highlighted. These issues included miscommunication between hybrid systems, inexperience or lack of training on the system and typing or drop-down menu errors.[97] Subsequently, this classification of EMM-related incidents was further refined, revealing both similar and previously unidentified errors in a separate sample of incident reports.[96]

System-related errors over time: An evidence gap

To date, studies have typically examined new errors that have emerged immediately after EMM system implementation, with very limited research evaluating system-related errors once routine use of an EMM system is established, often referred to as after the "shake-down" period.[16,43,78,103-106] Despite continuous efforts by hospitals to upgrade and improve their EMM systems, there is some evidence to suggest that system-related errors persist over time.[79,107] For example, one study showed that the risks associated with EMM systems continued with ongoing use, and that system-related errors were still present at least 2-years post-implementation.[104]

Although preliminary evidence suggests system-related errors persist, little is known about whether the errors that emerge immediately after the introduction of an EMM

system are the same as those that occur years after system implementation. A large US study surveyed 176 hospitals to determine the magnitude and significance of unintended consequences related to EMM systems.[107] The sites, which had introduced the EMM system between 6 months and 25 years prior, experienced eight types of unintended consequences, including new kinds of errors generated by the system. While the researchers concluded that there was no relationship between the types of unintended consequences and the length of EMM system use, the study did not compare the types of unintended consequences or new system-related errors across different sites. No research has investigated system-related errors between sites or over time to understand how these errors develop and evolve with long-term EMM system use. Additionally, research on system-related errors in Australia is still in its infancy due to the relatively recent adoption of EMM systems across the country.

The current research program aims to fill this research gap by investigating system-related errors over time within a health district. Our primary goal was to contribute significant knowledge to the understanding and advancement of EMM systems and system-related errors. Further, it was hoped that by identifying system-related errors that continue to persist or emerge later, actions can be taken to eliminate or reduce these errors, thereby facilitating effective medication management and providing later adopters of EMM systems the opportunity to pre-empt and prevent similar incidences.

AIMS OF THIS RESEARCH PROGRAM

The overall aim of this research program was to explore the short-term and long-term system-related errors associated with an EMM system, to understand the

causes and consequences of errors across time and determine strategies to mitigate error occurrence. The specific aims of this program of research were to:

1. Analyse and synthesise the existing literature on system-related errors, with a particular focus on research that specifies the length of time an EMM system has been in place, to determine what is currently known about short-, medium- and long-term system-related errors **(Chapter 2)**
2. Identify and classify the types of system-related errors reported to a district's incident management system, to determine the factors (i.e., EMM design, user or organisational factors) that contribute to these reported incidents and to explore how reports of system-related errors change over time **(Chapter 3)**
3. Explore key stakeholders' perceptions and experiences of system-related errors, including the types of errors that occur, the factors that contribute to errors and the consequences of these errors **(Chapter 4)**
4. Examine the detection and mitigation strategies adopted by a health district to target system-related errors, including existing and potential methods required to prevent future system-related errors from occurring **(Chapter 5)**
5. Describe and classify the types of enhancements made to an EMM system to target system-related errors, and examine how these changed over time **(Chapter 6)**

Schematic representation of the chapters in this research program

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Chapter 2: Narrative Review

Preface

Chapter 1 explained that implementing an EMM system can reduce medication errors, yet simultaneously introduce new system-related errors that were unlikely or not possible prior to system use. Research investigating system-related errors has largely focused on describing the error types and reporting the frequency with which errors occur. However, little is known about how system-related errors change and develop with ongoing EMM use, and no research has specifically evaluated system-related errors over time. Therefore, a narrative review was conducted to analyse and synthesise the current literature on system-related errors, with a specific focus on the length of time since EMM system implementation. By undertaking this review, we determined what is currently known about system-related errors in the short-, medium- and long-term, addressing the first aim of this research program.

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This statement describes the contribution made by Madaline Kinlay in the preparation and submission of the following manuscript: "*Medication errors related to computerized provider order entry systems in hospitals and how they change over time: A narrative review*". The convention is that the author with the principal contribution to the manuscript is the first author.

Madaline Kinlay, during her PhD candidature, developed the original concept of the review with her supervisors, and was responsible for conducting the literature review, independently reviewing articles, synthesising the data, drafting and revision of the manuscript, and coordinating submission for publication of the original research paper.

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Madaline Kinlay 28 June 2023

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statement above is correct.

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Melissa Baysari 28 June 2023

Title

Medication errors related to computerized provider order entry systems in hospitals and how they change over time: a narrative review

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Author contributions

MK was responsible for conducting the literature review, independently reviewing articles, synthesizing the data, drafting and revision of the manuscript. WYZ and MTB assisted in reviewing articles for inclusion, directly supervised the project and assisted in drafting the article. RB, IJ and RJM provided overall supervision to the

project and assisted in drafting the article. All authors read and approved the final article.

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ABSTRACT

Background

Evaluations of computerized provider order entry (CPOE) systems have revealed that reductions in certain types of medication errors occur simultaneously with the emergence of system-related errors – errors that are unlikely or not possible to occur with the use of paper-based medication charts. System-related errors appear to persist many years post-implementation of CPOE, although little is known about whether the types and rates of system-related errors that occur immediately following CPOE implementation are similar to those that endure or emerge after years of system use.

Objective

To analyze and synthesize the literature on system-related errors, specifically in relation to the length of time that CPOE systems have been in use, to determine what is currently known about how system-related errors change over time.

Methods

A literature search was undertaken using the PubMed database to identify English language articles published between January 2005 and March 2020 that provided original data on system-related errors resulting from CPOE system use. Studies were included if they provided results on system-related errors and information relating to the length of time that CPOE had been in use.

Results and discussion

Thirty-one studies met the inclusion criteria for this narrative review. System-related errors were identified and described during short, medium and long-term use of

CPOE systems, but no single study examined how errors changed over time. In comparing findings across studies, results suggest that system-related errors persist with long-term use of CPOE systems, although likely to occur at a reduced rate.

Conclusions

This review has highlighted a significant gap in knowledge on how system-related errors change over time. Determining what and when system-related errors occur and the system factors that contribute to their occurrence at different time points after CPOE implementation is necessary for the future prevention and mitigation of these errors.

Keywords

Computerized provider order entry; Medication error; Narrative review, System-related errors

INTRODUCTION

Over 20 years ago, a foundational paper by Bates et al. (1999) demonstrated that the introduction of computerized provider order entry (CPOE) systems led to a significant reduction in the rate of medication errors in hospitals.[1] This study collected data across four time periods; one pre-CPOE and three time points post-CPOE implementation, the last occurring four years post-implementation.[1] Patient chart review revealed that across this time period, medication errors (excluding missed-dose errors) reduced by 81% and rates of both preventable and non-preventable adverse drug events reduced by 28%.[1] Since this pioneering study, it has been repeatedly shown that the transition from paper-based medication management to CPOE is associated with reduced medication error rates.[2-6] Yet, evaluations of CPOE systems have also revealed that reductions in certain types of medication errors occur simultaneously with an increase in system-related errors; that is errors that are unlikely or not possible with the use of paper-based medication charts.[7-9]

What are system-related errors?

A seminal paper by Koppel (2005), the first to identify system-related errors, used both qualitative and quantitative methods to examine the extent to which CPOE facilitated medication errors.[9] This resulted in the identification of 22 medication error types enabled by the use of CPOE systems. Common issues included inflexible prescribing formats and fragmented CPOE displays, leading to incorrect orders, medication confusion and delays.[9] Koppel's findings ignited a surge of research into unintended consequences of CPOE systems, with numerous studies evaluating medication error rates pre- and post-implementation, and describing system-related

errors that emerged post-implementation, as well as quantifying their impact.[10-14] What these studies showed is that system-related errors appear to persist many years post-implementation, although little is known about whether the types and numbers of system-related errors that occur immediately following CPOE implementation are similar to those that endure, or emerge after years of system use.[10,15] Recent systematic reviews have outlined the types and prevalence of system-related errors, but none have explored how these errors change over time; that is how they evolve following the initial implementation of a CPOE system in a hospital.[16-18] Thus, this narrative review aimed to analyze and synthesize the literature on system-related errors, specifically in relation to the length of time that CPOE systems had been in use, to determine what is currently known about how system-related errors change over time.

METHODS

A search was undertaken using the PubMed database to identify English language articles published between January 2005 and March 2020 that provided original data on system-related errors resulting from CPOE system use. Search terms for CPOE ('computerized prescriber order entry' OR 'computerized provider order entry' OR 'electronic prescribing' OR 'electronic medication administration' OR 'electronic medication management') were combined with terms for error ('errors' OR 'unintended consequences'), and reference lists of included papers were also manually searched. As the purpose of this review was to assess system-related errors across time, papers were included only if their results described system-related errors (quantitatively or qualitatively) and papers provided information pertaining to the time that the CPOE system had been in use.

RESULTS AND DISCUSSION

Thirty-one original research papers were included in this review (see Table 1). Of these, 20 papers identified system-related errors using medication chart review. Other methods used included stakeholder interviews (n=8), observations (n=8) and questionnaires or surveys (n=4), in addition to the analysis of incident reports (n=6), pharmacy intervention logs (n=4), and key documents (n=4).

The following sections summarize system-related errors reported to occur with short, medium, and long-term use of CPOE systems.

Table 1: Studies evaluating system-related errors where time since CPOE system implementation is reported.

Timeframe of data collection since implementation	Study	Country	Hospital type and setting	Data source
Short-term				
0 - 3 months	Jheeta and Franklin, 2017[19]	UK	Teaching hospital Geriatric ward	Observations (nurses)
0 - 3 months	Armada et al., 2014[20]	Spain	Teaching hospital Cardiac intensive care unit	Medication charts
0 - 3 months	Whalen et al., 2018[21]	USA	General hospital Paediatric wards/beds	Voluntary incident reports

0 - 7 months	Spencer et al., 2005[22]	USA	Teaching hospital Two general medical wards	Voluntary incident reports Hospital discharge notes and medication doses (quality improvement data)
0 - 9 months	Shulman et al., 2005[23]	UK	Teaching hospital Intensive care unit	Medication charts
0 - 12 months	Rouayroux et al., 2019[24]	France	Teaching hospital Diabetology and cardiology departments	Pharmacy intervention logs
0 - 18 months	Lichtner et al., 2019[25]	Australia	Paediatric hospital Entire hospital	Voluntary incident reports

2 - 21 months	Magid et al., 2012[26]	USA	Specialty hospital (musculoskeletal and orthopaedic) Entire hospital	Medication charts
2.5 - 7 months	Westbrook et al., 2012[2]	Australia	Two teaching hospitals Hospital A: Geriatric ward Hospital B: Psychiatry and cardiology wards	Medication charts
3 - 12 months	Wetterneck et al., 2011[27]	USA	Teaching hospital Two intensive care units	Medication charts Pharmacy intervention logs Voluntary incident reports

				Questionnaires (physicians, physician assistants, and nurse practitioners)
3 - 12 months	Puaar and Franklin, 2018[28]	UK	Teaching hospital Twenty-four medical and surgical wards	Medication charts Semi-structured interviews (purposively sampled prescribers involved with a prescribing error)
3 - 12 months	Walsh et al., 2006[29]	USA	Teaching hospital Paediatric wards/beds	Medication charts (randomly selected inpatients)
4.5 months	Westbrook et al., 2013[30]	Australia	Two teaching hospitals	Medication charts

			Hospital A: Geriatric ward Hospital B: Psychiatry and cardiology wards	
5 - 8 months	Carayon et al., 2017[31]	USA	Teaching hospital Two intensive care units	Medication safety events
6 months	Donyai et al., 2008[32]	UK	Teaching hospital Surgery ward	Medication charts
6 - 12 months	Mozaffar et al., 2017[33]	UK	Five university hospitals, one general hospital	Semi-structured interviews (clinical staff and implementation teams)

				Observations (implementation meetings and system use) Documents (project plans, risk logs and business cases)
6 - 24 months	Savage et al., 2010[13]	UK	General hospital Medical, surgical and paediatric wards	Medication charts Semi-structured interviews (users and inpatients)
8 months	Wentzer et al., 2007[34]	Denmark	General hospital Two internal medical wards	Medication charts Pharmacy intervention logs Voluntary incident

				reports Questionnaire (users)
10 months	Colpaert et al., 2006[35]	Belgium	Teaching hospital Surgical intensive care unit	Medication charts
16 - 18 months	Mills et al., 2017[36]	UK	General hospital Entire hospital excluding mental health, maternity and paediatric wards	Medication charts Case notes and discharge letters
Medium-term				
2 - 3 years	Cresswell et al., 2014[37]	UK	Two hospitals	Semi-structured interviews (users and

				other stakeholders) Observations (strategic meetings and system use) Documents (implementation plans)
2 - 3 years	Estellat et al., 2007[38]	France	Teaching hospital Two surgical and eight medical wards	Medication charts
3 years	Villamañán et al., 2013[39]	Spain	Teaching hospital Entire hospital	Medication charts
4 years	Howlett et al., 2018[40]	Ireland	Paediatric hospital Intensive care unit	Voluntary incident reports

				Pharmacy intervention logs
Long-term				
5 - 7 years	Koppel et al., 2005[9]	USA	Teaching hospital	Surveys (clinicians) Structured interviews and focus groups (clinicians and other stakeholders) Observations (users)
6 years	Velez-Diaz- Pallares et al., 2017[41]	Spain	General hospital Geriatric internal medicine, general	Medication charts

			surgery and vascular surgery departments	
6 - 8 years	Slight et al., 2019[42]	UK	Teaching hospital Renal, cardiology, general medical and orthopaedic surgical wards	Medication charts
10 years	Khajouei et al., 2011[43]	Netherlands	Teaching hospital	Questionnaire (users)
11 - 12 years	Kadmon et al., 2017[44]	Israel	Teaching hospital Paediatric intensive care unit	Medication charts

Multiple				
1 - 4 years	Simon et al., 2013[45]		Five general hospitals	Semi-structured interviews (clinicians and other stakeholders) Observations (care processes)
1 - 30 years	Campbell et al., 2006[10]	USA	Four teaching hospitals, one general hospital	Semi-structured interviews (observed users and other stakeholders) Observations (users) Conference discussions

*Timeframe determined by the first implementation of CPOE until the end of research.

Short-term use of CPOE systems and system-related errors

To date, system-related errors have largely been explored as a by-product of evaluating medication error rates before and after the implementation of a CPOE system.[19,25] As a result, most system-related errors reported in the literature are identified in the first two years following implementation of a computerized system (see Table 1). Focusing on the period immediately following implementation, although important, is likely to lead to the identification of errors resulting from initial technological resistance by users and unfamiliarity with the system; errors that may not persist over time.[46,47]

The range and prevalence of CPOE-related errors occurring immediately following system implementation varied considerably across studies. Although similar broad types of errors were reported, including wrong order information (e.g. wrong drug, dose or route etc.) and medication omissions and duplications, there appeared to be inconsistencies in the specific types that were identified. For example, in an Australian study conducted in two hospitals using two different CPOE systems, 12 types of system-related medication errors were found, accounting for 34.8% of all prescribing errors occurring at the hospitals.[2] However, wrong route errors accounted for the largest proportion of system-related errors in one hospital (22.7%), while this error type was rarely found in the other hospital (<0.1%). The authors attributed this disparity to the inclusion of different features in each CPOE system, such as clinical decision support that auto-completed the route of administration. Differences in rates and presentation of system-related errors across studies can also be attributed to differences in the definitions used, with some studies defining system-related errors as medication errors not possible on paper,[20,32,39] and others

defining system-related errors as errors that were possible on paper, but related to CPOE functionality or design.[2,22,31]

Although types of system-related errors reported differ between studies, similar factors contributing to the emergence of system-related errors have been identified. Frequently reported contributing factors include paper-computer incompatibility, inflexible displays and default settings, and inappropriate use of the system.[16] As many hospitals transition to CPOE systems gradually, errors can emerge as a consequence of using a paper-computer hybrid system.[14] For example, as part of an initial CPOE implementation in a geriatric ward, before widespread adoption of the system, researchers reported that drug omissions occurred when transcribing from paper to the CPOE system.[19] The authors recommended minimizing the use of hybrid paper-computer environments during gradual phasing to CPOE, to avoid transcribing errors from occurring. The rigidity of the CPOE system has also been shown to lead to medication errors, in particular, the system's inability to replicate paper-based prescribing practices.[13,34] For example, a study showed that duplicate drugs were ordered because of difficulties clicking between screens to view current prescriptions.[24,27] Furthermore, a review of pediatric patient charts revealed that the same medication was ordered twice to achieve a desired dose because the CPOE system did not permit the drug to be prescribed at a certain dose.[29] Such constraints can encourage users to create workarounds, such as double ordering, which increases the risk of medication errors.

Medication selection errors and data entry errors are frequent sources of error during early CPOE use. [13,29,33,36] In a large UK qualitative study, concerns about incorrect data entry were raised during semi-structured interviews with clinicians and

implementation teams from six hospitals, providing a rich understanding of common concerns and errors related to the CPOE system.[33] Observations of implementation meetings and system use confirmed that errors arose from the entry and selection of wrong data, either from inflexible pre-populated options or the use of free-text fields with confusing instructions. Drop-down menus were not only time consuming, but also susceptible to miss-selection, either by unintentional scrolling or misreading order details, such as drug dosage. Another UK study showed that drop-down menus with pre-selected default suggestions were prone to generating errors.[28] Purposive interviews with clinicians involved in prescribing errors revealed that prescribers relied heavily on the default option as the correct option.

Medium-term use of CPOE systems and system-related errors

Described as the "medium-term consequences" of CPOE,[37] system-related errors that occur between two and five years after CPOE system implementation are less understood. The limited studies that have examined this time period were all conducted in Europe, with the largest of these employing a case study approach to identify the medium term consequences of CPOE at two UK hospitals.[37] In this study, interviews conducted with clinicians two years post-implementation revealed that the system-related errors identified soon after implementation, such as difficulties viewing current prescriptions, continued to concern users.[27] In one example, a ceased drug was not clearly displayed on a patient's medication chart, leading to a potential drug administration error.[37]

In a study conducted at a 1400-bed hospital in Spain, three years after CPOE implementation, 78% of medication errors identified via medication chart review in a 4-week period were deemed to be system-related, errors that could not have

occurred with manual prescribing.[39] Selection errors were the most common, accounting for 21% of all CPOE-related medication errors. However, it is unclear how system-related errors were determined, as it is challenging to ascertain if errors are CPOE-related using chart review, in the absence of complimentary methods like system-walkthroughs or user interviews. Another study used prospective chart review by pharmacists to identify prescribing errors.[38] Errors were then taken to an independent committee to determine if they were CPOE-related. Of the 95 prescribing errors identified, 49% were judged to be CPOE-related by the committee. The researchers attributed most of these errors to issues with the human-machine interface, including difficulties with modifying and viewing information when prescribing. Similarly, a review of voluntary incident reports at an Irish pediatric intensive care unit (ICU) found that a frequently reported cause of system-related errors included modifying an existing order which led to a new order being generated, increasing the possibility that a duplicate or incorrect medication was prescribed.[40] These cases demonstrate that during medium-term use, factors reported to have contributed to system-related errors are similar to those identified immediately post-implementation, including difficulties with selecting prescriptions, and inflexible system designs and functionalities. Importantly, these types of issues appear to persist several years after CPOE implementation.

As highlighted by studies that investigated the short-[28,30] and medium-term[40] use of CPOE systems, default settings continued to be problematic. For example, in a study which evaluated a commercial system for critical care and anesthesia wards, a multidisciplinary panel agreed that default settings led to system-related errors, particularly incorrect formulations.[40] In another study in an acute care hospital in France, the default unit of prescription was prone to manifesting in either route or

unit errors.[38] For example, the default setting was '1 international unit' and although one syringe was required, the default unit was not amended to syringe. With various CPOE systems defaulting to predefined selections and restricting the range of prescribing choices, clinicians work around these problems by entering prescribing information or instructions into free-text fields. However, this workaround can lead to errors and confusion, as information documented in free-text fields can be incongruent with information included in the remainder of the prescription (i.e. in pre-populated fields).[39,40] For example, a clinician may be forced to select a medication at a dose of 200mg as this is the only option available using the predefined choices, and then 'give 300mg' is written in the free-text field to overcome this restriction.

Errors associated with using hybrid paper-computer systems become less prevalent in the medium term. For example, one study determined that only 3% of drug omissions were due to handwritten prescriptions on patient charts, three years post-CPOE implementation.[39] Interestingly, while errors associated with the concurrent use of paper and computer systems become less frequent with longer use, errors related to poor integration of CPOE systems with other technology, such as electronic medical records, appear to become more frequent.[37]

Long-term use of CPOE systems and system-related errors

Only a small number of studies have explored how rates and types of system-related errors are affected by long-term (>5 years) use of a CPOE system, and inconsistent findings are reported. Ash and colleagues performed a large-scale mixed-methods program of work focusing on the implementation and subsequent unintended consequences of CPOE; evaluating various sites with CPOE systems for different lengths of time, including long-term use.[7,12,48-53] In one study involving three

hospitals, physician perspectives and experiences of computerized prescribing were explored utilizing observations, interviews, and focus groups.[49] Even though the sites had CPOE in place for different time periods, the research did not focus on time since implementation and did not compare errors across sites. However, the authors did suggest that it took ten years for physicians to fully accept the systems.

In a recent Spanish study in which 117 medication charts were reviewed six years after CPOE system implementation, 4% of prescribing errors were found to be system-related.[41] This rate is lower than that reported in earlier evaluations of CPOE (i.e. 21 - 42%[2,20,30,32]), although it is challenging to compare rates across studies due to variations in study methods and definitions.[2,39] Interestingly, most (96%) of CPOE-related errors related to human-computer interaction whilst only 4% were categorized as purely technical (e.g. software malfunctions). This is not unexpected, as most system malfunctions would have been identified and rectified during early use. System-related errors relating to human-computer interaction in this research were expressed as 'unclear orders' (49%), resulting from the incorrect use of interfaces or free-text fields, with unclear or contradictory information.[41] For example, pop-up windows requiring prescribers to select the days of the week that a drug should be administered were incorrectly used.

In a study in the pediatric ICU setting, rates of prescribing errors, including system-related prescribing errors, were measured three, 11 and 12 years after CPOE was introduced.[44] At 11-years post-CPOE, 58% of prescribing errors were identified to be system-related, and at the 12-year follow up, this had reduced by 16%. System updates during this one-year period, such as the introduction of clinical decision support and changes to default settings, were likely responsible for this error

reduction. Although a high rate of system-related errors was still present at 12 years, the pediatric ICU setting is prone to higher rates of medication errors than general wards[54] and the reported percentages could be misleading due to the small number of errors found (n=52).[44] Since system-related errors were not measured at the three-year timepoint, differences between short-term and long-term system-related errors were not examined.

Overview: how do system-related errors change over time?

We found no studies that compared system-related errors associated with short-, medium- and long-term use of CPOE systems. In fact, many studies failed to specify a timeframe since CPOE implementation. Current examination of the reported rates and types of system-related errors in studies with a specified timeframe since implementation suggests that system-related errors persist with long-term use of a CPOE system, although likely to occur at a reduced rate. Interestingly, comparable system-related errors have been described at each timepoint, with similar underlying factors. Table 2 illustrates the main error types that emerged across timeframes, although it is important to note that these types may not be exhaustive, as error classifications varied between papers and methods used did not always give a clear indication of error frequency. Yet, incorrect order information, medication omissions and duplications have been repeatedly cited in the literature, regardless of how long CPOE systems have been in place. Specific system factors, including display layouts, default settings, restricted and automated options, in addition to clinical decision support capabilities, continue to contribute to errors (see Table 3). Overall, a lack of information presented, system misuse and CPOE design flaws are common contributing factors to system-related errors. Although CPOE systems have evolved rapidly over the years, with improved functionality and design,[55] newer designs are

not without faults.[5,46,56] The reduced rate of system-related errors observed in one study following long-term use of CPOE likely reflects users becoming accustomed to, or working around CPOE system limitations, although further work is needed to explore this in-depth. While the concurrent use of paper and CPOE can lead to system-related errors, not surprisingly, this contributing factor is abating as CPOE implementation becomes more widespread across hospitals and the use of paper is eliminated. However, as this type of error dissipates, new errors are likely to emerge from the limited interoperability between CPOE and other electronic systems, such as pharmacy dispensing systems.[37,57]

Table 2: Main error types associated with the short-, medium- and long-term use of CPOE.

	Short term	Medium term	Long term
Main error types			
Error in component of an order (e.g. wrong dose)	x	x	x
Order duplicated	x	x	x
Order omitted	x	x	x
Incongruous component of order (e.g. free text includes conflicting information to template order)	x	x	x
Incomplete order (e.g. omission of order duration)	x	x	

Wrong patient	x		

Table 3: Main factors reported to contribute to system-related errors with the short-, medium- and long-term use of CPOE.

	Short term	Medium term	Long term
Main system factors			
Inflexible ordering processes (e.g. system does not support ordering variable dosage regimens)	x	x	x
Poor display of information (e.g. patient's complete medications not visible on one screen)	x	x	x
Inconsistent and poorly configured CDS	x	x	x
Software issue (e.g. system shutdown during maintenance, slow loading screens)	x	x	x
Lack of integration between CPOE and other electronic systems (e.g. information not transferring to pharmacy system)	x	x	x

Default settings (e.g. calendar defaulting to next day administration)	x	x	x
Use of hybrid CPOE and paper systems (e.g. information on paper charts not transcribed to CPOE)	x	x	
Main user factors			
Inappropriate use of the system (e.g. free text used instead of an order sentence)	x	x	x
Selection errors	x	x	x
Typographic errors	x	x	x
Overdependence on system (e.g. failure to check default time of administration)	x	x	

CDS, Clinical Decision Support; CPOE, Computerized Provider Order Entry

Limitations

This review is limited by the narrative approach taken and the use of only one database. Thus, selected papers may not be exhaustive of all studies undertaken on system-related errors. Further, no formal assessment of the heterogeneity or quality of the literature was undertaken. However, the intention of this review was not to be systematic, but to provide a novel overview of system-related errors in the context of

time spent using CPOE systems in order to inform implementation and ongoing use and monitoring of CPOE systems.

CONCLUSIONS

This review has highlighted a significant gap in evidence on how system-related errors change over time. No study to date has examined the same CPOE system or setting longitudinally and compared error types across various time-points. This review sought to ascertain how system-related errors change and evolve with ongoing CPOE use, however there was insufficient data available in the current literature to answer this question. Determining what medication errors occur and the system factors that contribute to their occurrence at different time points after CPOE implementation is necessary for the future prevention and mitigation of CPOE-related errors. Examining system and organizational changes adopted in response to the identification of system-related errors is also valuable for ensuring the safety benefits that are expected following CPOE system implementation are achieved and maintained over time. As CPOE systems become more widespread, and their use increases, we encourage researchers and clinicians to tackle this important area of patient safety.

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Chapter 3: Analysis of Incident Reports

Preface

The narrative review analysed and summarised the current evidence base on system-related errors during the short-, medium- and long-term use of EMM systems. Results from the 31 original research papers included in the review indicated that system-related errors persisted with long-term EMM system use. Similar types of system-related errors were described at each timepoint, including medication omissions. Additionally, certain contributing system factors appeared repeatedly in the literature, irrespective of time since EMM system implementation, such as default settings and restricted options. However, we identified no single study that examined system-related errors over time. Therefore, in this chapter, to fill this evidence gap, incidents reported at three hospitals in a single health district in Sydney Australia were analysed to identify and classify system-related error types and determine the factors (i.e., EMM design, user or organisational factors) that contributed to reported incidents. Further, we explored how reports of system-related errors changed over time.

The manuscript focused on the analysis of incident reports is currently under review at the *Journal of Patient Safety.* Details are as follows:

Manuscript under review

Kinlay M, Zheng WY, Burke R, Juraskova I, Ho LMR, Turton H, Trinh J, Baysari M. An analysis of incident reports related to electronic medication management: How they change over time. *J Patient Saf*. 2023 – under review

Authorship attribution statement

This statement describes the contribution made by Madaline Kinlay in the preparation and submission of the following manuscript: “An analysis of incident reports related to electronic medication management: How they change over time”. The convention is that the author with the principal contribution to the manuscript is the first author.

Madaline Kinlay, during her PhD candidature, developed the original concept of the study with her supervisors, and was responsible for collecting and de-identifying the data, analysing the data with the assistance of her co-authors, drafting and revision of the manuscript, and coordinating submission for publication of the original research paper.

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Madaline Kinlay 28 June 2023

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statement above is correct.

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Melissa Baysari 28 June 2023

Title

An analysis of incident reports related to electronic medication management: How they change over time

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Declaration of interest

No conflicting interests to declare.

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ABSTRACT

Objective

Electronic medication management (EMM) systems have been shown to introduce new patient safety risks not possible, or unlikely to occur with the use of paper charts. Our aim was to examine the factors that contribute to EMM-related incidents and how these incidents change over time with ongoing EMM use.

Methods

Incidents reported at three hospitals between 1 January 2010 and 31 December 2019 were extracted using a keyword search and then screened to identify EMM-related reports. Data contained in EMM-related incident reports were then classified as unsafe acts made by users and the latent conditions contributing to each incident.

Results

In our sample, 444 incident reports were determined to be EMM-related. Commission errors were the most frequent unsafe act reported by users (n=298), while workarounds were reported in only 13 reports. User latent conditions (n=207) were described in the highest number of incident reports, followed by conditions related to the organisation (n=200) and EMM design (n=184). Over time, user unfamiliarity with the system remained a key contributor to reported incidents. Although fewer paper to electronic transfer errors were reported over time, incident reports related to the transfer of information between different computerised systems increased as hospitals adopted more clinical information systems.

Conclusion

EMM-related incidents continue to occur years after EMM implementation, and are driven by design, user and organisational conditions. Although factors contribute to reported incidents in varying degrees over time, some factors are persistent, and highlight the importance of continuously improving the EMM system and its use.

Abstract word count

249

Keywords

Electronic medication management, patient safety, medication error, workflow

INTRODUCTION

Digital solutions have proliferated in a range of industries, and healthcare is no exception. A key example is the shift from paper medication charts to electronic medication management (EMM) systems in hospitals. EMM systems allow clinicians to prescribe, review and administer medications via a digital platform. This change has been associated with significant patient safety benefits, including reductions in medication errors.[1-3]

While beneficial, EMM has also been shown to introduce new patient safety risks that were not possible, or highly unlikely to occur, prior to system introduction. For example, a doctor typing a word segment (e.g. morph) and generating morphine and hydromorphone, resulting in a potential mis-selection of a medication. Although these incidents are known to occur, we know less about the factors or conditions that contribute to their occurrence.

Despite the well-known limitations of safety incident reports,[4,5] particularly underreporting of events and inadequate detail included in incident descriptions, incident reports can provide insight into the types of issues or concerns that hospital staff encounter, including those related to EMM. A recent study examined 1508 medication-related safety reports associated with the use of health information technology, including EMM, and found that 97% of reports described a usability issue, including difficulties in data entry, concerns with workflow and alerts, and inappropriate system defaults and automation.[6] Additional risks identified through EMM-related incident analysis included limitations or errors in the visual display of information [7-10], the use of hybrid (i.e. paper and electronic) and dual electronic systems,[11,12] and insufficient training of users.[13,14]

This research provides us with useful insights on how and why EMM-related incidents occur, but no research to date has examined how reported incidents change over time with ongoing EMM use and continuous improvement of an EMM system.[15] The aim of this study was to examine the types of EMM-related incidents reported in hospitals, to understand the factors that contribute to these incidents, and importantly, to explore how these reports change across time.

METHODS

Setting and electronic medication management system implementation

Incident reports from three hospitals with the same EMM (Cerner Millennium®, Kansas City, Missouri, United States) in a Local Health District in NSW, Australia, were analysed. At the time of data collection, the EMM system had been in place for different time periods at each hospital (see Figure 1). Across the time period, a number of changes were made to enhance the EMM system[16] and as a result, the EMM implemented in Hospital B and C was a more advanced and mature system than in Hospital A. Although we aimed to explore the factors that contributed to reported incidents, examining the impact of each EMM enhancement on incident reports was out of scope for this project.

This study was approved by the local health districts' Human Research Ethics Committee (HREC reference number: 2020/ETH00198)

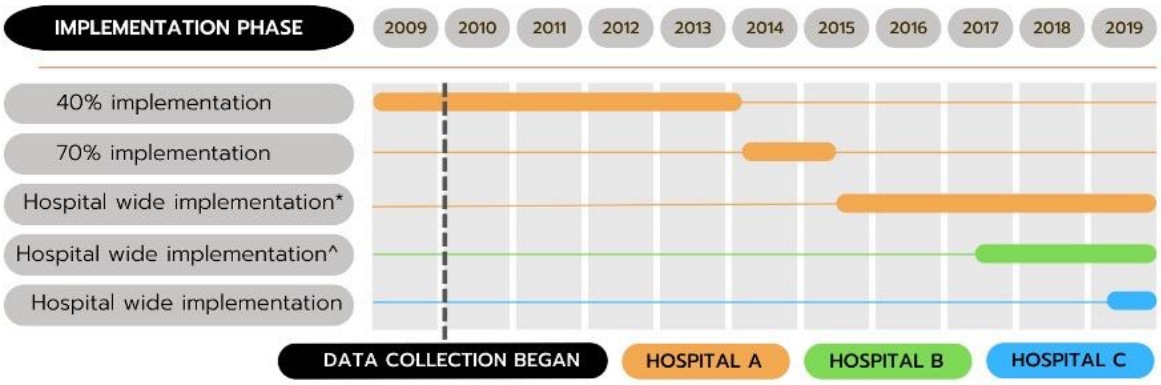

Figure 1: Gantt chart illustrating hospitals' implementation of electronic medication management across time. *Excluding Intensive Care Unit, ^A different electronic medication management system was in use in the Intensive Care Unit

Study design and data collection

A retrospective analysis was performed of EMM-related incidents reported at the three hospitals between 1 January 2010 and 31 December 2019. In this study, EMM-related incidents were defined as incidents where it was clear that the EMM was involved (e.g. user selected the wrong item from a drop-down menu). Incident reports were extracted in January 2021 from the district's Health Incident Information Management System (IIMS), the state-wide online database that allows clinicians to voluntarily record clinical, work health and safety, and security events that occur in hospitals. Incidents were initially identified using a free-text keyword search (see Figure 2) adapted from a previous study of EMM-related safety reports.[17]

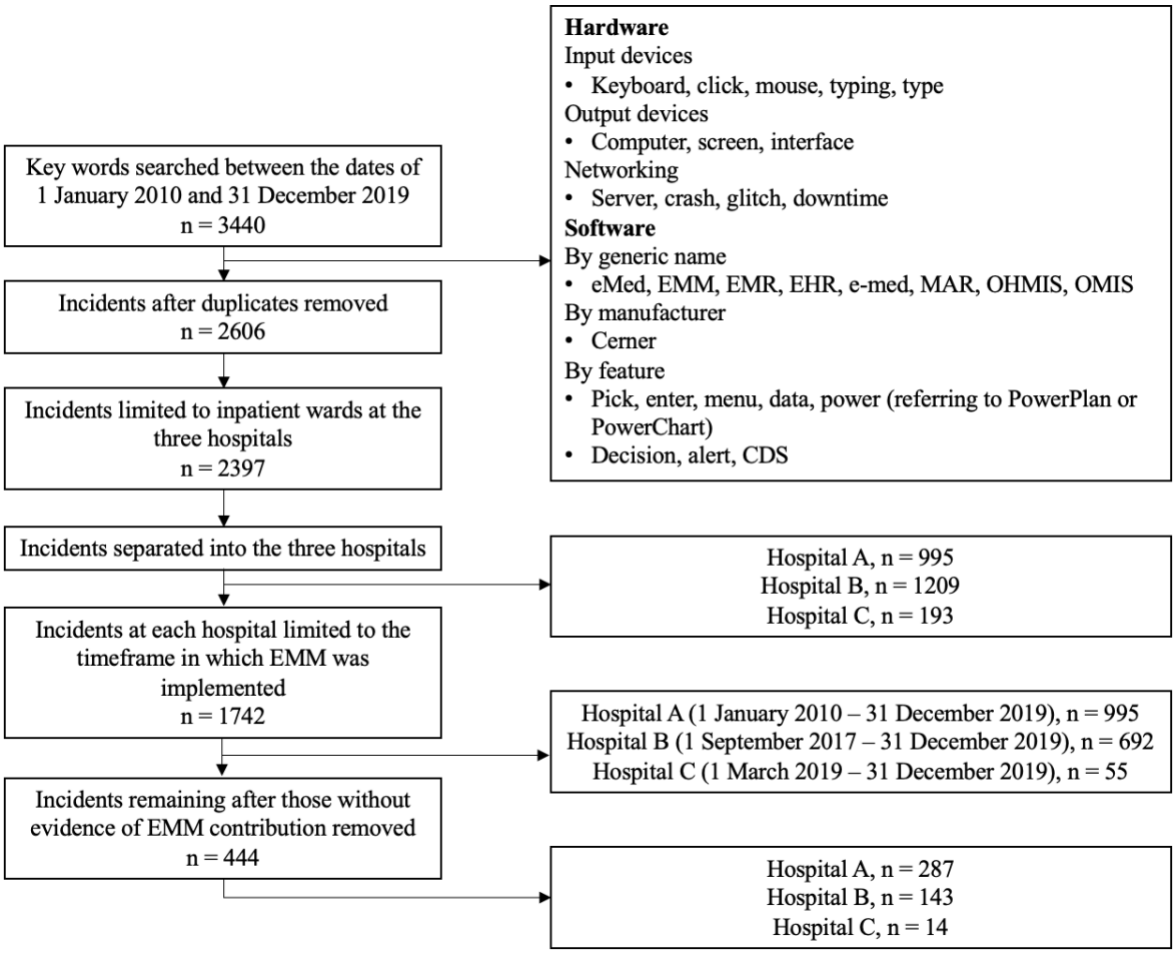

Figure 2: Flowchart depicting the process of selecting incident reports for inclusion.

Incident identification

The incident report identification process is depicted in Figure 2. Extracted incident reports were de-identified and exported into a Microsoft Excel file and duplicates were removed using the unique ‘Incident ID’. Incident reports were then limited to inpatient wards at the three hospitals and the time-period in which the EMM system had been implemented at each hospital. The remaining incident reports were subsequently screened by at least two members of the research team to determine which incidents were EMM-related. EMM-related incidents were those where it was clear to researchers, based on the incident description, that the EMM was involved,

and the incident was unlikely to have occurred if a paper medication chart was in use.

Classification selection and development

Researchers reviewed several existing incident classifications (i.e. Magrabi et al.[17], Schiff et al.[11], Amato et al.[18], Van de Vreede et al.[14], Lichtner et al.[7], Iqbal et al.[8]), and determined that categories were either too specific to enable reported incidents to be classified (given the level of detail in reports), or too broad to capture the range of contributory factors reported in incidents. Therefore, a classification based on our prior qualitative research investigating EMM-related errors in this setting,[19] was used and iteratively modified as analysis progressed. This classification, modelled on Reason's accident analysis approach,[20,21] views incidents in terms of the *unsafe acts* taken by users (i.e. omission errors, commission errors and workarounds) and the *latent conditions* that contributed to the incidents (i.e. EMM system design, user conditions and organisational conditions; see Appendix A in the Supplementary Material).

Incident classification

Three researchers (MK, MB and WYZ) with expertise in psychology, human factors, and EMM, classified the EMM-related incident reports with respect to the unsafe act that had occurred and the latent conditions that had contributed to each incident. Each incident report could describe multiple unsafe acts and latent conditions. Each incident report was independently classified by at least two researchers, who then came together to discuss and resolve any discrepancies in coding.

Analysis

The results were presented by tallying the number of reports grouped into each respective category and transforming each count into a percentage of the total number of incident reports. In order to examine incident classifications over time and across different hospitals, the reported incidents were stratified by the year they occurred and the hospital in which they took place. Narrative results are presented separately for Hospital A, as this site acted as the state's pilot site, so unlike Hospital B and C, implemented the EMM system in stages (Figure 1).

RESULTS

Summary of incidents

As shown in Figure 2, 444 incident reports in the sample were determined to be EMM-related. Of these, incidents were most frequently classified as errors of commission, followed by errors of omission (see Table 1). Fourteen incident reports described two unsafe acts, and 34 incident reports described latent conditions without detailing an unsafe act that had occurred.

Table 1: Number of incident reports describing unsafe acts.

Unsafe act	Number of incidents (% of total incidents)
Error of commission	288 (65%)
Error of omission	99 (22%)
Workaround	9 (2%)
Error of commission and omission	10 (2%)

Error of commission and workaround	4 (1%)
None identified	34 (8%)
Total	444

There were 694 latent conditions described within the 444 incident reports. Each incident report described between zero and six latent conditions, with incidents most often describing one or two latent conditions (83% of incident reports). In the sample, latent conditions relating to the users, EMM system and organisation were described in a similar proportion of reports (41% – 47%; see Table 2).

Table 2: Number of incident reports describing each latent condition and the most frequently reported latent conditions.

Latent condition	Number and percentage of total incident reports (N = 444)	Most frequent latent condition subcategories	Number of incident reports
EMM design	184 (41%)*	• Sub-optimal display of information	43
		• Current configuration does not support work, is complex or inflexible	41

		• Error in the EMM	27
		• Failure of the EMM to encourage policy adoption	25
		• Additional tasks required by EMM	23
User condition	207 (47%)	• Misunderstanding or unfamiliarity with EMM or workflow	112
		• Communication breakdown external to EMM	55
		• Time poor or stressed	27
		• Unsafe acts by other users	24
		• Overreliance on the EMM	22
Organisational condition	200 (45%)	• Inadequate training or education	99
		• Simultaneous use of paper and EMM system	45

		• Transfer of information between paper and EMM system	41
		• Complexity of workflow	18
		• Transfer of information between the EMM and another electronic system	16

*Incident reports could describe multiple latent conditions and therefore percentages do not total to 100%. EMM = Electronic Medication Management

Staged rollout of the electronic medication management system at Hospital A

During the first four years of data collection, when only 40% of Hospital A used an EMM system, all unsafe acts were reported as errors (i.e. commission and omission errors), and there were no workarounds described in incident reports (Table 1B in Appendix B in the Supplementary Material). It was only 7 years after the EMM implementation (2 years post hospital-wide implementation) that workarounds appeared in incident descriptions.

With respect to latent conditions, in incidents reported during the first year of EMM implementation at Hospital A, the largest proportion of latent conditions were related to the organisation (60% of latent conditions), with all incident reports describing at least one organisational factor (see Table 1C and 2C in Appendix C in the Supplementary Material). Of these, the most frequent category was the transfer of information between paper medication charts and the EMM. In the following year (i.e.

second year of 40% EMM implementation), a high proportion of latent conditions related to the EMM design (78% of latent conditions in this year related to the EMM design), although this was more variable in the years that followed.

The most frequently identified latent conditions in reports five years after initial implementation (i.e. 70% EMM implementation) were ‘misunderstanding or unfamiliarity with EMM or workflow’ (57% of incident reports), ‘inadequate training or education’ (36%) and ‘error in the EMM’ (29%). All other latent conditions were described in two or fewer incident reports during 70% EMM implementation.

Hospital wide implementation of the electronic medication management systems

Incident reports describing EMM workarounds were reported at Hospital A and B after hospital-wide implementation but were not reported at Hospital C (see Appendix B in the Supplementary Material).

Figure 3 presents the proportion of latent conditions that were classified into each category of latent condition (i.e. EMM design, user condition, organisational condition) across time at each hospital. During the first year of hospital-wide implementation, user-related latent conditions comprised the highest proportion of those described in incident reports across all three hospitals (see Figure 3). Reported incidents at Hospital A in the second year following hospital-wide EMM implementation most frequently involved conditions related to the organisation, while at Hospital B user conditions were the most common. EMM design was the least frequently reported condition across both hospitals during this year. In the third year, the spread of latent conditions (i.e. EMM design, user conditions and organisational conditions) appeared similar between Hospitals A and B.

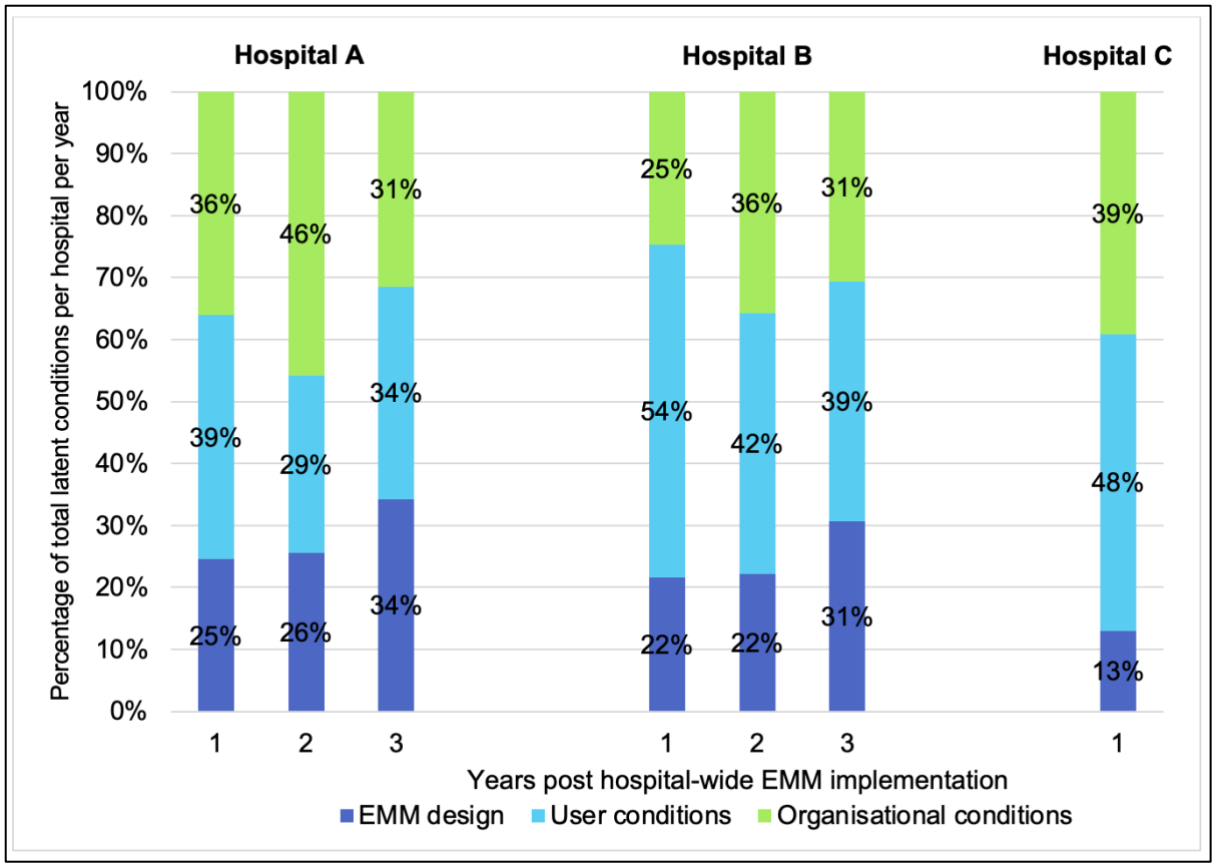

Figure 3: Proportion of latent conditions described in incident reports that related to users, the organisation and electronic medication management design during the first three years of hospital-wide electronic medication management implementation. Note that Hospital C only had the electronic medication management system in place for one year at the time of data collection.

Figure 4 shows the percentage of incident reports that contained latent conditions at each hospital across time. Although small, the percentage of incident reports describing EMM design appeared to increase in Hospital A across the three years of hospital-wide implementation. In contrast, at Hospital B, the number of incident reports involving latent conditions related to the EMM design clearly decreased across the three years. Latent conditions related to the EMM design were only present in 21% of incident reports at Hospital C, while both user and organisational conditions were described in 64% of incident reports.

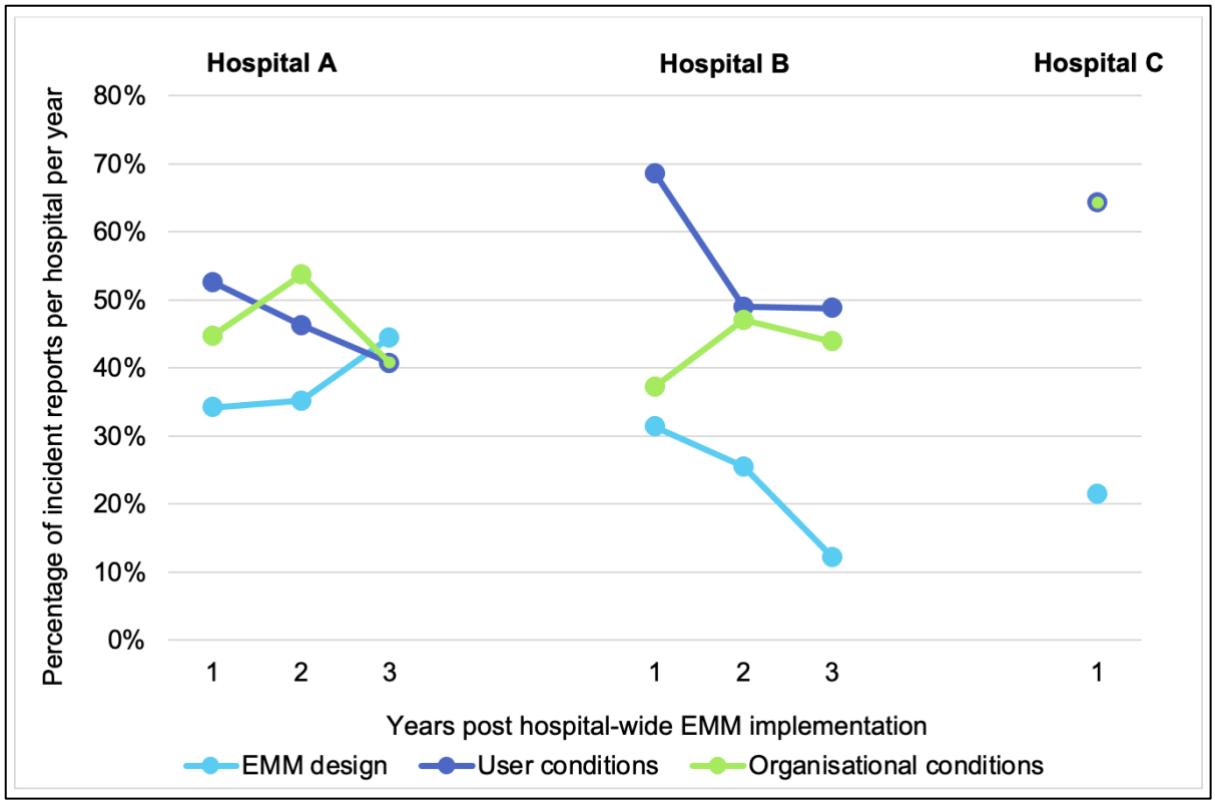

Figure 4: Percentage of incident reports per year that included conditions related to users, the organisation and electronic medication management design during the first three years of hospital wide electronic medication management implementation. Note that Hospital C only had the electronic medication management system in place for one year at the time of data collection.

User conditions were present in a large percentage of incident reports at Hospital B in the first year of EMM implementation (69%), however this decreased and remained stable for the following two years. At Hospital A, the presence of user conditions in incident reports decreased gradually over the first three years of hospital-wide EMM implementation. Organisational latent conditions fluctuated amongst incident reports at both Hospital A and B. See Appendix D in the Supplementary Material for the most frequent latent conditions described in incident reports during the first three years of EMM implementation at each hospital.

Electronic medication management design across time

'Sub-optimal display of information' was the most frequent EMM-related latent condition at Hospital A, appearing in 10% of total incidents reported. The proportion of incident reports each year with this condition ranged from 5 – 16%. At Hospital B, this latent condition was most prevalent in the first year of EMM implementation and then reduced in the following two years. The most frequently reported EMM-related latent condition at Hospital B overall was 'current configuration does not support work, is complex or inflexible' (14% of total incidents reported). Incident reports at Hospital A also described this latent condition across time, although lower in prevalence.

Incident reports classified with 'error in the EMM' emerged at Hospital A during the second year of 40% EMM implementation. The highest proportion of incident reports describing this latent condition occurred in the fourth year of EMM implementation (50% of incidents reported during this year), and then reduced over time to 3% of incidents reported in the fifth-year following hospital-wide implementation of EMM (i.e. 10 years following initial implementation). Although low in number, incident reports describing this latent condition emerged at Hospital B (3% of incidents reported) and were also identified in reports at Hospital C (7%).

'Failure of EMM to encourage policy adoption' was rarely described in incident reports at Hospital A until four years after hospital-wide implementation of EMM, at which point 19% of incidents reported described this condition. This latent condition was uncommon at Hospital B and did not appear in incident reports at Hospital C.

User conditions across time

‘Misunderstanding or unfamiliarity with EMM or workflow’ represented the highest percentage of user-related latent conditions at all three hospitals (A: 21%, B: 31% and C: 57% of total incident reports). Incident reports describing this classification fluctuated across time at Hospital A, and although most common in the second and fourth year of partial EMM implementation (i.e. 40% and 70% EMM implementation; 67%, and 57% respectively), this latent condition continued to contribute to 25% of incident reports in the fifth year of hospital-wide implementation. At Hospital B, 59% of incidents reported in the first year of EMM implementation described ‘misunderstanding or unfamiliarity with EMM or workflow’, and this latent condition remained a leading contributing factor in incident reports across time.

The user-related condition ‘communication breakdown external to EMM’ was also described in incident reports at Hospital A and B (A: 11% and B: 15% of total incident reports). Frequency of reporting of this classification fluctuated over time at Hospital A. At Hospital B, incident reports describing this user-related condition were highest in the first two years, and then subsequently decreased in frequency. The user-related latent condition ‘time poor or stressed’ made up a large proportion of user conditions described in reported incidents at Hospital B, however this was not the case at the other two hospitals.

Organisational conditions across time

The most frequent organisational condition described in incident reports at the three hospitals was ‘inadequate training or education’ (A; 21%, B: 21% and C: 64% of incident reports). This condition was the sole organisational condition identified in incident reports at Hospital C and was consistently described in reports at Hospital A and B (A: 11% – 67% and B: 20% – 24% of incident reports per year).

At Hospital A and B, the ‘simultaneous use of paper and EMM’ contributed to incidents across time, and this condition was still present in reports in the fifth year of hospital-wide EMM implementation at Hospital A (16% of incidents reported in this year) and the third year at Hospital B (17% of incidents reported in this year). A high proportion of incident reports at Hospital A related to the ‘transfer of information between paper and the EMM’, particularly during the first two years of hospital wide EMM implementation (18% and 33% of incidents reported per year), after which they reduced in number. Incident reports describing this organisational condition were infrequent at Hospital B (2% of incident reports). The ‘transfer of information between the EMM and other electronic systems’ emerged amongst incident reports following two years of hospital-wide EMM implementation at both hospitals, although low in number. Incident reports at Hospital C did not describe the involvement of the simultaneous use of paper and EMM, the transfer of information between paper and the EMM, or transfer between the EMM and other electronic systems.

DISCUSSION

This study analysed incident reports to explore how incidents associated with EMM use changed over time. Based on the incidents reported, commission errors were the most frequent unsafe act reported by users, while workarounds were infrequent. Each hospital demonstrated a unique combination of latent conditions contributing to reported incidents, however overall, user conditions were present in the highest number of incident reports, followed by conditions related to the organisation and EMM design.

Misunderstanding or unfamiliarity with EMM or workflow was the most frequent user-related latent condition at all three hospitals and persisted across time. Similarly,

inadequate training or education remained present in incident reports at all hospitals, irrespective of time following implementation, and represented the highest proportion of organisational conditions reported. The persistence of these factors challenges the notion that incidents related to unfamiliarity with an EMM and EMM-training needs will reduce once initial inexperience with the system is overcome.[22] Rather, our review revealed that ongoing unfamiliarity and inadequate training are likely to be related to the recruitment of new clinical staff, ongoing rotations of staff across the district, as well as continuous improvements or modifications to the EMM system (e.g. the addition of new functionalities). Our findings highlight the need for ongoing staff training, particularly with new EMM functionalities, and ongoing support for end-users, even those experienced in using EMM.

Incident reports describing EMM-related design contributory factors varied in proportion and type between sites across time, and generally design issues were the least frequent condition reported in incident reports. System functionality and configuration is known to differ considerably between hospitals,[23] and as a result of this, error types and design concerns often vary at each site.[3] Across the data collection period, incident reports describing design conditions increased at Hospital A, while these types of incidents declined, or were less frequently reported, at Hospital B and C. Hospital sites in this study were part of a single District and therefore used the same EMM system, however each site developed a unique EMM configuration in response to site specific needs. Further, as two sites implemented the system after it had been well established at Hospital A, these sites benefited from lessons learnt and implemented an enhanced system, where previous design issues had been resolved. The lower rate of design issues uncovered in incident

reports in Hospital B and C suggests it is advantageous to share information and learnings between sites.

It is interesting to note that workarounds only appeared in incident descriptions at Hospital A seven years after EMM implementation (two years post hospital-wide implementation), and rarely appeared at the other two hospitals. Keeping in mind the intentional nature of workarounds (i.e. users intentionally adjusting behaviours to bypass perceived system barriers,[24]) and the voluntary nature of incident reports, it is unlikely that incident data captured the full picture of workarounds that occurred. However, the emergence of workarounds within our data highlights their occurrence and warrants further investigation. The rigid structure and design of EMM can often impede users when completing required tasks, and adaptations to existing work processes may eventuate.[25,26] Our results suggest that these inventive practices are likely to develop over time as clinicians learn the restrictive nature of the system and develop strategies or solutions to overcome these. As such, we suggest sites remain vigilant to system shortcomings and provide a feedback loop for communication between users and EMM support staff.

Incidents where the simultaneous use of paper and the EMM, as well as the transfer of information between paper and the EMM were factors, were reported at Hospital A and B. This finding is not surprising as some wards remained on paper post hospital-wide implementation (i.e. the ICU at Hospital A), as did certain medication types (i.e. chemotherapy medications). This finding is consistent with a large body of work demonstrating that information transfer when hybrid systems are in place is a particularly risky time for patients.[11,14,15,18,22] Previous qualitative research suggests that the additional work needed with the simultaneous use of paper and EMM

systems, particularly during transfers of care between wards,[27] often results in overlooked patient information or treatment.[28]

Further, we found that incidents related to the transfer of information between the EMM system and other electronic systems emerged at Hospital A and B. Although the use of paper-based processes declined over time, with the introduction of additional electronic systems, incident reports related to the transfer of information between systems rose sharply. This finding supports the use of a single platform for patient management within and across organisations.

This study had some limitations. First, the free-text word search used to identify incident reports related to the EMM may not have captured all relevant reports. Additionally, we did not correlate fluctuations in incidents reported with EMM updates and other potential confounding factors (i.e., changes in incident reporting behaviours) and were therefore unable to draw conclusions about these relationships. Incident reports cannot be used to quantify the frequency with which incidents occur due to their voluntary nature and other internal and external factors (e.g. reporter bias). However, incident reports do provide some insight on general patterns in the types of incidents that are reported by staff across time. We have complemented our analysis of reports with other qualitative methods[19] to allow a more comprehensive understanding of incidents and errors types.

CONCLUSION

This study revealed that EMM-related incidents reported to a voluntary incident reporting system are dynamic and can be attributed to a combination of EMM design, user and organisational conditions. These factors contribute to reported incidents in varying degrees and their contribution to incidents likely reflects the

continuous process of improving the EMM system and its use. User unfamiliarity with the system is a persistent contributor to reported incidents, irrespective of how long EMM has been in place, and targeted training and ongoing support are needed to mitigate this risk. Further, incidents involving conditions related to EMM design are highly dependent on the configuration of the system and vary between sites. When an error relates to the design of the system, it can impact multiple patients and clinicians. As such, a considered approach that examines the limits of the system, the task demands of the users and organisational policies, is required to anticipate the impacts of modifying design features and ensuring these changes do not have unexpected consequences. Finally, this work demonstrates the value from sharing knowledge between sites and capturing EMM-related incidents more systematically to monitor trends in these types of incidents.

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SUPPLEMENTARY MATERIAL

Appendix A: Classification

Code	Type*	Definition	Example
1	Omission	User failed to take a course of action	• Prescriber did not change the default administration time from 0800 to 1000
2	Commission	User performed an incorrect action	• Prescriber selected the incorrect order sentence
3	Workaround	User deliberately circumvented the EMM or bypassed formal rules, protocols, standards, or procedures when using the EMM	• Nurse did not take the computer to the bedside for medication administration

Note: * = Only include incidents where an unsafe act is described, not an unsafe scenario; EMM = Electronic Medication Management

Code	Latent Conditions	Definition	Examples
	Local workplace conditions		
	EMM design		
1.1	Additional tasks required	The system requires additional steps that were not necessary on paper	• Future admin times need to be updated • Removal patch was not prescribed • User is required to refresh page for updated medications
1.2	Navigation required for information retrieval	The system requires users to navigate to a different part of the EMM to retrieve information for clinical decision making	

1.3	Inappropriate EMM defaults	The system's default settings are incongruent with what is required by the user	• Default selection opened the last encounter for patient • Checking time for blood to clot (INR) automatically generates order for warfarin
1.4	Sub-optimal display of information	The visual representation of information on screen is unclear or confusing	• Dosage written as dosage of tablet with number of tablets below • Nursing and medical task tiles are indistinguishable in the MAR
1.5	Current configuration does not support work, is complex or inflexible	The system or its components are inflexible, rigid or overly complex. The EMM functions in a way that is not	• User cannot sign for medication more than one hour ahead of time

		aligned with current workflow or practices.	• EMM cannot display warfarin brand on the MAR due to current build • Clicking next patient or 'forward' does not take you to next patient • Order sentence contains an incorrect dose or PowerPlan does not contain medications required
1.6	Error in the EMM	The system displays incorrect information or functions in an incorrect way	• Obscured screens during ordering • Task tiles dropped onto MAR at 0800 instead of 2000

1.7	Multiple screens and encounters allowed	The system enables multiple screens or encounters to be open or existing at the same time	• Four patient screens able to be opened at a time
1.8	Failure of EMM to encourage policy adoption	The system design does not encourage compliance to policy. The incident must have an explicit mention that it failed to enforce a policy or protocol.	• The system enables external clinicians to prescribe from a separate ward, not matching approved policy (e.g. Prescribers external to the ICU) • Witness changed administrator to avoid double checking
	User conditions		
2.1	Time poor or stressed	Users are busy, time poor or stressed	• New workplace and stressed about workload

			• Staffing
2.2	Over-reliance on the EMM	Users over-rely on the system when making clinical decisions or taking actions, without double checking system outputs or information	• Using a historical record to populate chart
2.3	Misunderstanding or unfamiliarity with EMM or workflow	Users misunderstand or are unfamiliar with the system and EMM workflow, due to recent EMM implementation or to users being new to the setting	• ‘New system’, ‘implementation of EMM’ • Ward converted to electronic medications a few days before • New staff to ward
2.4	Unsafe acts by other users	The sub-optimal use of the EMM by one user impacts another users’ actions on the system	• Failure of another user to close chart • Failure of another user to sign the chart

2.5	Interruption or distraction	Users are distracted or interrupted while using the EMM	• Nurse as disrupted by another patient when administering medications
2.6	Communication breakdown external to the EMM	Users fail to communicate information external to the EMM	• Insufficient handover
	Organisational conditions		
3.1	Use of hybrid systems	The organisation uses multiple systems	
- 3.1.1	Simultaneous use of paper and the EMM		• Patient was charted for chemo using both paper and EMM prescribing.

-	3.1.2	Transfer of information between paper and the EMM		• During conversion to electronic orders, order chosen as 'daily' with first dose details modified from default 0800hrs to 2000hrs
-	3.1.3	Transfer of information between the EMM and another electronic system		• EMM orders weren't discontinued by ICU staff and since the administration tasks were not signed, they were listed as being overdue on the other ward • Difficulty in reviewing medications across two systems (Pharmacy systems and EMM)

3.2	Downtime	The EMM is unavailable due to downtime	• Confused hospital downtime workflow with another hospital workflow
3.3	Inadequate training or education	Training or education related to the EMM is not sufficient	• If education (related to EMM) is recommended or a contributing factor
3.4	System or infrastructure unavailable	System or computers are unavailable or inaccessible	• Single room and nurse was unable to bring computer in • System does not load at bedside
3.5	Complexity of workflow	The organisation's workflow to support EMM use is described as complex	

EMM = Electronic Medication Management, INR = International Normalised Ratio, MAR = Medication Administration Record, ICU = Intensive Care Unit

Appendix B: Unsafe acts

Table 1B: Number of unsafe acts amongst incident reports at **Hospital A** by year of data collection at hospital and implementation phase.

Implementation phase	Year	Number of incident reports	No unsafe act		Omission error		Commission error		Workaround	Omission and commission error	Commission error and workaround	
40%	1	6	1	17%*	4	67%	1	17%				
40%	2	7			1	14%	6	86%				
40%	3	3			1	33%	2	67%				
40%	4	4	3	75%			1	25%				
70%	5	14	3	21%	3	21%	8	57%				
100%	6	38	6	16%	9	24%	22	58%			1	3%

100%	7	54	2	4%	19	35%	29	54%	2	4%	2	4%	
100%	8	27	3	11%	6	22%	17	63%			1	4%	
100%	9	102	7	7%	16	16%	72	71%	5	5%	1	1%	1 1%
100%	10	32	1	3%	5	16%	25	78%	1	3%			
	Total	287	26	9%^	64	22%	183	64%	8	3%	4	1%	2 1%

* Percentage of total number of incident reports per year. ^ Percentage of total number of incident reports. Percentages may not equal to 100 due to rounding.

Table 2B: Count of unsafe acts amongst incident reports at **Hospital B** by year of data collection and implementation phase.

Implementation phase	Year	Number of incident reports	No unsafe act		Omission error		Commission error		Workaround		Omission and commission error		Commission error and workaround
100%	1	51	2	4%	13	25%	34	67%	1	2%	1	2%	

100%	2	51	2	4%	8	16%	36	71%			3	6%	2	4%
100%	3	41	3	7%	8	20%	29	71%			1	2%		
	Total	143	7	5%^	29	20%	99	69%	1	1%	5	3%	2	1%

* Percentage of the total number of incident reports each year. ^ Percentage of total number of incident reports. Percentages may not equal to 100 due to rounding.

Table 3B: Number of unsafe acts amongst incident reports at **Hospital C.**

Implementation phase	Year	Number of incident reports	No unsafe act		Omission error		Commission error		Workaround		Omission and commission error		Commission error and workaround	
100%	1	14	1	7%^	6	43%	6	43%			1	7%		

^ Percentage of total number of incident reports. Percentages may not equal to 100 due to rounding.

Appendix C: Latent conditions

Table 1C: Number of each latent condition subcategory described in incident reports at **Hospital A** by year of data collection and implementation phase (see Appendix A for latent conditions as they relate to codes).

			Number of latent condition subcategories in incident reports																						
Implementation phase	Year	Number of incident reports	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1	2.1	2.2	2.3	2.4	2.5	2.6	2	3.1.1	3.1.2	3.1.3	3.2	3.3	3.4	3.5	3
40%	1	6					1				1			1	1		1	3	1	4			1			6
40%	2	7	1		1	1	1	1	1	1	7		1					1					1			1
40%	3	3									0	1		2				3		1			2			3
40%	4	4	1			1	1	2			5						1	1								0
70%	5	14	1					4	1		6			8			1	9	2				5			7

100%	6	38	3		4	2	2	3	1		15	1	1	16		2	4	24	5	7	1		7		2	22
100%	7	54	2	2	1	4	5	5	4	1	24	5	2	7	3	1	9	27	3	18	5	1	6	1	9	43
100%	8	27	1		1	4	3	3			12	1	1	2	2		6	12	2	4			5			11
100%	9	102	6	2	5	12	6	2	3	19	55	1	7	15	2	1	10	36	6	3	3	7	28	1	6	54
100%	10	32	2		2	5	1	1	2	2	15	1	1	8	3		1	14	5	1	1	2	5		1	15
	Total	287	17	4	14	29	20	21	12	23	140	10	13	59	11	4	33	130	24	38	10	10	60	2	18	162

Table 2C: Number of incident reports classified with a latent condition at **Hospital A** by year of data collection and implementation phase.

	Number and percentage of incident reports with latent condition

Implementation phase	Year	Number of incident reports	EMM design		User conditions		Organisational conditions	
40%	1	6	1	17%	3	50%	6	100%
40%	2	7	7	100%	1	14%	1	14%
40%	3	3	0	0%	3	100%	2	67%
40%	4	4	4	100%	1	25%	0	0%
70%	5	14	6	43%	8	57%	5	36%
100%	6	38	13	34%	20	53%	17	45%
100%	7	54	19	35%	25	46%	29	54%
100%	8	27	12	44%	11	41%	11	41%
100%	9	102	50	48%	32	31%	47	46%

100%	10	32	15	47%	14	44%	12	38%
	Total	287	127	44%	118	41%	130	45%

Table 3C: Number of each latent condition subcategory described in incident reports at **Hospital B** by year of data collection and implementation phase.

			Number of latent condition subcategories in incident reports																						
Implementation phase	Year	Number of incident reports	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1	2.1	2.2	2.3	2.4	2.5	2.6	2	3.1.1	3.1.2	3.1.3	3.2	3.3	3.4	3.5	3
100%	1	51	1			7	9		2	1	20	7	1	30	4	1	9	52	5	2	1		12	4		24
100%	2	51	2	1	1	4	6	2	2		18	8	2	8	4	4	8	34	9	1	4	2	10	3		29
100%	3	41	2			3	5	3	5	1	19	2	4	7	5	2	4	24	7		1		8	3		19

Total	143	5	1	1	14	20	5	9	2	57	17	7	45	13	7	21	110	21	3	6	2	30	10	72

Table 4C: Number of incident reports classified with a latent condition at **Hospital B** by year of data collection and implementation phase.

			Number and percentage of incident reports with latent condition					
Implementation phase	Year	Number of incident reports	EMM design		User conditions		Organisational conditions	
100%	1	51	16	31%	35	69%	19	37%
100%	2	51	13	25%	25	49%	24	47%
100%	3	41	5	12%	20	49%	18	44%
	Total	143	34	24%	80	56%	61	43%

Table 5C: Number of each latent condition subcategory described in incident reports at **Hospital C.**

			Number of latent condition subcategories in incident reports																						
Implementation phase	Year	Number of incident reports	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1	2.1	2.2	2.3	2.4	2.5	2.6	2	3.1.1	3.1.2	3.1.3	3.2	3.3	3.4	3.5	3
100%	1	14	1				1	1			3		2	8			1	11					9			9

Table 6C: Number of incident reports classified with a latent condition at **Hospital C.**

			Number and percentage of incident reports with latent condition					
Implementation phase	Year	Number of incident reports	EMM design		User conditions		Organisational conditions	
100%	1	14	3	21%	9	64%	9	64%

Appendix D: Most frequent latent conditions per year per hospital

	First year	Second year	Third year
	EMM design		
Hospital A	• Inappropriate EMM defaults • Error in the EMM • Additional tasks required	• Error in the EMM • Current configuration does not support work, is complex or inflexible • Sub-optimal display of information • Multiple screens or encounters allowed	• Sub-optimal display of information • Error in the EMM • Current configuration does not support work, is complex or inflexible
Hospital B	• Current configuration does not support work, is complex or inflexible	• Current configuration does not support work, is complex or inflexible	• Current configuration does not support work, is complex or inflexible

	• Sub-optimal display of information • Multiple screens or encounters allowed	• Sub-optimal display of information • Multiple screens or encounters allowed • Error in the EMM • Additional tasks required	• Multiple screens or encounters allowed • Sub-optimal display of information • Error in the EMM
Hospital C	• Error in the EMM • Current configuration does not support work, is complex or inflexible • Additional tasks required		

	User conditions		
Hospital A	• Misunderstanding or unfamiliarity with EMM or workflow • Communication breakdown external to the EMM • Interruption or distraction	• Communication breakdown external to the EMM • Misunderstanding or unfamiliarity with EMM or workflow • Time poor or stressed	• Communication breakdown external to the EMM • Misunderstanding or unfamiliarity with EMM or workflow • Unsafe acts by other users
Hospital B	• Misunderstanding or unfamiliarity with EMM or workflow • Communication breakdown external to the EMM	• Misunderstanding or unfamiliarity with EMM or workflow • Communication breakdown external to the EMM	• Misunderstanding or unfamiliarity with EMM or workflow • Communication breakdown external to the EMM

	• Time poor or stressed	• Time poor or stressed	• Over-reliance on the EMM
Hospital C	• Misunderstanding or unfamiliarity with EMM or workflow • Over-reliance on the EMM • Communication breakdown external to the EMM		
	Organisation conditions		
Hospital A	• Transfer of information between paper and the EMM	• Transfer of information between paper and the EMM	• Inadequate training or education

	• Inadequate training or education • Simultaneous use of paper and the EMM	• Complexity of workflow • Inadequate training or education	• Transfer of information between paper and the EMM • Simultaneous use of paper and the EMM
Hospital B	• Inadequate training or education • Simultaneous use of paper and the EMM • System or infrastructure unavailable	• Inadequate training or education • Simultaneous use of paper and the EMM • Transfer of information between the EMM and another electronic system	• Inadequate training or education • Simultaneous use of paper and the EMM • System or infrastructure unavailable
Hospital C	• Inadequate training or education		

Chapter 4: Interviews Part 1

Preface

The examination of incidents reported at three hospitals revealed the unsafe acts leading to EMM-related incidents, as well as the EMM design, user and organisational conditions that contributed to reported incidents. Further, through our analysis we explored how incident reports evolved over time with ongoing EMM system use. EMM design conditions were shown to fluctuate in their contribution to incident reports, while user unfamiliarity and the organisational condition of inadequate training persisted, irrespective of time since EMM system implementation. Although incident reports provided useful insight into the types of EMM-related incidents experienced by users, and how incidents changed over time, descriptions were generally brief and did not capture the full scope of system-related errors. In particular, unsafe acts were not described in detail, and we were unable to ascertain the full range of consequences that resulted from system-related errors. Therefore, in this chapter, we conducted in-depth interviews with key stakeholders to explore their perceptions and experiences of system-related errors, to comprehensively understand the types of errors that occur, the factors that contributed to errors and the consequences of these errors. This addresses the third aim of this program of research.

This original research paper was peer reviewed (submitted 27 March 2022, resubmitted with revisions according to reviewer's comments on 2 June 2022) and published (18 June 2022), details are as follows:

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Authorship attribution statement

This statement describes the contribution made by Madaline Kinlay in the preparation and submission of the following manuscript: "*Stakeholder perspectives of system-related errors: Types, contributing factors, and consequences*". The convention is that the author with the principal contribution to the manuscript is the first author.

Madaline Kinlay, during her PhD candidature, developed the original concept of the study with her supervisors, and was responsible for conducting the interviews, interpreting and analysing the interview data with the assistance of her co-authors, drafting and revision of the manuscript, and coordinating submission for publication of the original research paper.

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Madaline Kinlay 28 June 2023

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statement above is correct.

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Melissa Baysari 28 June 2023

Title

Stakeholder perspectives of system-related errors: Types, contributing factors, and consequences

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ABSTRACT

Background

Despite growing evidence of the benefits of electronic medication management systems (EMMS), research has also identified a range of new safety risks linked with their use. There is limited qualitative research focusing on system-related errors that result from use of EMMS. The aim of this study was to explore in-depth stakeholders' perceptions and experiences of system-related errors.

Methods

Semi-structured interviews were conducted with EMMS users and other relevant staff (e.g. supporting roles in EMMS) across a local health district in Sydney, Australia. Analysis was conducted iteratively using a general inductive approach, and then mapped to Reason's accident causation model, where codes were categorized as 1) unsafe acts (i.e. what error occurred), 2) latent conditions (i.e. what factors contributed to errors), and 3) consequences resulting from the error.

Results

Twenty-five participants were interviewed between September 2020 and May 2021. Participants most frequently described omission errors (e.g. failure to check for duplicate orders) as unsafe acts, although commission errors and workarounds were also reported. Poor EMMS design was reported to be a significant workplace factor contributing to system-related errors, however participants also described user factors, such as an overreliance on the system, and organizational factors, such as system downtime, as contributing to errors. Reported consequences of system-

related errors included medication errors, but also impacts to the EMMS and on workers.

Conclusions

EMMS design is a significant contributor to system-related errors, but this research showed that user and organizational factors are also at play. As these factors are not independent, minimizing system-related errors requires a multi-faceted approach, where mitigation strategies target not only the EMMS, but also the context in which the system has been implemented.

Keywords

Electronic medication management system, medication errors, patient safety, accident causation model, hospital

INTRODUCTION

Electronic medication management systems (EMMS), now utilised in many hospitals, enable clinicians to order, review and administer medications using a single integrated platform.[1] There is strong evidence to show that the implementation of EMMS is associated with reductions in both prescribing[2-4] and administration errors[5-7] and in increased efficiency.[8,9] Despite growing evidence of benefits, research has also identified a range of new safety risks linked with their use.[10,11] System-related errors are new errors that result from use of EMMS, errors not possible with paper-based medication charts.[12,13] Examples include prescribing errors generated from a failure of users to modify default settings where not appropriate,[13,14] the mis-selection of medication items from lists,[15] and contradictory order information entered into free-text boxes to overcome restrictive order templates.[16] If system-related errors and their contributing factors are not detected and minimized, medication errors and subsequent patient harm may result from EMMS use.[17,18]

Although these new types of errors have been described in the literature, typically identified via incident reporting systems and medication chart reviews, insights from EMMS users and staff that support the use of these systems is likely to contribute further to our understanding of how and why these system-related errors manifest and their impact on both hospital staff and patients. To date, qualitative studies focusing specifically on system-related errors associated with use of EMMS are limited. A recent study by Mozaffar et al. conducted in the U.S. explored stakeholder perceptions of unintended consequences relating to EMMS and identified three main factors contributing to these safety threats: system design, use of systems, and implementation strategies.[19] Although this previous research examined safety risks associated with system use, the research comprised a re-analysis of data collected

for a larger study, so did not explore new system-related errors and did not examine consequences of system-related errors.

The aim of the current study was to build on this previous research by exploring stakeholders' perceptions and experiences of system-related errors associated with the use of EMMS. In addition to investigating the origins of these errors, or the factors contributing to them, we also elicited stakeholder views on the types of errors that occur, and the consequences resulting from error occurrence.

MATERIALS AND METHODS

Setting

This study was undertaken at a Local Health District in Sydney, Australia, comprising three hospitals (total beds approx. 1600; admissions per annum approx. 150,000). The EMMS had been in place at these hospitals for 14 years, 4 years and 2 years at the time of interviews. Length of roll-out and strategies for implementation varied between sites. This study was approved by the district's Human Research Ethics Committee (HREC reference number: 2020/ETH00198).

Participant recruitment

All hospital staff who interacted directly or indirectly with the EMMS were eligible to participate. This included end-users (i.e. doctors, nurses, pharmacists), clinical informatics team members (e.g. system trainers), members of relevant committees (e.g. medicine safety committee) and department directors. Participants were initially purposively recruited by a clinical informatics pharmacist at each site, who identified individuals they believed to be most knowledgeable of EMMS or had relevant working roles. This method was used in conjunction with snowball (word-of-mouth)

sampling, where existing participants were prompted to suggest other staff members for inclusion. Forty-five potential participants received an email with an invitation to participate.

Data collection

Semi-structured interviews were conducted either face-to-face in the hospital or via video conferencing. Two interview guides were developed; one for end-users and another for those who had EMMS supporting roles. Interviews included two parts. In Part 1, participants were asked to describe specific cases of system-related errors, including what happened, what factors contributed to the errors and the consequences of these errors. In Part 2, participants were asked to discuss how system-related errors were detected and mitigated. Here, we report findings on Part 1 only (See Appendix A and B). Interviews were conducted, audio recorded and transcribed verbatim using the Otter.ai software by the lead investigator (MK), with all identifiable information removed. Transcripts were not returned to participants for checking, although participants were provided with an opportunity to contact the researcher with further questions or comments. Interviews were ceased once data saturation was reached. All participants provided written informed consent before taking part in an interview.

Theoretical framework

To facilitate an in-depth, systematic investigation of system-related errors, we used an accident analysis approach. Accident analysis approaches enable clear identification of the cause, process, and consequence of accidents, or in this case, errors.[20] Reason's accident causation model considers accidents to be the result of active failures and latent conditions; the precipitating conditions of the incident and

the external influences that exist in the organization before an incident occurs, respectively.[21] We selected this model as it distinguishes between the three domains that contribute to errors (e.g. unsafe acts, the local workplace and the organization) and recognizes that these do not occur in isolation from one another. Guided by this model,[22] we viewed system-related errors as resulting from active failures in the form of *unsafe acts* by users. These unsafe acts were the result of a combination of *latent conditions*, including contributory factors related to the local workplace and to the organization. These high-level categories (unsafe acts and latent conditions) were used to provide an overarching framework for subcategories. In addition, we analyzed and classified the reported consequences of system-related errors.

Data analysis

Analysis was conducted iteratively using a general inductive approach, where codes were assigned as concepts emerged from the data.[23] One student and two researchers (MK, MB and WYZ), with expertise in psychology, human factors and EMMS, independently coded the data contained in transcripts into three major categories as shown in Figure 1: 1) unsafe acts (i.e. what error occurred), 2) latent conditions (i.e. what factors contributed to error occurrence), and 3) consequences resulting from the error. Researchers met regularly to discuss identified themes and sub-themes under each major category and resolve any differences. Once a coding framework was developed, researchers coded the remaining interviews and completed a final review to resolve any discrepancies and identify key themes.

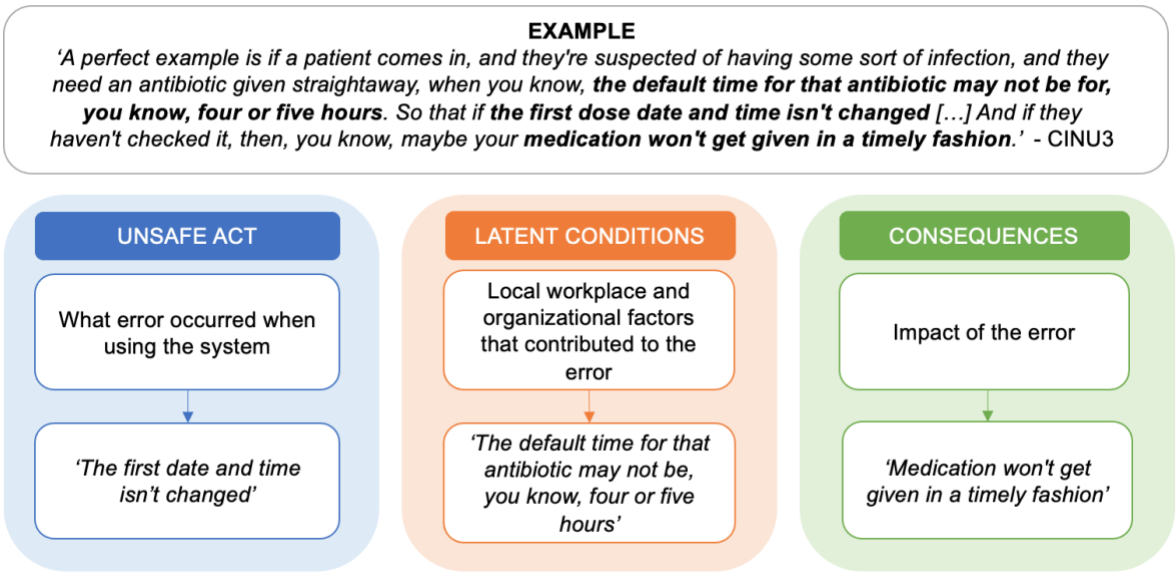

Figure 1: The framework used to guide a systematic analysis of system-related errors, including unsafe acts, latent conditions and consequences. An example is provided, with quotes from the example below the framework demonstrating how the framework was used to classify interview responses into each major category.

Classification development

The existing classification developed by Mozaffar and colleagues,[19] as described above, was used as a starting point for classification of coded data. However, some categories within this classification contained overlapping components, making it difficult to describe unsafe acts, latent conditions, and consequences separately. For example, the category 'inappropriate system use' included both actions taken by the user and contributing factors. Consequently, a new classification was iteratively developed from the data and appears in the results section (see Table 2). In classifying unsafe acts, we adopted the well-known dichotomy of 'errors of omission' (i.e. the user failed to take a course of action), and 'errors of commission' (i.e. user initiated an incorrect action)[24] and also added workarounds to describe cases where

users deliberately circumvented intended system use.[25] Latent conditions were categorized as those related to local workplace, including system design and the user, and to the organization. The consequences of system-related errors were categorized as those that impacted patients, end-users and the EMM system.

RESULTS

Participants

Twenty-five participants were interviewed between September 2020 and May 2021 (see Table 1). Interviews were on average 32 minutes long (range 9 - 55 minutes). Interviews were conducted with one participant, except for three, which were conducted with two participants.

Table 1: Participant demographics

Implementation and support team	**10**
Medical	2
Nursing	5
Pharmacy	3
Years in current role	
< 5 years	5
5 – 10 years	5
> 10 years	0

Clinicians	**15**
Doctor	3
Nurse	8
Pharmacist	4
Years in current role	
< 5 years	8
5 – 10 years	5
> 10 years	2
Length of EMMS use	
< 2 years	2
2 – 5 years	10
> 5 years	3
Frequency of EMMS use	
Daily	13
Weekly	2
Experience with paper-based medication charts	
Yes	14

No	1

Types of unsafe acts, latent conditions, and consequences

Table 2 outlines the system-related errors that participants described, categorized into unsafe acts taken by users, the latent conditions that led to these errors and the subsequent consequences.

Table 2: Classification of system-related errors separated into the unsafe acts taken by users, the latent conditions that led to these actions and the consequences of them. High-level categories from Reason's accident causation model are underlined.

UNSAFE ACTS	LATENT CONDITIONS	CONSEQUENCES
Omission	***Local workplace conditions***	**On the patient**
Did not check for other orders	**EMMS* design**	Medication errors
Did not check default settings	Complexity	**On EMMS system**
Did not resume withheld medication	Additional tasks required	Disconnect between practice and documentation in the system
Commission	Additional navigation for information retrieval	**On the user**
Selected wrong order component (including wrong patient)	Defaults	Additional work or time
Workaround	Cluttered display	Confusion

Changed ‘performed by’ field to avoid double checking	Absence of prompts that existed on paper	
Marked off incomplete tasks as complete	Inflexibility	
Used ‘unlisted med’ field for listed medications	Limited or filtered view	
	User	
	Time poor	
	Over reliance on system	
	Misunderstanding or unfamiliarity with system	
	Organization conditions	

Use of hybrid systems
Downtime
Inadequate training

*EMMS: Electronic medication management system

What types of unsafe acts occurred?

Omission errors

When asked to describe key examples of system-related errors, the most frequently reported example of an unsafe act was users not checking for duplicate or contraindicated orders when prescribing and administering medications.

'It's a different screen that you look at when you order, as opposed to when you look at what orders are in for the patient already, so there tends to be duplication.' (PH4)

Not checking the accuracy or appropriateness of medication information in the EMMS was another frequent omission error described by participants. For example, failure to check default settings on the system was common, with participants reporting that this often led to medications being given at the wrong time.

"It defaulted to the next set time, which was a good like 12 hours away. So, for a septic patient to wait 12 hours to get some antibiotics, that was really bad." (PH1)

Several participants reported that it was not uncommon for doctors to forget to resume withheld medications, particularly when ceasing multiple doses of a medication.

'You can withhold one dose of a medication, otherwise, you're required to sort of cease, so they're normally suspended and [then] future resume, and quite often the medications don't get resumed. And then they're withheld unintentionally, for long periods of time.' (CIDR1)

Commission errors

Although not reported as frequently as omission errors, a number of commission errors were also described by stakeholders. The most frequent were selection errors, where users selected the wrong item or order component in the EMMS. This included, for example, the incorrect selection of an order sentence or order component from pre-formulated fields, such as the formulation or dose of a medication while prescribing.

'*But when you're forced to select an option from a drop-down menu, you may click on the wrong one without realising it. And it still looks perfectly official, because it's the order sentences all pre-formulated, the spelling's all correct.'* (PH3)

Additionally, selecting the wrong patient while both prescribing and administering medications was described as a frequent error.

'*Instead of me clicking my ward on level one, I click level three. […] and then not even realizing you're on a different level and different ward. And then you just administer medication for that person.'* (NU7)

Workarounds

Participants described several workarounds, where users performed an action to overcome perceived system limitations. For example, inappropriate 'top boxing', where the user administering a high-risk medication changed the name of the witness to themselves, and the administrator to another nurse, to avoid the requirement for another nurse to be approached for double checking or entering the witness' EMMS password. Interviewees explained that this permitted nurses to mark off tasks as complete prior to actioning them.

'We call it top boxing, where nurses can actually not have a secondary witness and put in the EMR (electronic medical record), they can make it look as though there was another nurse there witnessing it.' (CINU5)

Participants also reported that when doctors were unable to locate a medication in the system catalogue, they would chart a medication using the 'unlisted' function, which could unknowingly prevent safety features, such as drug-drug interaction alerts, from triggering.

'*If you type in a medication you can't find, because you don't know what the proper name of it is, for example, you can type in an unlisted medicine, which is like a free form. But then you don't get any interaction checks, or any of the allergy checks, or the pre formulated sentences that make it safer.'* (PH3)

When users were unable to modify a default setting and sought to prescribe an immediate dose, participants recounted that stat ('at once') doses were ordered as well, increasing the chance of duplicated orders or administrations.

'Because they've charted it as 8 and 12 regularly, and it's now 10am, they'll just assume that […] you won't give that. They'll just then prescribe the stat dose. I've definitely noticed that double up of orders, because they've ordered something as regular, but they want a dose given then and now.' (NU6)

What latent conditions contributed to system-related errors?

Latent conditions related to the local workplace

Conditions related to design of the electronic medication management system

Most latent conditions described by participants related to the local workplace, most frequently the design of the EMMS. As shown in Table 2, we identified eight contributing factors related to the EMMS. Here we discuss the four most frequently mentioned factors. Participants reported that the EMMS was generally complex and required users to perform additional tasks that were not necessary with paper charts. For example, many participants explained that the system mandated certain fields be completed before allowing the user to progress; fields that were often left blank on the paper medication chart. It was also reported that navigation was required to retrieve relevant information from the system. For example, when prescribing medications, participants described being unable to review the current medication chart or read consultation notes at the same time. Thus, for users to review this information while prescribing, they were required to navigate between screens.

'There's no Save button. It's hard for you to go and look at what you need to see on the medication chart and come back. You're kind of forced to address everything on this one screen.' (CIDR1)

Participants frequently referred to inappropriate default settings, where the pre-filled option included in the system was incongruous with the most frequently preferred selection, which led to errors when not reviewed or changed.

'*If a doctor prescribes an antibiotic at eight o'clock in the morning, the system defaults the antibiotic to be given at midday. Now for a patient with severe infection, and they needed the antibiotic to be given immediately, this is not an ideal situation where they can wait for another four hours before receiving their drugs.'* (CIPH2)

Participants also highlighted that many of the visual cues that existed on paper, such as the grid boxes indicating medication administrations, and the ability for users to

flag vital information with color and text, were absent from the EMMS. Without these, required actions were overlooked or forgotten. For example:

'*We do have a solution for that withholding one dose. But it's not as intuitive as putting 'w' on a piece of paper.'* (CINU1)

Further, participants explained that paper charts ended after 7-days, which acted as a physical reminder to review medications when recharting medications onto a new paper chart. Without this prompt, medications were less likely to be reviewed and this could result in prescriptions continuing indefinitely.

Conditions related to the user

Participants described a range of user factors that were perceived to be contributing to system-related errors. A key factor appeared to be time, with participants explaining that clinicians were often time poor, as they had competing responsibilities, and were often distracted.

'*You do not have enough time to review all these orders for your patients and you may tend to overlook certain things on [EMMS].'* (CIPH1)

Users were also described to over-rely on the system. For example, when making a drug choice, the EMMS provides a list of pre-written orders to select from, eliminating the requirement for doctors to know the correct doses, routes, formulations, and other components of medication orders. This could lead to users making incorrect assumptions and potential medication errors.

‘*Instead of remembering doses […] we just type it into EMR, pick the best one that comes out, as opposed to thinking, ‘Oh, what’s the usual dose for this indication?’* (DR1)

Related to this, some participants explained that users could assume that all medications have been documented on the system, which may not be the case when the hospital has a hybrid paper-computer system in place.

‘*While we have the capacity to still use the paper at the moment, […], people aren't looking at it, because they're used to more stuff being online now. And they're used to the fact that anything that should be in addition to the chemotherapy should be charted on the MAR (Medication Administration Record)’.* (NU8)

Unfamiliarity with system functionality or users misunderstanding how the system works were also perceived to be factors contributing to system-related errors. Examples included a lack of understanding about default settings, inputting variable dose regimens, and different order types (e.g. once off or ongoing).

‘*When you sort of really drill down to the root cause of the problem, that's usually when the clinician hasn't used the system properly, or they've made an error in using the system.’* (CINU2)

Latent conditions related to the organization

System downtime, when the system becomes unavailable to users, was frequently described as an organizational contributing factor, as this disrupted workflow and generated safety risks. Irrespective of whether downtime was scheduled or unplanned, participants explained that there was an increased risk of transcription errors when transferring information from the EMMS to paper and vice versa.

'*Even if you have an electronic system, you do still need a paper-based system or a backup system to manage medications […] when the system is down. And it is a big issue because transitioning from electronic back to paper and then from paper back to electronic, when the system is back up again, there is a big risk in it and there needs to be a lot of resources put in to ensure the transfer of information is accurate coming in as well.'* (PH2)

Staged implementation of the EMMS across wards and hospitals resulted in not all settings using the EMMS at the same time. The use of hybrid paper-computer systems was described as risky, primarily because medications were being recorded in multiple systems. Some participants also suggested that the use of different clinical information systems between wards increased the likelihood of errors occurring.

'*Having some medications on paper, rather than having it all together in the system, things get missed or duplicated.'* (CIPH1)

Another factor reported to be contributing to system-related errors was inadequate training. Given the complexity of the EMMS system, initial training was described by many participants, particularly clinical informatics staff, as inadequate.

What were the consequences of system-related errors?

Consequences to the patient

The most frequently reported consequence of system-related errors was the occurrence of medication errors, such as duplicated orders and duplicated administrations. Some participants also mentioned adverse patient outcomes such

as increased length of stay, admission to the Intensive Care Unit and in some cases, death.

'*Couple of incidents where a staff member may have not signed off the medications, within the [EMMS], and then […] somebody else has come along and given the medication as well, and the patients received a double dose.'* (CINU2)

Both prescribing and administering the wrong medication to a patient were risks, often due to nurses reviewing incorrect patient charts. Additionally, participants, particularly pharmacists, reported that timing errors were frequent, with medication administrations occurring too early or late.

'Something might be urgent, and it needs to start now. But they accidentally schedule it to start tomorrow. […] So it could, you know, have patient implications if things are delayed, or they're started too soon, or they accidentally finish at the wrong time.' (CIPH1)

Other types of medication errors described included incorrect and missed doses, as well as allergy errors and those relating to intravenous medications.

Consequences on the electronic medication management system

A key consequence of system-related errors was reported to be a disconnect between what occurred in practice and what is documented in the EMMS, with information contained in the system not accurately reflecting clinical practice.

'*You're essentially telling the system that you've checked it, and you've administered it and completed it, just to be able to give that second bag when you haven't given that first one.'* (NU8)

'*Part of its documentation, like it doesn't necessarily reflect what happened.'* (CIPH1)

Consequences on the user

Participants, particularly end-users, reported that additional work and time spent on tasks was a consequence of system-related errors. When system functionality constrained users' ability to complete necessary tasks, these tasks could take more time than when performed on paper. In addition to this, the other main consequence of system-related errors was perceived to be confusion, particularly when the system was unintuitive.

'*It's like just so specific, if your [order frequency is] daily and if you're past 8am today, you just can't go back and do it for today. Like you have to have like a stat order for that day. That's a good thing to be very specific and not to have errors. But it also creates extra work*.' (DR3)

DISCUSSION

This study examined EMMS system-related errors holistically by applying Reason's accident causation model[22] to guide analysis of error occurrence. Participants identified a variety of EMMS system-related errors, a large number of contributory factors, and a range of consequences of errors. Omission errors were most frequently reported, and participants identified poor EMMS design as a key contributor to system-related errors. System-related errors were primarily seen to result in medication errors, however, they were also reported to have an impact on the EMMS and on workers.

Participants described many instances where users did not review information in the system when ordering or administering medications. This included failing to check

the accuracy of default settings or not reviewing the current list of active medications. In many cases, these omissions were the result of EMMS requiring users to navigate between screens to find relevant information. To reduce navigation and so omission errors, systems can display relevant information to users at the point of decision-making.[26-28] For example, making relevant pathology results visible on screen at the point of prescribing (e.g. liver function test results when prescribing paracetamol products) would enable clinicians to use this data to inform appropriate drug selections.[29] Training has also been shown to be effective in assisting users to locate key clinical information (e.g. default times), promoting review and safe practices.[30]

Participants described a range of workarounds adopted by users while navigating the EMMS, several of which were unique examples, not described in previous research.[25,31] For example 'top boxing' and prescribing 'unlisted' medications have not been previously reported, adding to the available evidence on workarounds. This highlights that workarounds can take many forms, and likely reflect variability in clinical workflows and EMMS configurations.[32] The workarounds in our study sought to bypass system limitations in order to complete medication-related tasks efficiently and in line with workflow. This indicates that although workarounds can threaten patient safety,[33] they may also signal that system redesign is necessary to allow users to perform "work as done" and in an efficient way.[31,34,35] Our findings highlight that this is particularly important for medication-related work.

In line with previous research on system-related errors in general,[36,37] poor system design was reported to be the most critical factor contributing to system-related errors associated with EMMS. Although system redesign is a common approach taken in response to the identification of system-related errors,[29] our results suggest

that conditions related to the workplace and organization, such as user workload and training, are also factors impacting error occurrence. The three categories that emerged as contributing organizational factors in our study, system downtime, hybrid systems, and inadequate training, have also been identified in other studies of system-related errors,[19] highlighting that these are critical challenges faced by organizations implementing EMMS. Although not always possible, limiting the simultaneous use of multiple systems and providing clear guidance around processes during EMMS downtime are likely to minimize these errors. At the very least, organizations should be mindful that these situations represent a risky time for patients, and extra vigilance and monitoring for safety issues may be needed. Further, continuous training, rather than one-off training, may be beneficial, in addition to the availability of 'superusers' or clinicians with additional knowledge of the system, who can provide ongoing support to other users.[38]

In addition to medication errors, participants described instances where system-related errors resulted in additional work and time for users. Previous research on EMMS impact on time spent completing medication-related work has been inconsistent. A systematic review by Farre et al.[39] found that prescribing and dispensing of medications was quicker using EMMS than on paper. However, another review paper investigating the consequences of EMMS on clinical workflow determined that ordering time increased after system implementation.[40] Our study results suggest that identifying and rectifying system-related errors may constitute an extra task for end-users of EMMS, tasks not required with paper-based systems. These new tasks have not been specifically captured in previous time-and-motion studies, highlighting we know little about the additional time system-related errors actually consume.

This research utilized a qualitative approach, and therefore does not permit conclusions to be drawn about how frequently system-related errors and their consequences occur. However, the purpose of this research was to explore stakeholder experiences and perceptions of system-related errors and to deconstruct how and why errors occurred. This study was conducted in one Local Health District, with three hospitals using the same EMMS, so generalizability to other settings and EMMS may be limited. The consequences to patients were from the perspective of healthcare providers and therefore are unlikely to capture the true or full impact that these errors have on patients. Future work could apply our classification to additional cohorts and datasets to determine its relevance and usefulness.

CONCLUSION

This study adds to the existing research on system-related errors by providing an in-depth analysis of unsafe acts, the workplace and organizational factors that lead to errors, and the consequences of system-related errors to patients, hospital staff and the EMMS. Although EMMS design appears to be a significant contributor to system-related errors, user factors and organizational elements are also at play. As these factors are not independent, ensuring that EMMS systems are safe and are used safely requires a multi-faceted approach, in which mitigation strategies target not only the EMMS, but also the context in which the system has been implemented. Further qualitative research is currently underway to examine the mitigation strategies to target these system-related errors.

Author contributions

MK, MB and WYZ designed the study. RB, LMH, HT and JT assisted in the recruitment of participants. MK analyzed the data, with assistance from MB and

WYZ. All authors assisted in interpreting results and writing the manuscript. All authors read and approved the final manuscript.

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Conflicting interests

No conflicting interests to declare.

Summary table

What was already known on the topic

- Research has identified a range of new safety risks associated with the use of electronic medication management systems.
- One of these new safety risks are system-related errors, which are errors unlikely to occur with use of paper-based medication charts.

What this study added to our knowledge

- An in-depth, systematic investigation of system-related errors, investigating the origins of these errors, the factors contributing to them, and the consequences resulting from their occurrence.
- Stakeholders' perceptions and experiences of system-related errors associated with the use of electronic medication management systems.
- Strategies to mitigate system-related errors should primarily target the design of the electronic medication management, but also focus on workplace and organization conditions, as these contextual factors are key in ensuring systems are safe and are used safely.

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SUPPLEMENTARY MATERIAL

Appendix A: Semi-structured interview questions for hospital staff members/clinicians directly using electronic medication management

Basic demographics

1. What type of staff member/clinician are you (i.e. nurse, doctor, pharmacist) and roughly how many years have you been in this role?
2. What ward/specialty do you predominantly work in?

About EMM

3. How long have you been using the *EMM* system?
4. Did you have experience with paper-based medication systems prior to using *EMM*?
5. How often do you use *EMM*? For example, to prescribe.
6. What training did you receive on *EMM*?
7. How proficient do you feel you are in using *EMM*?

System-related errors

As mentioned, I'm interested in system-related errors of EMM.

8. How would you define a system-related error?

In my study, I am defining a system-related error as any error that was unlikely or unable to occur in paper-based medication management systems. In other words, these errors would be unlikely or not possible without EMM.

Using this definition:

9. How often do you think a system-related error happens?
10. What are the most common types of system-related errors?
11. Can you think of a recent example of a system-related error that you have experienced or heard about?

(If needed, I will prompt with an example of an error: For example, a system-related error could be clicking the incorrect dosage of a medication because the dose you required was not visible on the screen)

1. Could you describe what happened step-by-step?

What was the situation that led to the error being made?

What actions were taken?

What were you trying to be achieved when the error occurred?

2. What was the consequence of this error?

Was there an effect or impact on the user?

Was there an effect or impact on others, such as the patient or colleagues?

Were there potential consequences that could have happened but didn't?

What was the outcome of the error?

3. What do you believe were the contributing factors that led to this error?

For example, did the design of the system make it difficult to use?

How do you think this error could be prevented in the future?

12. Do you have any other examples of system-related errors that you've experienced or heard of? *(Repeat questions 11a-12 if yes)*

Appendix B: Semi-structured interview questions for all other stakeholders

Basic demographics

1. What is your current role and roughly how many years have you been in this role?
2. What interactions do you have with *EMM*?

About EMM

3. How long have you been supporting the use of the *EMM* system?
4. What training did you receive on *EMM*?

System-related errors

As mentioned, I'm interested in the system-related errors of EMM.

5. How would you define a system-related error?

In my study, I am defining a system-related error as any error that was unlikely or unable to occur in paper-based medication management systems. In other words, they would be unlikely or not possible without EMM.

Using this definition:

6. How often do you think a system-related error happens?
7. What are the most common types of system-related errors?
8. Can you think of a recent example of a system-related error that you have experienced or heard about?

(If needed, I will prompt with an example of an error: For example, a system-related error could be clicking the incorrect dosage of a medication because the dose you required was not visible on the screen)

a. Could you describe what happened step-by-step?

What was the situation that led to the error being made?

What actions were taken?

What were you trying to be achieved when the error occurred?

b. What was the consequence of this error?

Was there an effect or impact on the user?

Was there an effect or impact on others, such as the patient or colleagues?

Were there potential consequences that could've happened but didn't?

What was the outcome of the error?

c. What do you believe were the contributing factors that led to this error?

For example, did the design of the system make it difficult to use?

How do you think this error could be prevented in the future?

9. Do you have any other examples of system-related errors that you've seen or heard of? *(Repeat questions 8a-9 if yes)*

Appendix C: COREQ (COnsolidated criteria for REporting Qualitative research) checklist

A checklist of items that should be included in reports of qualitative research. You must report the page number in your manuscript where you consider each of the items listed in this checklist. If you have not included this information, either revise your manuscript accordingly before submitting or note N/A.

Topic	Guide questions/description	Reported on page #
Domain 1: Research team and reflexivity		
Personal characteristics		
Interviewer/facilitator	Which author/s conducted the interview or focus group?	137
Credentials	What were the researcher's credentials? e.g. PhD, MD	138
Occupation	What was their occupation at the time of the study?	138
Gender	Was the researcher male or female?	N/A
Experience and training	What experience or training did the researcher have?	138
Relationship with participants		
Relationship established	Was a relationship established prior to study commencement?	136

Participant knowledge of the interviewer	What did the participants know about the researcher? e.g. personal goals, reasons for doing the research	137
Interviewer characteristics	What characteristics were reported about the interviewer/facilitator? e.g. bias, assumptions, reasons and interests in the research topic	138
Domain 2: Study design		
Theoretical framework		
Methodological orientation and Theory	What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis	137
Participant selection		
Sampling	How were participants selected? e.g. purposive, convenience, consecutive, snowball	136
Method of approach	How were participants approached? e.g. face-to-face, telephone, mail, email	137
Sample size	How many participants were in the study?	140
Non-participation	How many people refused to participate or dropped out? Reasons?	137
Setting		
Setting of data collection	Where was the data collected? e.g. home, clinic, workplace	137

Presence of nonparticipants	Was anyone else present besides the participants and researchers?	140
Description of sample	What are the important characteristics of the sample? e.g. demographic data, date	140
Data collection		
Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	137
Repeat interviews	Were repeat interviews carried out? If yes, how many?	N/A
Audio/visual recording	Did the research use audio or visual recording to collect the data?	137
Field notes	Were field notes made during and/or after the interview or focus group?	N/A
Duration	What was the duration of the interviews or focus group?	140
Data saturation	Was data saturation discussed?	137
Transcripts returned	Were transcripts returned to participants for comment and/or correction?	137
Domain 3: Analysis and findings		
Data analysis		
Number of data coders	How many data coders coded the data?	138

Description of the coding tree	Did authors provide a description of the coding tree?	143 - 145
Derivation of themes	Were themes identified in advance or derived from the data?	139
Software	What software, if applicable, was used to manage the data?	137
Participant checking	Did participants provide feedback on the findings?	137
Reporting		
Quotations presented	Were participant quotations presented to illustrate the themes/findings? Was each quotation identified? e.g. participant number	146 - 154
Data and findings consistent	Was there consistency between the data presented and the findings?	146 - 154
Clarity of major themes	Were major themes clearly presented in the findings?	154
Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?	146 - 154

Developed from: Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care*. 2007. Volume 19, Number 6: pp. 349 – 357

Chapter 5: Interviews Part 2

Preface

Stakeholder interviews provided an in-depth exploration of system-related errors, detailing the various types of system-related errors, and describing the underlying conditions that resulted in error occurrence. Additionally, we examined the consequences of system-related errors beyond medication errors. Omission errors were the most frequent unsafe act reported, with key examples including the user not checking current orders or the accuracy of information in the EMM system. EMM design components, such as inappropriate default settings and a cluttered display, were frequently identified by participants as having the potential to contribute to system-related errors. Yet, system-related errors were found to be multi-factorial, indicating that mitigation strategies should address both the EMM system and its context of use. There is currently limited research investigating how system-related errors are detected by the healthcare organisations affected by them, and importantly how these errors are managed or rectified once identified. Therefore, in this chapter, addressing the fourth aim of this research program, stakeholder interviews explored the detection and mitigation strategies adopted by a health district to target system-related errors, including existing and potential methods required to prevent future system-related errors from occurring.

The manuscript reporting on the detection and mitigation strategies for system-related errors is current under review at the *International Journal of Medical Informatics.* Details are as follows:

Manuscript under review

Kinlay M, Zheng WY, Burke R, Juraskova I, Ho LMR, Turton H, Trinh J, Baysari M. How do we detect and mitigate system-related errors over time? A qualitative study in an Australian health district. *Int J Med Inform*. 2023 – under review

Authorship attribution statement

This statement describes the contribution made by Madaline Kinlay in the preparation and submission of the following manuscript: "*How do we detect and mitigate system-related errors over time? A qualitative study in an Australian health district*". The convention is that the author with the principal contribution to the manuscript is the first author.

Madaline Kinlay, during her PhD candidature, developed the original concept of the study with her supervisors, and was responsible for conducting the interviews, interpreting and analysing the interview data with the assistance of her co-authors, drafting and revision of the manuscript, and coordinating submission for publication of the original research paper.

_____

Madaline Kinlay 28 June 2023

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statement above is correct.

_____

Melissa Baysari 28 June 2023

Title

How do we detect and mitigate system-related errors over time? A qualitative study in an Australian health district

Authors

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ABSTRACT

Background

Electronic medical record (EMR) systems provide timely access to clinical information and have been shown to improve medication safety. However, EMRs can also create opportunities for error, including system-related errors or errors that were unlikely or not possible with the use of paper medication charts. Limited research has focused on methods for detecting system-related errors and little is known about how healthcare organizations manage these errors once detected.

Methods

Semi-structured interviews were conducted with EMR users and other key stakeholders (e.g. clinical informatics team members) working across three hospitals within a health district in Sydney, Australia. Participants were asked to reflect on how system-related errors changed over time, and to describe approaches taken by their organization to detect and mitigate these errors. Thematic analysis was conducted iteratively using a general inductive approach, where codes were assigned as themes emerged from the data.

Results

Interviews were conducted with 25 stakeholders between September 2020 and May 2021. Participants reported that most system-related errors were detected by front-line clinicians. Following error detection, clinicians had the option to both report system-related errors directly to the clinical informatics team and submit reports to the incident information management system. System-related errors were also reported to be detected via reports run within the EMR, or during organizational

processes such as incident investigations or system enhancement projects. EMR redesign was the main approach described by participants for mitigating system-related errors, however other strategies, like regular user education and minimizing the use of hybrid systems, were also reported.

Conclusion

This research highlighted that initial detection of system-related errors relies heavily on front-line clinicians, however other organizational strategies that are proactive and layered can improve the systemic detection, investigation, and management of errors. Together with EMR design changes, complementary error mitigation strategies including targeted staff education can support safe EMR use and development.

Keywords

Electronic medical record, medication errors, patient safety, error detection, error prevention, hospital

INTRODUCTION

An electronic medical record (EMR) provides access to longitudinal patient data and clinical information in a timely and convenient manner,[1] while allowing clinicians to prescribe, review and administer medications on a single digital platform, often with the assistance of clinical decision support. Improvements in medication safety have been cited as a significant benefit of introducing an EMR in hospitals.

Although the use of EMR systems result in fewer medication errors,[2] they are not without their own potential risks and can create opportunities for error. System-related errors are errors that were highly unlikely or not possible with the use of paper medication charts. For example, a doctor selecting the wrong dose from a drop-down menu, resulting in a dosing error, or failing to change the default administration time in an order sentence, resulting in a timing error. Previous research has identified the types and factors contributing to system-related errors,[3-5] as well as their prevalence,[6] but the detection of these errors can be challenging in both a clinical and research context. Research investigating the types and rates of system-related errors at two hospitals revealed that of the 493 system-related errors that were discovered, only 13% were detected by hospital staff prior to the study.[4] Further, the rate of system-related errors is known to vary between studies, ranging from 1.2% to 34.8% of all errors[7] and the estimated frequency of system-related errors has been shown to depend on the detection method employed.[6]

Evidence to date has indicated that the detection of system-related errors is inconsistent, and to our knowledge, there is no research that has specifically examined how system-related errors are detected by the organizations impacted by them. While the first step in reducing system-related errors is error detection, another

important component of error management is learning from previous errors and improving on processes and systems.[8,9] Our previous work has described system enhancements made to target system-related errors,[10] however research on how system-related errors are rectified or managed once error detection has occurred is in its infancy. Therefore, the aim of the current study was to identify the detection and mitigation strategies adopted by a health district to target system-related errors, and to explore stakeholder views on strategies needed to curb future system-related errors that may emerge.

MATERIALS AND METHODS

Context

This study formed part of a larger research project examining stakeholder understanding and experiences of system-related errors, and as such, the detailed method appears in our previous publication.[11] In summary, the research was conducted at three hospitals that used the same commercial EMR system (Cerner Millennium®), which had been in place for different durations at each site and roll-out strategies varied (see [11] for further information). This project was approved by the district's Human Research Ethics Committee (HREC reference number: 2020/ETH00198).

Recruitment and data collection

Participants included any hospital employee who dealt with the EMR directly or indirectly, including end-users (i.e., doctors, nurses, pharmacists), clinical informatics team members (e.g. system trainers), members of relevant committees (e.g. medicine safety committee) and department directors. A clinical informatics pharmacist at each site identified individuals who they believed were knowledgeable

about the EMR or had relevant roles. This technique was combined with snowball sampling, where participants were asked to propose additional staff members for inclusion. In total, 45 email invitations were distributed.

Semi-structured interviews were conducted either by video conference or in-person at the hospital. Separate interview guides were created for end-users and for individuals who supported EMR use. Interviews were in two parts. In Part 1, reported elsewhere,[11] participants were asked to describe common system-related errors and factors contributing to them. In Part 2, reported here, participants were asked to reflect on how system-related errors changed over time, and to describe detection and mitigation strategies their organization had adopted (see interview guides in the Appendix A and B). Participants had the option to contact the researcher with any additional questions or comments following the interview. The lead investigator (MK) obtained written consent from participants and conducted all interviews. Interviews were audio-recorded, transcribed verbatim and de-identified. Data collection ceased upon reaching thematic saturation.[12]

Data analysis

Interviews were thematically analysed using a general inductive approach, where codes were assigned as themes emerged from the data.[13] Three researchers (MK, MB and WYZ) independently coded the data into themes and met at regular intervals to discuss categories and resolve discrepancies. After agreeing upon a coding framework, researchers coded the remaining interviews and undertook a final review to discuss ambiguities, inconsistencies and confirm major themes and subthemes.

RESULTS

Participant demographics

Interviews were conducted with 25 stakeholders, comprising 15 clinicians (end users of the EMR) and 10 staff from the EMR implementation and support team. Participant demographics appear in Table 1 (see [1] for more detailed demographics). Interviews occurred between September 2020 and May 2021 and took an average of 35 minutes, ranging from 9 to 55 minutes.

Table 1: Interview participant demographics.

Specialty	
Medical	5
Nursing	13
Pharmacy	7
Years in current role	
< 5 years	13
5 – 10 years	10
> 10 years	2

Detection of system-related errors

Participants described several methods by which system-related errors were detected by the hospital sites (see Figure 1).

Detection of system-related errors by clinicians

Detection by front-line clinicians was the primary method of system-related error detection reported by participants. Specifically, participants explained that pharmacists identified system-related errors during medication review or reconciliation, and nurses detected system-related errors when completing routine checks prior to administering medications.

'All orders get verified by a pharmacist, so that pharmacist might intervene if they recognize that an error has occurred by reviewing the order. And nursing staff will also check orders and before administering medications, and they may recognize one of these system errors.' (CIDR2)

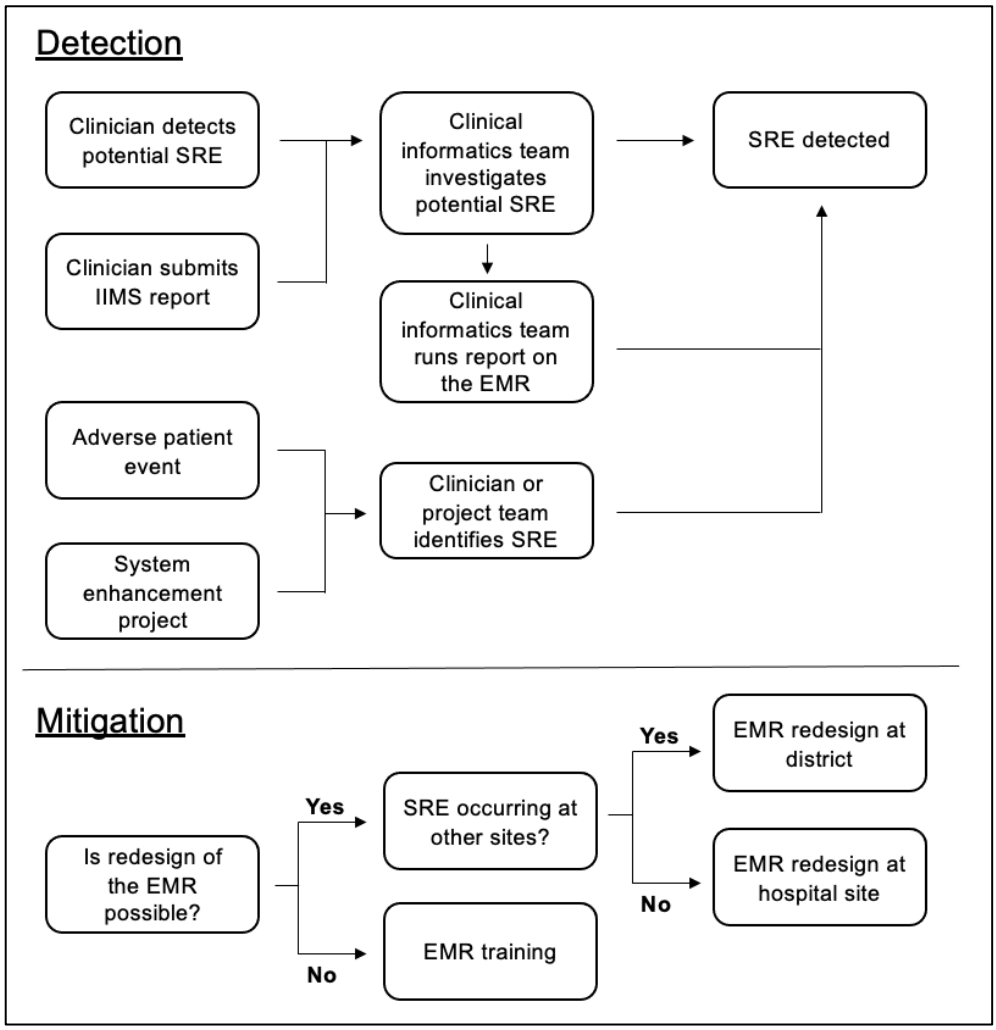

Figure 1: Flowchart depicting the process by which system-related errors are detected and mitigated by hospital staff, based on the themes extracted from interviews with key stakeholders. SRE = System-related error, IIMS = Incident information management system, EMR = Electronic medication record

However, some participants noted that detecting system-related errors was often difficult for nurses as it required them to discern the intended prescription from the recorded prescription.

'If [nurses] are working on a renal transplant ward and they see a funny order for some pain medication that's not normally used in the renal transplant setting, then they may question did the doctor choose the right thing. But it's very hard to pick that up.' (CINU3)

Organizational processes in place to detect system-related errors

Participants reported organizational strategies that complemented clinicians' detection of system-related errors. One of the most frequent approaches highlighted by participants was clinicians reporting potential system-related errors to the clinical informatics team, who then ascertained whether the error was in fact system-related. Clinical informatics team members noted that system-related errors were difficult to detect without clinician input, and investigations into system-related errors were often dependent on clinicians bringing potential cases to their attention.

'Frankly speaking, you don't have anything that can alert you […] It requires a lot of clinicians reporting these issues back to me, for me to be able to know these things are happening on the ward.' (CIPH2)

'It often just comes by word of mouth. Like someone might say something to me. Say, "Oh, can you look at this? This is a bit weird."' (CIPH1)

Participants also explained that system-related errors could be detected via the Incident Information Management System (IIMS); the organization's voluntary reporting system for clinical, work health and safety, and security events.

'So, at a high level they can be reported through our incident monitoring system.' (PH3)

Once a system-related error was reported, participants said that the incident was reviewed and if necessary, investigated by managerial staff. However, interviewees also noted that this detection strategy relied upon clinicians identifying and proactively self-reporting system-related errors.

'In terms of how we found out about them, incident reporting is something I think we are hoping to be more and more proactive about.' (CIDR2)

Another method reportedly used by clinical informatics staff to detect system-related errors was the generation of specific reports within the EMR, such as a monthly report of pharmacy interventions to identify reports that cited the involvement of an EMR system issue. These reports displayed trends in error types and were viewed as useful for determining whether specific system-related errors occurred regularly and what factors could be contributing to error occurrence.

'I will run reports on the EMR to see whether there is a consistent pattern that is happening across the facility. […] Identifying patterns, identifying whether it's a prescribing issue or whether it's a nursing workflow issues, or whether it is actually an EMR issue.' (CIPH2)

Some participants reported that errors were detected by a clinician or project team during inquiries into adverse patient events or during EMR system enhancements when intensive testing sometimes uncovered system-related errors. For instance, when creating a new cancer module in the EMR, project team members discovered that chemotherapy prescriptions did not display all the necessary order components to the user.

Management and mitigation of system-related errors over time

Participants described various approaches to manage and reduce system-related errors, including EMR design changes and organizational strategies, such as training and education (see Figure 1).

Electronic medication record design changes to mitigate system-related errors

When asked to describe strategies to minimize system-related errors, participants explained that after clinicians escalated concerns to the clinical informatics team and a system-related error was confirmed, the EMR system design was modified, if this was deemed to be essential and possible. Modification of the EMR system design could occur when the clinical informatics team recognized a patient safety or workflow benefit from the change and the system was able to be altered (i.e. no system configuration limitations).

'Where we have found people making mistakes, we've been able to implement some actions to circumvent them.' (PH3)

Looking forward, participants stated that over time they would expect fewer system-related errors, attributing this reduction to the fact that errors had been identified and rectified.

'Because, one, we are better aware of how to design the system to reduce the likelihood of some of these errors.' (CIDR2)

Participants provided specific examples of system redesign to target system-related errors (see Table 2). A frequently reported category of system redesign was the addition of alerts for specific processes and medications, such as high-risk medications. Participants stated that in the future, redesigning existing alerts would improve their effectiveness in reducing system-related errors. Improved visibility and clarity of information in the EMR was another strategy reported by participants to mitigate system-related errors.

When reflecting on what would reduce system-related errors in the future, participants described a more intuitive and consistent system (see Table 2). References were made to incorporating human factors design principles into the EMR and ensuring the system aligns with workflow. For example, one doctor suggested that the system become more user-friendly when adjusting doses and times, while a pharmacist proposed that the system provide more clarity of the job role required so that clinicians know which tasks to attend to on the system (i.e., checking off a box is only for nurses).

Although EMR design changes were said to decrease system-related errors, participants highlighted that it was possible for these system functionality changes to result in new types of errors over time.

'As we continue to change it and change the workflows, we will get different errors' (CIPH3)

Participants also noted that some current system-related errors would remain, citing constraints in the system build, preventing design changes that could resolve errors and therefore requiring other strategies to manage these system-related errors.

'There's always going to be the [errors] that we can't resolve, in that we can't change the way the system is built' (CINU1)

Table 2: Specific examples of system redesign described by participants to reduce system-related errors.

EMR design change	Rationale	Quote
Former EMR changes made to reduce system-related errors		
Addition of an alert to notify doctors that the default medication time had been prescribed	• To ensure the time of the medication was reviewed prior to finalizing a prescription • To reduce timing errors associated with the use of antibiotics	'The system now will pop up and say to you that oh, you know, the antibiotic that you've prescribed, the start time is more than an hour away. Is this intentional? Or do you want to change the order?' (PH1)
Addition of a duplication alert for high-risk medications, such as anticoagulants	• To minimize the risk of a patient receiving two medications from the same therapeutic class; an error that	'So now we have what we call a dual anticoagulant pop-up alert. What I mean is, for example, if the patient has already been

	was said to result from patients' current medications not appearing on the EMR screen while prescribing	prescribed a blood thinning medication and the doctor attempts to prescribe another one, they will get a pop-up alert notifying them that, you know, "you have got a blood thinning agent already prescribed."' (CIPH2)
Forcing functions for high-risk medications, such as hydromorphone	• To ensure clinicians reviewed medication parameters selected as part of an order sentence, such as dosage, prior to prescribing or administering medications	'They get a pop-up alert to confirm that they are wanting to prescribe hydromorphone, and the dose that they are wanting to prescribe, to try and prevent overdoses of that medication.' (CINU2)
Introduction of Tallman lettering	• To reduce the risk of selection errors by making medications that sound and look similar more	'There's a lot of work that's been done in relation to, you know, Tallman lettering and all that kind of stuff, to make

	distinguishable from one another	sure that the medicines with a similar name etc are better identified in the EMR.' (CINU5)
Change made to the display of the medication warfarin	• To improve visibility and decrease fragmentation of the warfarin order	'There was a prescribing and administration issue with warfarin. […] So we fixed that up so that you could actually see the order details in the right chronological order rather than it being a bit fragmented' (CINU5)
Recommended changes to the EMR to reduce system-related errors in the future		
Redesign of existing alerts, such as the wording, layout, and complexity of alerts	• To improve their effectiveness in reducing system-related errors	'If you've got multiple alerts at the moment, you get each one individually, and you have to review them. Newer designs will lay them all out and you can make decisions about each of them within one screen, less clicks, less

		movement and a cleaner interface.' (CIDR2)

Organizational strategies to mitigate system-related errors

The most frequently reported organizational strategy employed to minimize system-related errors was education, either to an individual user, a group of clinicians, or hospital-wide. Providing individual feedback or training was said to occur in response to a specific incident, usually in cases where unfamiliarity with the EMR was believed to have contributed to the error. When system-related errors were more widespread, occurring across a particular cohort, ward or hospital, participants explained that education was delivered more broadly.

'Once [nurses] have flagged the problem to the helpdesk, the supervisor or whoever's in charge, […] they will try to find the problem and then give us advice on what to do next.' (NU7)

Participants referred to examples where system functionality or configuration was unable to be changed after identification of a system-related error, and so staff education and training focused on safely bypassing system limitations or constraints so that work could continue. One example provided was with reference to a 'task tile' on the EMR turning red when a medication was not given for more than an hour after it was due. Nurses were instructed not to action these red task tiles if unable to administer the medication to patients (e.g., because of no medication stock), irrespective of whether the system flagged these medications as overdue, to ensure a clinician would be prompted by the red tile in the future.

'There was a bit of education about trying to get them to leave the task tiles as red, so that these doses aren't missed or given at a completely wrong time.' (CIPH1)

Although education was viewed to be an effective strategy for reducing system-related errors, some participants reported the challenge of system-related errors persisting due to staff turnover and the employment of new clinicians.

'Because its constantly new staff coming in, they then don't know the messages that have been sent out last year, for example, so they are not careful. They tend to make the same mistake again at some point or another.' (PH3)

However, participants explained that with more widespread EMR use in the future, users would become more familiar and confident with the system, leading to fewer system-related errors. For example, a clinical informatics doctor explained that with more hospital sites implementing an EMR, more staff had existing experience.

'For example, in New South Wales, I think [understanding of the system] gets easier and easier, as more and more of your staff have used the system elsewhere.' (CIDR1)

Despite this, new errors were reported to also arise when users take more shortcuts or workarounds as they become more familiar with the system. For example, a clinical informatics pharmacist described clinicians exporting information from previous admissions into the patient's current medication chart without consulting the patient.

'You're seeing different types of errors where prescribers are very comfortable now with using information from previous admissions but forgetting that they also need to talk to patient and get updated information to prevent medication errors from

happening. […] When you're familiar with the system, you kind of take certain shortcuts.' (CIPH2)

Some clinical informatics team members noted that raising issues with the chief executive or information officer of the local health district was another organizational strategy used to mitigate system-related errors, particularly when system-related errors were likely to be occurring at other hospital sites and system changes at a district level were necessary.

Finally, minimizing the use of hybrid systems (i.e., paper and electronic systems, dual electronic systems), was mentioned by a few participants as an organizational strategy to reduce system-related errors. However, participants noted that as users become less familiar with paper-based medication charts, new errors may arise when clinicians are required to use paper charts during EMR downtime.

'Some of the new, younger generation, they find it difficult to use as a paper form, when a downtime happens.' (NU5)

DISCUSSION

In this study, interviews with hospital stakeholders provided us with a detailed understanding of detection and mitigation strategies implemented by a health district to target system-related errors, including existing and potential methods required to prevent future errors from occurring. Initial detection of system-related errors was highly dependent on clinicians identifying errors. Once error detection occurred, clinicians had the option to both report these errors directly to the clinical informatics team and submit an IIMS report for escalation. In some cases, system-related errors were detected by reports run on the EMR, or during organizational processes such

as incident investigations or system enhancement projects. EMR redesign was described as the main approach for error reduction, however other organizational strategies, like regular user education and minimizing the use of hybrid systems were also reported.

It is noteworthy that many of the reported approaches for system-related error detection put the onus on clinicians to identify and subsequently report errors. Although verbal and incident reporting by clinicians are conventional methods of error detection, irrespective of EMR involvement,[14] system-related errors are challenging for clinicians to recognize and may go unnoticed unless they lead to an error (i.e. medication error) or adverse patient event.[15] Clinicians' reliance on the EMR system for various elements of delivering clinical care is growing due to an increase in automation and system guidance,[16,17] influencing their ability to recognize a system-related error. Additionally, the complexity of the EMR system,[18] unfamiliarity with the EMR, and distraction caused by competing priorities[19] can all hinder detection of system-related errors.

In addition to difficulties in error detection, challenges associated with reporting of system-related errors are also likely. Clinicians may not report system-related errors if they fear individual blame or punishment,[20] or are unsupported in their efforts to improve patient safety.[21,22] Factors driving under-reporting of incidents are likely to also be at play in reporting of system-related errors to clinical informatics teams, including a perception of low value of reporting if reports are not used to identify error patterns and prevent future incidents.[23] Implementing a systematic feedback process, where clinicians are informed of changes to EMR systems or processes

that result from reporting, would increase the perceived value, confidence and motivation of clinicians to report system-related errors.

The challenges associated with clinician detection and reporting of system-related errors highlight the importance of utilizing complementary strategies to detect these errors. We found that system enhancement projects, as well as reports carried out on the EMR, were other methods of detection, though reported less often. System enhancement projects and reports represent proactive approaches to error detection to harness staff knowledge, as well as historical information about the system, to monitor potential system issues. Combining reactive front-line detection with proactive clinical surveillance and monitoring is likely to ensure system-related errors are promptly identified and investigated.[15]

EMR design changes were the most common approach suggested by participants to reduce system related errors, with many believing EMR redesign would result in fewer system-related errors. However, an unintended consequence of modifying system configuration was the generation of different system-related errors, and several participants stated that certain errors would persist as constraints in the EMR system build limited design alterations (e.g. challenges with large EMR vendors implementing design changes based on one hospital or country). While incremental design changes are necessary for maintenance and development of the EMR system,[24] the dual effect of design changes on system-related errors highlights the challenges in ‘getting it right’ and reinforces the importance of testing environments that simulate real-life EMR situations prior to the go-live of any modifications.[25]

Education, either one-on-one, to a particular cohort, or hospital wide was another mitigation strategy suggested by participants to reduce system-related errors.

Despite the reported benefits of education, participants noted that staff turnover and the employment of new staff could contribute to an increase in errors. By regularly updating training material and providing periodic, targeted education (e.g. as part of onboarding new staff), this would ensure new staff are aware of the most up-to-date material and minimize the risk of medication errors.[26] Further, participants indicated that as a greater number of district staff become proficient in using an EMR, there would likely be fewer system-related errors. However, previous research has shown that as clinicians became more familiar with an EMR system, they develop workarounds to address system inefficiencies and to overcome time constraints.[27,28] Although workarounds can compromise patient safety and quality of care,[29] comprehensive training about its risks and ongoing support for EMR users, can reduce clinicians' use of workarounds.[3]

This research had several limitations. First, interviews were conducted with clinicians and key stakeholders in one Local Health District, and therefore results may not be generalizable to other settings and the detection and mitigation approaches identified may not be exhaustive. Qualitative research methods allowed the authors to conduct an in-depth investigation of detection and mitigation strategies, however this research did not measure how often system-related errors are detected or the effectiveness of improvement methods.

CONCLUSION

To our knowledge, this is the first study to examine how system-related errors are detected by organizations and adds to the growing body of evidence exploring error mitigation. Front-line clinicians play a critical role in system-related error detection, however other organizational approaches, such as system enhancement projects,

improve systemic error detection, investigation, and management. Organizations must take a proactive approach to error identification and ensure detection processes are layered. Although EMR design changes were highlighted as important to error reduction, balancing the utility of design changes with their potential to cause unintended consequences remains a challenge. Complementary error mitigation strategies, such as targeted staff education, can support safe use of the EMR and its continual development.

Author contributions

MK, MB and WYZ designed the study. RB, LMH, HT and JT assisted in the recruitment of participants. MK analyzed the data, with assistance from MB and WYZ. All authors assisted in interpreting results and writing the manuscript. All authors read and approved the final manuscript.

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Conflicting interests

No conflicting interests to declare.

Summary table

What was already known on the topic

- System-related errors, or errors that were unlikely to occur with paper-based medication charts, have been identified as an unintended consequence of electronic medical records.
- Previous research has identified the types and factors contributing to system-related errors, as well as the prevalence of these errors.

What this study added to our knowledge

- A comprehensive overview of the detection and mitigation strategies targeting system-related errors, including existing and potential methods required to prevent future errors from occurring.
- Front-line clinicians play a critical role in detecting system-related errors, however other organizational approaches such as system enhancement projects and EMR reports are also important for proactive detection.
- Although EMR design changes were suggested as a key strategy to reduce system-related errors, complementary strategies such as targeted staff education can support safe EMR use and continual development.

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SUPPLEMENTARY MATERIAL

Appendix A: Semi-structured interview questions for hospital staff members/clinicians directly using the electronic medication record

Basic demographics

1. What type of staff member/clinician are you (i.e. nurse, doctor, pharmacist) and roughly how many years have you been in this role?
2. What ward/specialty do you predominantly work in?

About EMR

3. How long have you been using the *EMR* system?
4. Did you have experience with paper-based medication systems prior to using the *EMR*?
5. How often do you use the *EMR*? For example, to prescribe.
6. What training did you receive on the *EMR*?
7. How proficient do you feel you are in using the *EMR*?

System-related errors

As mentioned, I'm interested in system-related errors of the EMR.

8. How would you define a system-related error?

In my study, I am defining a system-related error as any error that was unlikely or unable to occur in paper-based medication management systems. In other words, these errors would be unlikely or not possible without the EMR.

Using this definition:

9. How are system-related errors identified or detected in the hospital?
10. Once a system-related error is detected, how are these errors managed or rectified?

Timing of system-related errors

In thinking about the types of system-related errors that happen now:

11. Do you think they were different to the types of errors that occurred when the system was first implemented (e.g. during the first 6-months of use?)
12. Do you think these errors will be different in the future, once using the system becomes routine/as the system continues to be used?

Future of the EMR

13. In your opinion, what interventions or changes have improved the system or reduced system-related errors?
14. What would you like to see change about the system?
    a. Why?
15. Do you have anything further to add that has not already been discussed?

Appendix B: Semi-structured interview questions for all other stakeholders

Basic demographics

1. What is your current role and roughly how many years have you been in this role?
2. What interactions do you have with the *EMR*?

About EMR

3. How long have you been supporting the use of the *EMR* system?
4. What training did you receive on the *EMR*?

Detection of system-related errors

As mentioned, I'm interested in the system-related errors of the EMR.

5. How would you define a system-related error?

In my study, I am defining a system-related error as any error that was unlikely or unable to occur in paper-based medication management systems. In other words, they would be unlikely or not possible without the EMR.

Using this definition:

6. How are system-related errors identified or detected in the hospital?
7. Once a system-related error is detected, how are these errors managed or rectified?

Timing of system-related errors

In thinking about the types of system-related errors that happen now:

8. Do you think they were different to the types of errors that occurred when the system was first implemented (e.g. during the first 6-months of use?)
9. Do you think these errors will be different in the future, once using the system becomes routine/as the system continues to be used?

Future of the EMR

10. In your opinion, what interventions or changes have improved the system or reduced system-related errors?
11. What would you like to see change about the system?
    a. Why?
12. Do you have anything further to add that has not already been discussed?

Appendix C: COREQ (COnsolidated criteria for REporting Qualitative research) checklist

A checklist of items that should be included in reports of qualitative research. You must report the page number in your manuscript where you consider each of the items listed in this checklist. If you have not included this information, either revise your manuscript accordingly before submitting or note N/A.

Topic	Guide questions/description	Reported on page #
Domain 1: Research team and reflexivity		
Personal characteristics		
Interviewer/facilitator	Which author/s conducted the interview or focus group?	183
Credentials	What were the researcher's credentials? e.g. PhD, MD	183
Occupation	What was their occupation at the time of the study?	183
Gender	Was the researcher male or female?	N/A
Experience and training	What experience or training did the researcher have?	183
Relationship with participants		
Relationship established	Was a relationship established prior to study commencement?	183

Participant knowledge of the interviewer	What did the participants know about the researcher? e.g. personal goals, reasons for doing the research	183
Interviewer characteristics	What characteristics were reported about the interviewer/facilitator? e.g. bias, assumptions, reasons and interests in the research topic	183
Domain 2: Study design		
Theoretical framework		
Methodological orientation and Theory	What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis	183
Participant selection		
Sampling	How were participants selected? e.g. purposive, convenience, consecutive, snowball	182 - 183
Method of approach	How were participants approached? e.g. face-to-face, telephone, mail, email	183
Sample size	How many participants were in the study?	184
Non-participation	How many people refused to participate or dropped out? Reasons?	183
Setting		
Setting of data collection	Where was the data collected? e.g. home, clinic, workplace	183

Presence of nonparticipants	Was anyone else present besides the participants and researchers?	183
Description of sample	What are the important characteristics of the sample? e.g. demographic data, date	184
Data collection		
Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	183
Repeat interviews	Were repeat interviews carried out? If yes, how many?	N/A
Audio/visual recording	Did the research use audio or visual recording to collect the data?	183
Field notes	Were field notes made during and/or after the interview or focus group?	N/A
Duration	What was the duration of the interviews or focus group?	184
Data saturation	Was data saturation discussed?	183
Transcripts returned	Were transcripts returned to participants for comment and/or correction?	183
Domain 3: Analysis and findings		
Data analysis		
Number of data coders	How many data coders coded the data?	183

Description of the coding tree	Did authors provide a description of the coding tree?	185
Derivation of themes	Were themes identified in advance or derived from the data?	183
Software	What software, if applicable, was used to manage the data?	N/A
Participant checking	Did participants provide feedback on the findings?	183
Reporting		
Quotations presented	Were participant quotations presented to illustrate the themes/findings? Was each quotation identified? e.g. participant number	185 - 195
Data and findings consistent	Was there consistency between the data presented and the findings?	185 - 195
Clarity of major themes	Were major themes clearly presented in the findings?	195
Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?	185 - 195

Developed from: Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care*. 2007. Volume 19, Number 6: pp. 349 – 357

Chapter 6: Review of Electronic Medication Management System Enhancements

Preface

The second component of stakeholder interviews explored the detection and mitigation strategies adopted by a health district to target system-related errors, including existing and potential methods required to prevent future system-related errors from occurring. Front-line clinicians were reported as the chief source of detection for system-related errors. In addition, errors were identified through reports performed on the EMM system or organisational processes, including incident investigations or system enhancement projects. Ongoing user education on the EMM system and minimising the use of hybrid systems were described by participants as key error mitigation strategies. However, redesign of the EMM system was the primary approach reported for managing system-related errors. Despite the importance of EMM system redesign, no research has specifically examined the system changes introduced to address system-related errors. Therefore, this chapter sought to describe and classify the types of enhancements made to an EMM system to target system-related errors, and examine how these changed over time, fulfilling the fifth and final aim of this research program.

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Authorship attribution statement

This statement describes the contribution made by Madaline Kinlay in the preparation and submission of the following manuscript: "*Electronic Medication Management Systems: Analysis of Enhancements to Reduce Errors and Improve Workflow*". The convention is that the author with the principal contribution to the manuscript is the first author.

Madaline Kinlay, during her PhD candidature, developed the original concept of the study with her supervisors, and was responsible for interpreting and analysing the documents containing EMM system enhancements with assistance from her co-authors, drafting and revision of the manuscript, and coordinating submission for publication of the original research paper.

_____

Madaline Kinlay 28 June 2023

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statement above is correct.

_____

Melissa Baysari 28 June 2023

Title

Electronic medication management systems: Analysis of enhancements to reduce errors and improve workflow

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ABSTRACT

Background

Electronic medication management (eMM) has been shown to reduce medication errors, however new safety risks have also been introduced that are associated with system use. No research has specifically examined the changes made to eMM systems to mitigate these risks.

Objectives

To 1) identify system-related medication errors or workflow blocks that were the target of eMM system updates, including the types of medications involved, and 2) describe and classify the system enhancements made to target these risks.

Methods

In this retrospective qualitative study, documents detailing updates made from November 2014 to December 2019 to an eMM system were reviewed. Medication-related updates were classified according to ‘rationale for changes’ and ‘changes made to the system’.

Results

One hundred and seventeen updates, totaling 147 individual changes, were made to the eMM system over the 4-year period. The most frequent reasons for changes being made to the eMM were to prevent medication errors (24% of reasons), optimize workflow (22%) and support ‘work as done’ on paper (16%). The most frequent changes made to the eMM were options added to lists (14% of all changes), extra information made available on the screen (8%) and the wording or phrasing of

text modified (8%). Approximately a third of updates (37%) related to high-risk medications. The reasons for system changes appeared to vary over time, as eMM functionality and use expanded.

Conclusion

To our knowledge, this is the first study to systematically review and categorize system updates made to overcome new safety risks associated with eMM use. Optimization of eMM is an ongoing process, which changes over time as users become more familiar with the system and use is expanded to more sites. Continuous monitoring of the system is necessary to detect areas for improvement and capitalize on the benefits an electronic system can provide.

Keywords

Medical order entry systems, patient safety, medication error, workflow

BACKGROUND AND SIGNIFICANCE

The introduction of electronic medication management (eMM) systems in hospitals, (also referred to as computerized provider order entry systems), has been transformative in healthcare, with research showing that implementation of eMM reduces medication errors.[1,2] An eMM, often one component of an electronic medical record (eMR),[3] allows clinicians to prescribe and review medications, as well as reconcile and record their administration. In addition, the embedding of clinical decision support (CDS) into an eMM system provides information to users in real-time on potential medication-related harms by, for example, alerting clinicians to known allergies or drug interactions.[4]

Given the complex nature of medication management in hospitals, the interaction between eMM systems, the tasks required to be performed by their users and existing workflows can give rise to unintended consequences.[5] A key example of this is the introduction of new safety risks that were previously not possible with the use of paper records. Research has shown that new types of medication errors can occur as a direct consequence of using electronic systems, errors referred to as system-related errors.[6-8]

In a recent systematic review that synthesized evidence of the effectiveness of eMM to reduce medication error rates and associated patient harms, 12 of the 18 included studies reported the emergence of system-related errors. In the four studies quantifying these types of errors, they reported that between 1% - 35% of all medication errors were system-related.[2] Examples of system-related errors described in these papers included medication errors resulting from the incorrect

selection of order components,[9-11] the failure to modify incorrect default options,[12] and misuse of system functionalities, including clinical decision support.[13,14]

Another systematic review providing further insight into how and why these new errors emerge, identified eight key areas that contribute to eMM-related prescribing errors, such as the computer display and system configuration, unintuitive and automated task processes, and current user workflows.[15] There is now little doubt that system-related errors do not result purely from technical issues, but rather incompatibilities between system design and user factors.[16,17] Users frequently report that eMM systems introduce additional steps to complete tasks compared to paper-based records, and identify a range of usability issues with systems, often leading clinicians to adopt workarounds.[18,19] For example, the inflexible design of structured order templates has led clinicians to use free-text boxes to communicate prescribing information, limiting the system's ability to detect possible drug interactions and contributing to inconsistent order information, both of which can lead to significant errors.[20-22]

OBJECTIVE

This research provides us with a good foundation for understanding the types and prevalence of new medication errors that arise with the use of eMM systems, but some clear evidence-gaps exist. We know very little about the longitudinal effects of system use on system-related errors (i.e. whether errors change over time?),[23] and about modifications made to eMM systems in order to mitigate system-related errors.[24] Following the implementation of eMM, the system is continuously updated in response to the identification of glitches, errors, workflow blocks, and user feedback,[25] but to date, no research has specifically examined the changes made to

eMM systems to mitigate risks and streamline clinician workflow. In this study, we aimed to 1) identify potential system-related errors or workflow blocks which were the target of eMM system updates, including the types of medications involved, and 2) describe and classify the system updates made to target these new risks.

METHODS

Design and setting

This retrospective qualitative study reviewed and classified updates made to the eMM component of a commercially available electronic medical record (Cerner Millennium®) at three acute public hospitals within a Local Health District (LHD) in New South Wales (NSW), Australia. The NSW State Government (Australia) guidance recommends documenting all updates made to an eMM and the rationale for these changes.[3] This study was approved by the districts' Human Research Ethics Committee.

A staged roll-out of the eMM occurred in the first hospital between November 2007 and May 2015. The other two sites introduced the eMM system hospital-wide in September 2017 and March 2019 respectively, over a two-week period.

Information and Communications Technology (ICT) services are delivered by a central district-wide Information Management and Technology Division (IM&TD), as well as facility-based ICT support teams and specialist staff. For this reason, eMM system updates typically occur at a LHD level. When a clinician requests an eMM change, the application team determine what is possible, build the change into the testing domain of the eMM and seek feedback from the clinician. Once the clinician approves the change, wider group approval is sought from affected stakeholders

(e.g. changes to antimicrobial prescribing require consultation with the infectious diseases team) and the health informatics medical, nursing and pharmacy teams. Once approved, users complete further testing and the change is released on the eMM system, while the ICT team prepares the monthly document detailing recent changes.

Data collection

Documents detailing key system updates and new features in the electronic medical record across the LHD, published from November 2015 to December 2019, were reviewed. This time period was selected as it commenced with the regular monthly updates made within the district and concluded prior to the COVID-19 pandemic. These documents are compiled by the district's IM&TD staff approximately once a month and distributed to staff via the intranet. Each document was read thoroughly and all updates relating to the medication management process were included in the analysis. Medication-related updates were excluded if they described improvements related to clinical information systems external to the three hospitals. Documents generally followed a similar format with sub-components of the eMR highlighted by headings (e.g. eMM). However, compared to recent reports, earlier documents were less detailed and structured. Updates ranged from a single sentence, with or without an image, to a comprehensive update specifying multiple individual changes, with detailed descriptions and images of each change (Figure 1).

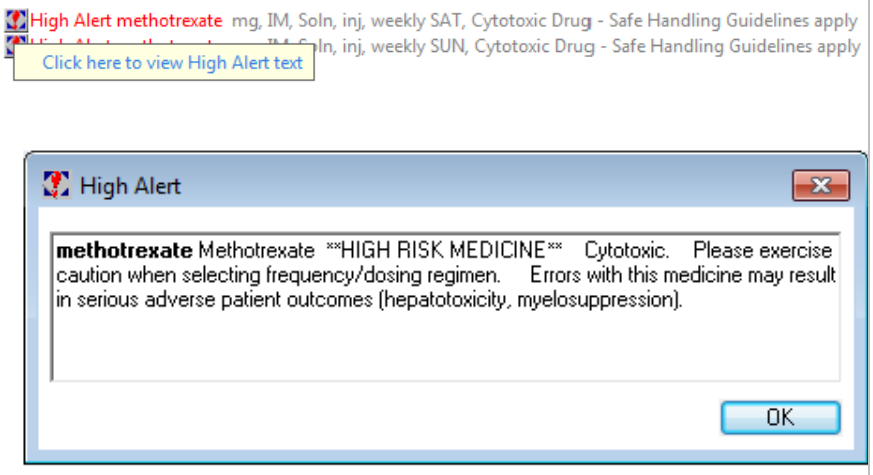
a)	**New medication void reasons**	
b)	**High alert functionality on Methotrexate and Toujeo**	Methotrexate (and its brand) and Toujeo (insulin glargine 300 IU) will have “High Alert” icon in front of the medication name and the text will be in red. There will be an associated high alert text. 

Figure 1: Examples of medication-related updates in the electronic medication record (eMR), detailing a) one system change made to the options available in a drop-down list for reasons a medication was voided and b) multiple system changes for two high-risk medications, including changing the font to red and the addition of an icon and alert.

Classification

Initially, an attempt was made to categorize medication-related updates and the reason for updates using three existing classifications,[6,26-28] including a classification tool for health service organizations based on pioneering work by Westbrook et al.[6,12] and Magrabi et al.[16,29-32] However, when mapping eMM updates to categories,

many were classified into the broad category of ‘problems with clinical information system functionality’, which provided limited insight into the nuances of system enhancements.

As no suitable pre-existing classification could be identified, medication-related updates were classified according to ‘Rationale for change’ (Table 1) and ‘Change made to the system’ (Table 2; see Appendix A in the Supplementary Material for full classifications with definitions and examples). This classification system was iteratively developed using cases as they emerged. Specifically, an initial sample of 10 updates was independently classified by three researchers with expertise in psychology, human factors and clinical informatics (MK, MB and WYZ). Researchers met to review assigned codes, discuss disagreements and develop the classification framework. In developing the categories, researchers ensured they described general changes and concepts that could be applied to other settings. The remaining updates were then classified by one researcher (MK), with all complicated or unclear updates discussed initially with the other researchers, and if still unclear, with a specialized eMM pharmacist (LMH) from one of the hospital sites, to ensure consistent and credible results.

RESULTS

Overview of system updates

The sample included 43 documents with 117 updates, totaling 147 individual changes made to the eMM system over the 4-year period.

We identified between one and three reasons for each update, with a total of 140 reasons for the changes made in our sample. Eight broad categories of reasons for

the changes made to the eMM system were identified in the dataset: prevent error, support ‘work as done’, optimize workflow, improve documentation, improve monitoring, avoid confusion or misinterpretation, support the expansion of eMM use, and improve compliance with policies/guidelines (Table 1). Across the timeframe (Nov. 2015 - Dec. 2019), the most common rationale for an update to the eMM system was to prevent medication errors (24% of all rationales). Of the 34 updates that were made to prevent errors, the addition of an alert was the most common change (13% of the changes that were made to prevent errors). For instance, an alert was added to inform prescribers of an existing active anticoagulant order when ordering a new anticoagulant, to prevent duplication and possible contraindication. Updates also frequently occurred to optimize workflow (22% of all rationales), replicate work as done on paper charts (16%) and support the expansion of eMM use (14%), either to another ward or cohort of patients in the hospital, or to another hospital site in the district. Remaining updates were made to improve documentation (9%), avoid confusion or misinterpretation (6%), improve monitoring (5%), and to improve compliance with policies and guidelines (4%). Of the 31 updates made to optimize workflow, eight updates included additional information on the screen, such as the display of relevant pathology results during prescribing. Other frequent system changes to optimize workflow included the addition of an MPage or tab to support clinical decision making, the addition of a PowerPlan or Care Set and the addition of options to lists, specifically folders to menu lists (e.g. addition of a nurse initiated medications folder). For example, an MPage (see definition in Box 1) was added to provide clinicians with a consolidated view of their patients’ diabetes therapy over the last 30 days, allowing review of the trend in blood glucose and ketone levels over time, and facilitating therapeutic decisions.

Box 1: Definitions of eMM system components

PowerPlan	A set of orders that are grouped together to support a specific condition, procedure or process. This could describe multiple phases of care and can include additional orders
Care Set	Similar to a Powerplan, but describes a single phase of care and cannot be modified
Order sentence	A pre-written medication order with pre-filled values/components
Order form field	A component of a medication order requiring a value to be inputted
Alert	A ‘pop-up’ window notifying the user that an action or event is about to occur, providing relevant information, providing a recommendation, or warning of a potential risk
MPage/tab	A page in the eMR or web browser that displays specific data from multiple eMR sections (e.g. pathology and medications) based on certain parameters to assist in decision-making

Note: eMR = electronic medical record

Table 1: The rationale and most frequent medication-related changes made to the system for each rationale.

Rationale for change (%*)	Definition	Most frequent changes
Prevent error (24.3)	To directly or indirectly reduce the likelihood of a medication error occurring	• Alert/s added • Extra information made available • Font/background changed • Component/s of an order sentence modified
Support 'work as done' (16.4)	To ensure the system supports practices that were previously completed on paper, for example by capturing the range of possible order components and regimens used by clinicians	• Option/s added to list • Field/s added • Use of free text data entry broadened
Optimize workflow (22.1)	Capitalizing on the capacity of the electronic system to facilitate more efficient and streamlined workflow, including supporting decision making, providing a	• Extra information made available • MPage/tab added • PowerPlan/Care Set added • Option/s added to list

	better overview of the patient or patient group, or reducing the number of actions required by the user	
Improve documentation (8.6)	To maintain accurate and thorough records of use, for example when completing medication reconciliation	• Field/s added • Option/s added to list • Option/s removed from list
Improve monitoring (5.0)	To capture and monitor the use of the system	• Report added
Avoid confusion or misinterpretation (5.7)	To reduce the likelihood of users being confused about system functions, for example by improving terminology and/or phrasing	• Wording and/or phrasing modified • Option/s removed from list • Alert/s removed
Support the expansion of eMM use (13.6)	To enable the broadening of eMM use, for example to ensure consistency across the district when eMM use expands to additional sites or to support expanded functionality of the eMM to other patient wards	• Wording and/or phrasing modified • PowerPlan/Care Set removed • PowerPlan/Care Set added • Order sentence/s added

Improve compliance with policies/guidelines (4.3)	To ensure staff are adhering to hospital-, district-, state- or nation-wide rules as determined by policies or guidelines	• Forced review • PowerPlan/Care Set removed

* Percentages reflect the proportion of changes made for each rationale. Note: eMM = electronic medication management

Ninety-six updates reported one change, with the remaining 21 updates reporting between two and five changes. Six broad categories of changes made to the eMM system were identified in the dataset: change to the visual display, change to the options available, change to the clinical decision support, adding a forcing function, improved information transmission and other. As shown in Table 2, the most common change to the system was ‘changes to the options available’, followed by ‘changes to the content on the visual display’. This former category included options added to lists, which was the most frequent subcategory of changes. The latter category included extra information made available on the screen or the wording or phrasing of text modified. Options added to lists were most frequently to ‘support work as done’, ‘optimize workflow’ and ‘prevent errors’. For example, ‘IV infusion therapy day’ was added as a route of administration for antineoplastic medications, as this is regularly prescribed by clinicians. Extra information was made available on the screen primarily to optimize workflow and prevent errors, such as including the date and time of the final scheduled medication dose in the clinical display line to prevent errors resulting from the incorrect continuation of a medication regimen. Modifications to the wording or phrasing of text were most frequently implemented to avoid confusion or misinterpretation and support the expansion of eMM use.

Some updates represented modifications or successive additions to previous updates. Figure 2 provides examples of linked updates.

Table 2: A classification of updates made to an eMM specifying changes made to the system.

Category	Area of change	Change made on the system	Number of changes	% of total changes*
Change to the visual display	Design	Font/background changed	5	3.4%
		Icon added	3	2.0%
		Order of information modified	3	2.0%
	Content	Extra information made available	11	7.5%
		Wording and/or phrasing modified	11	7.5%
Category total			33	22.4%
Change to the options available	PowerPlans/Care Sets	PowerPlan/Care Set added	9	6.1%
		PowerPlan/Care Set removed	4	2.7%

		Component/s of a PowerPlan/Care Set modified	1	0.7%
		Use of PowerPlan/Care Set broadened	1	0.7%
	Order sentences	Order sentence/s added	4	2.7%
		Order sentence/s removed	1	0.7%
		Component/s of an order sentence modified	7	4.8%
		Filter added for order sentence/s	1	0.7%
	Order form fields	Field/s added	4	2.7%
		Field/s removed	1	0.7%
		Field/s combined	1	0.7%

		Field/s modification restricted	1	0.7%
	Lists	Option/s added to list	20	13.6%
		Option/s removed from list	4	2.7%
		Use of option/s broadened	1	0.7%
	Free text data entry	Use of free text data entry broadened	3	2.0%
Category total			63	42.9%
Change to clinical decision support	Alerts	Alert/s added	7	4.8%
		Alert/s removed	7	4.8%
		Alert/s content modified	3	2.0%
		Alert/s use broadened	3	2.0%
	MPages/tabs	MPage/tab added	7	4.8%

		MPage/tab removed	2	1.4%
	Other	Task automation or calculation	3	2.0%
Category total			32	21.8%
Adding a forcing function	Forced review		5	3.4%
	Forced selection		2	1.4%
Category total			7	4.8%
Improved information transmission	Between eMM and other eMR modules		2	1.4%
	Between eMR and other HIS		2	1.4%
Category total			4	2.7%
Other	eMM use broadened		1	0.7%
	Report added		7	4.8%

Category total	8	5.4%
Total	**147**	**100%**

* Percentages may not add up to their category totals due to rounding. Note: eMM = electronic medication management, eMR = electronic medical record, HIS = health information system

July 2017

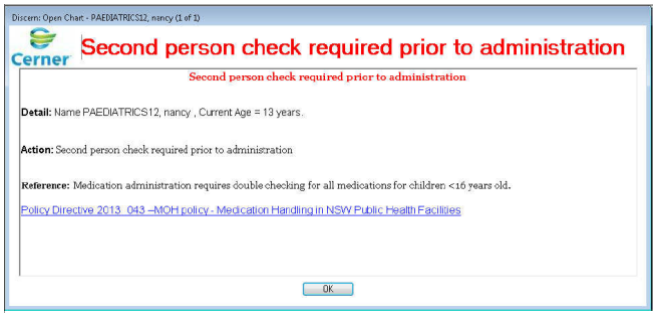
A **new Glucose Management MPage was added** in the High-risk Medication tab to provide clinicians with a consolidated view of their patient's diabetes therapy over the last 30 days.

September 2017

The **Glucose Management MPage was optimised to load more quickly**, as it was loading slower than expected, particularly when opened for the first time on a patient's profile.

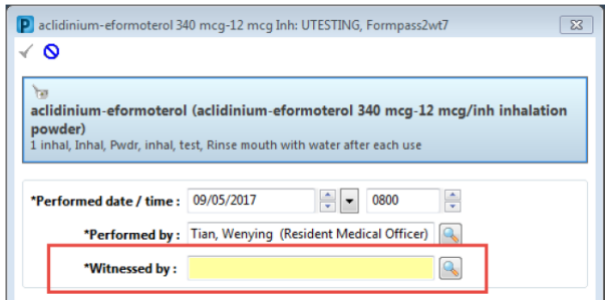
Prior to June 2017

If a patient is younger than 16 years, **an alert** reminds each nurse that this patient requires two signatures for medication administration, although the "witnessed by" field is not currently mandatory.



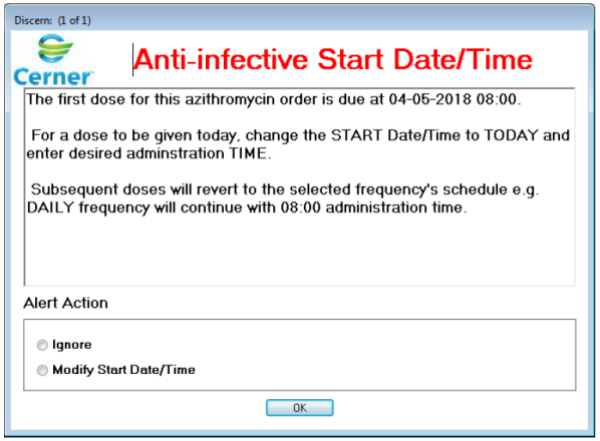
June 2017

The alert was replaced by the mandatory second witness functionality in the medication administration window for patients under 16 years.



April 2017

An alert is modified to appear for both anti-infective orders with a 6-hour frequency and a start date/time that is **not today.**



May 2018

An alert is further modified to also appear for all anti-infective orders with a first dose date/time **beyond one hour from the current time.**

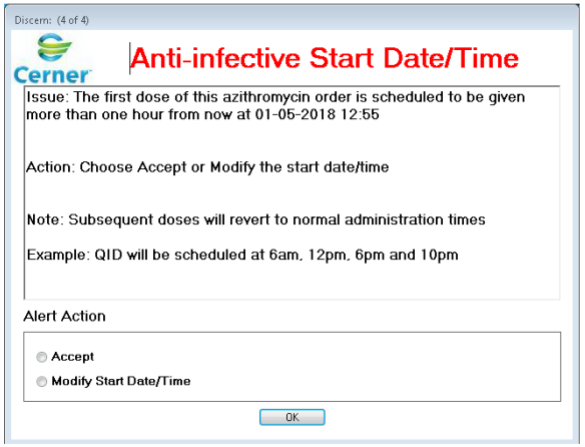


Figure 2: Examples of updates that reflect modifications to previous updates.

Medications that were the focus of updates

Approximately a third of updates (37%) related to high-risk medications or to medicines known to have an increased risk of causing significant patient harm when misused or used in error.[33] These include antimicrobials, insulin, narcotics, electrolytes, anticoagulants and chemotherapeutic drugs.[34] For example, an antimicrobial surveillance MPage was implemented to monitor patients with one or more anti-infective drugs at any point during admission. Additionally, PowerPlans or electronic order sets were added and modified for anticoagulants, insulin, and chemotherapy to comply with local protocols. High-risk medications frequently required multiple changes. For example, updates to make hydromorphone safer included the introduction of tallman lettering with red text, the forced selection of brand name or therapeutic substitution when prescribing, and high-risk alerts for both prescribers and administrators. Although the focus of many system updates, each high-risk medication was managed differently and there did not appear to be a standard approach or set of systematic changes for high-risk medications. For example, updates to hydromorphone included those listed above, while updates for insulin included high-risk alerts combined with a diabetic patient care MPage and the forced review of blood glucose results at the point of prescribing.

Rationale for the system changes made across time

As shown in Figure 3, reasons for system changes appeared to vary over time. Updates to support the expansion of eMM use increased from 6% of updates in 2016 to 24% of updates in 2019. In contrast, 29% and 12% of changes were made to optimize workflow and improve documentation in 2016, respectively, but these decreased to 10% and 3% in 2019.

System changes made to improve compliance with policies and guidelines occurred only in 2017 and changes to improve monitoring only in 2019. These latter updates represented the addition of reports to the eMR menu that allowed monitoring of specific elements of eMM use (e.g. medication administration by dose, date and time).

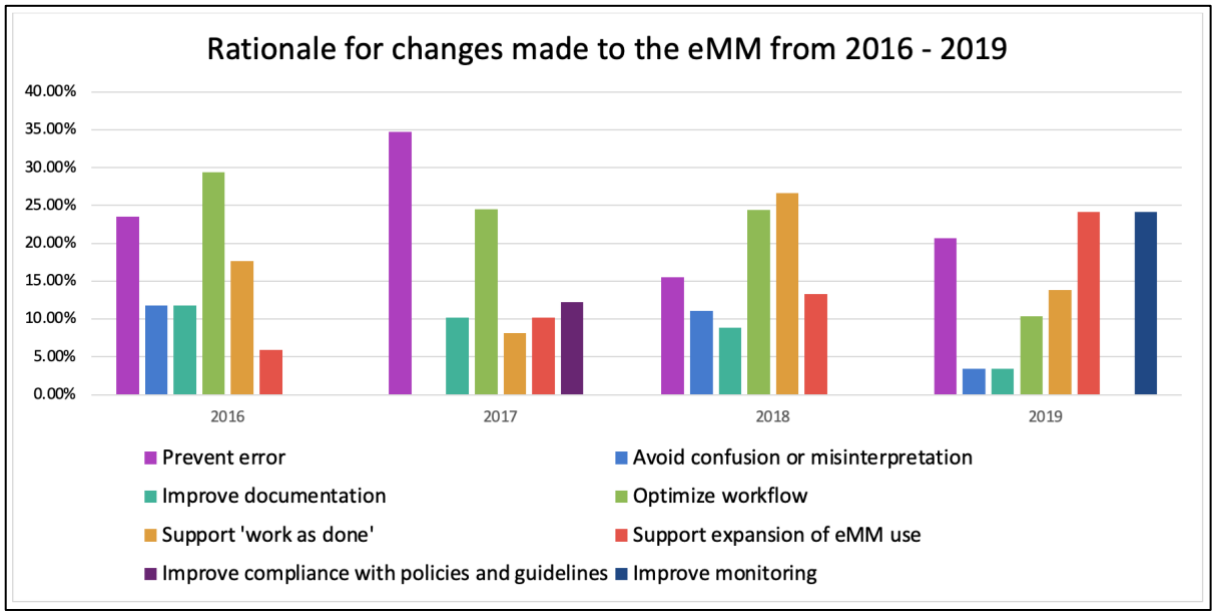


Figure 3: Rationale for changes made to the eMM across the time-period, as a percentage of total rationales per year.

DISCUSSION

This study used the unique approach of reviewing and classifying eMM system updates, providing concrete examples of system changes introduced to prevent error and improve workflow. We found nearly 150 changes were made to the eMM system over a 4-year period, with most introduced to prevent medication errors and optimize workflow. Options were made available in the eMM to allow continuity of work practices from paper to the eMM. Updates also sought to capitalize on eMM functionality and provide additional support to assist in decision making and guide

appropriate user action; these were not possible in a paper-based system. Although a large proportion of updates related to high-risk medications, and often multiple changes were introduced in the eMM system to target high-risk medication errors, there did not appear to be a consistent approach taken to optimize high-risk medication use. Over time, with ongoing eMM use, the focus of updates shifted towards monitoring eMM system use and supporting its expansion to other locations both internally and externally.

Updates reviewed in this study most frequently targeted the prevention of medication errors. Although medication error rates have been shown to reduce after eMM implementation,[12,35,36] the system has also been associated with new types of errors.[6,37] Further, the degree of improvement following eMM implementation can vary depending on context, implementation strategy and system design.[1,38] Therefore, fulfilling the benefits of eMM requires hospitals to develop error prevention strategies that also minimize the risk of system-related errors, with consideration of clinical and organizational needs. Of note, the introduction of an electronic alert was the most common change aimed at error prevention in our sample. However, an increased number of alerts can lead to alert fatigue, a well-recognized phenomenon,[39] where clinicians become overburdened and their ability to determine which alerts are clinically significant declines, leading to habitual overrides.[40] The importance of optimizing alerts and continually reviewing their effectiveness in preventing errors is now well-recognized.[41] In our study, we found that although alerts were added, some were also modified or removed, suggesting that the local eMM team were aware of the risk of alert fatigue and its negative impacts.

We found that options were frequently added to drop-down lists and menus (e.g. adding the frequency of ‘every 12 hours on therapy day’ to antineoplastic orders), to ensure the system supported prescribing and administration practices previously completed on paper. When adding items to lists, we recommend that sites be mindful that incorrect selection from drop-down lists is one of the most frequent system-related errors reported in the literature.[6,9,42,43] Long lists of options can result in excessive scrolling and clicks, increasing the chance of selection errors.[6,44] Irrelevant or limited options on lists encourage the use of manual entry and free-text ordering, with flow on effects like unclear or inconsistent order information, or medication orders that are unable to trigger clinical decision support.[45,46] These potential pitfalls highlight the importance of only including relevant list items and good design of lists. Placing frequently used items at the top of a list, rather than alphabetically, can reduce selection errors and the likelihood of picking medication names that look and sound alike.[6,15]

The use of eMM allows relevant information to be available to users at the point of decision making but research has shown that some system designs require users to search for pertinent information across screens and pages.[43] For example, a qualitative case study of eMM implementation at two hospitals found a reported increase in workload as a result of the time taken to search for information between systems and computer screens.[43] Good design minimizes navigation between screens and the requirement for users to remember vital information as they move between eMR pages.[47] In our sample, we found that providing extra information on the screen (e.g. displaying the date and time for the final scheduled dose during administration), was a frequently employed strategy to facilitate the streamlining of workflow and to prevent error. Further, some changes involved the consolidation and

summary of pertinent clinical information into one location, easily accessible via dedicated MPages to assist in clinical decision making. Although a common approach, non-interruptive CDS may not influence decision making unless actively integrated into workflow.[48] Rather, we suggest anticipating specific patient needs by integrating frequently grouped orders into user workflows can act as non-interruptive CDS. We found that grouping orders (e.g. PowerPlans and Care Sets) was another strategy for optimizing workflow and guiding appropriate action. By providing timely patient specific clinical information, improvements can be seen in the quality, efficiency and safety of medication management.[49]

Our results also demonstrate that particular attention is paid to high-risk medications when preventing errors, as a large proportion of updates related to these. Changes were often implemented simultaneously in the eMM system, and at multiple timepoints, typically targeting different users (e.g. prescribers and administrators) of the system. This is in line with recommendations from the Institute for Safe Medication Practices,[50] proposing that strategies for risk minimization should be multi-layered and target multiple phases in the medication use process. We also found there did not appear to be a single approach used for these medications; instead careful consideration was given to the appropriate ways to support the use of each high-risk medication. This involved understanding the specific information required for decision making, as well as the interdependencies in clinician workflows, before developing appropriate solutions. For example, the dose and frequency of insulin relies heavily on blood glucose results. In response, a diabetic MPage with a consolidated view of associated patient details, medications, and results were made available to prescribers in the eMM system, while nurses were required to acknowledge previous blood glucose results prior to the administration of insulin. In

another example, prescribers were required to select a brand name when ordering hydromorphone, as it has a narrow therapeutic window requiring the correct form to be given (i.e. immediate-release or extended-release). These examples highlight the complexity of medication management and suggests that when implementing updates to reduce the risk of high-risk medication errors, careful consideration should be given to what information is necessary at each point in the medication use process.

Implementation of an eMM system is rarely district-wide, with most implementations in New South Wales (Australia's largest state), occurring sequentially by piloting at one site first and then expanding to others.[51] In this study, we found that expanding eMM use to other sites necessitated a number of system changes, particularly to the options available for selection (e.g. removing Care Sets that comply with site specific policies), and the wording or labelling of existing orders in the form of order sentences, PowerPlans and Care Sets. This coincided with the removal of alerts that were no longer relevant, and the implementation of forcing functions, such as mandatory second signatures. These changes were implemented to minimize the likelihood of users misinterpreting system functionality and to enforce standardization across hospitals, as well as accommodate any site specific services (e.g. chemotherapy PowerPlans available at a site that offers these services). As clinicians frequently move between sites within a district, and find variability between sites challenging to navigate,[52] we recommend ensuring consistency in wording and workflows to minimize the risk of error and the time required to learn to navigate a new system.

Additionally, monitoring of system use was facilitated by the addition of reports in 2019. Reports import selected data in a meaningful way to monitor areas of interest. These changes are likely to reflect increased vigilance with site expansion and accreditation. Once routine use of the eMM system is reached, attention can be refocused from acute system safety risks to long term maintenance and improvement. Although knowing what and how to measure system use is difficult,[53] all efforts to improve understanding of the eMM in a specific context are valuable and essential for succesful widespread use and interoperability with other information systems.

Limitations

This study is limited by the quality of the data contained in the documents reviewed, which did not include all system changes (e.g. updates to the drug catalogue) and were not always exhaustive, particularly with respect to why system changes were made. To fully understand the 'why' of system changes, we plan to complement this study with a qualitative investigation of stakeholder perspectives of system-related errors and updates implemented to improve the eMM system. While our study analyzed system changes, it did not evaluate the impact of these changes on medication error rates or workflows. Despite this, our data provides valuable insights into why changes were made and expected benefits from eMM enhancements. Our analysis was conducted primarily by one researcher, but all difficult cases were reviewed by a group to ensure accurate and consistent coding. Our study was further limited by its qualitative nature and the fact that only one type of eMM system in a single local health district was assessed, and although our findings provide general understanding and lessons for those implementing or optimizing medication

systems, caution should be taken when generalizing results to other hospitals or different eMM systems.

CONCLUSION

Following system implementation, new safety risks can emerge as a result of eMM use, including system-related errors and workflow blocks. To our knowledge, this is the first study to systematically review and categorize system updates that have been made to overcome these risks over time, providing real-life examples that can be considered and applied in other settings. We found that updates or changes to the system sought to guide user actions by refining options available in selection lists, and implementing order sentences and grouped orders. Screen displays were modified to utilize clear language with important information emphasized to reduce misunderstanding and improve decision making. Particular attention was paid to high-risk medications, which require a multi-layered approach to limit the chance for error. Overall, interventions like eMM systems are likely to change over time as users become more familiar with the system and use is expanded to more sites. This research has shown that this is an ongoing process in which continual monitoring of the system is necessary to detect areas for improvement and capitalize on the benefits an electronic system can provide.

CLINICAL RELEVANCE STATEMENT

The transition from paper-based medication charts to electronic medication management has reduced medication errors but also introduced new safety risks. Systems are continuously updated in response to these risks, and this paper outlines changes made to a system to mitigate system-related errors and streamline clinician workflow. For institutions planning to implement electronic medication management,

it is important to recognize that these are not ‘set-and-forget’ systems and therefore require ongoing surveillance and maintenance.

MULTIPLE CHOICE QUESTIONS

1. What was the most common reason that changes were made to the system?

a) To support ‘work as done’

b) To prevent error

c) To optimize workflow

d) To support the expansion of eMM use

Correct answer: The correct answer is option b. Changes were made most frequently to prevent medication errors (24% of all rationales).

2. To minimize the risk of errors associated high-risk medications, what types of strategies can be used in electronic systems to align with the Institute for Safe Medication Practices recommendations?

a) Strategies should be standardized across hospitals

b) Strategies should be multi-layered

c) Strategies should be integrated into workflow

d) None of the above

Correct answer: The correct answer is option b. The Institute for Safe Medication Practices proposes that strategies for risk minimization should be multi-layered, combining various approaches to target specific risks.

AUTHOR CONTRIBUTIONS

MK, MB, WYZ and RB designed the study. LMH provided expertise in the electronic medication system and refining the classification. MK analyzed the data, with assistance from MB, WYZ and LMH. All authors assisted in interpreting results and writing the manuscript. All authors read and approved the final manuscript.

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CONFLICTING INTERESTS

No conflicting interests to declare.

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SUPPLEMENTARY MATERIAL

Appendix A: Classification of updates made to an electronic medication management system

Rationale for the change			
		Definition	Example
A.	Prevent error	To directly or indirectly reduce the likelihood of a medication error occurring	'Potassium Chloride 40 mmol in Sodium Chloride 0.9% IV sol 100 mL' has been removed from the system due to concerns of unsafe prescribing /administration in age care wards
B.	Support 'work as done'	To ensure the system supports practices that were previously completed on paper, for example by	All medication orders will have the taper dosing function option enabled, allowing for the system

		capturing the range of possible order components and regimens used by clinicians	to assist with the prescribing of an increasing or decreasing dose schedule
C.	Optimize workflow	Capitalizing on the capacity of the electronic system to facilitate more efficient and streamlined workflow, including supporting decision making, providing a better overview of the patient or patient group, or reducing the number of actions required by the user	The option to document a numeric 'Blood Glucose Level' bedside will be replaced with an acknowledgement check box for the most recent BGL value recorded
D.	Improve documentation	To maintain accurate and thorough records of use, for example when completing medication reconciliation (excludes the addition of information	When the action of 'Chart Not Done' is performed, there is a new value for the 'Reason Not

		in the medication order to reduce incomplete orders – see 'Prevent error')	Done' which is 'Downtime – See paper chart'
E.	Improve monitoring	To capture and monitor the use of the system	A report has been added that provides a list of current inpatients with a completed medication reconciliation
F.	Avoid confusion or misinterpretation	To reduce the likelihood of users being confused about system functions, for example by improving terminology and/or phrasing	The wording of 'Cancel/DC' has been changed to 'Cancel/Discontinue' to avoid misinterpreting as 'Discharge'
G.	Support expansion of eMM use	To enable the broadening of eMM use, for example to ensure consistency across the district when	A new frequency of '2 hourly (while awake)' has been added to facilitate

		eMM use expands to additional sites or to support expanded functionality of the eMM to other patient wards.	ordering of Duodopa. This frequency is available as part of the state-based build and thus this change aligns the LHD with state design
H.	Improve compliance with policies/guidelines	To ensure staff are adhering to hospital-, district-, state- or nation-wide rules as determined by policies or guidelines	Any diluent information in the order comment section of injectable medication order sentences will be replaced by 'Refer to Australian Injectable Medicines Handbook'
Change to the eMR system			
		Definition	Example

A.	Change to visual display	A change to the visual interface	
A1.	Design	The appearance of the display	
A1.1	*Font/background changed*	Design change (capital letters, colour etc.) to the printed letters, numbers, symbols or background of text	Medication font changed to Tallman lettering
A1.2	*Icon added*	The addition of a graphic representation in the form of an icon	When searched, medications containing hydromorphone appear with new exclamation point icon
A1.3	*Order of information modified*	Change to the order of information displayed in lists, menus, or orders	Drop-down list made alphabetical except for 'Other: See comments' which appears last

A2.	Content	The content within the display	
A2.1	*Extra information available*	Extra information provided (pathology results, blood results etc.) on the display	The 'White Cell Count' pathology result will now display when prescribing Azathioprine
A2.2	*Wording and or/phrasing modified*	Change to the words or phrases used to express something, including updating information Excludes changes to wording/phrasing in clinical decision support (see C1.3)	The medication Prothrombinex has been changed from 'Factor IX Complex (Prothrombinex)' to 'Prothrombin Complex (Prothrombinex-VF)'

B.	Change to options available	A change made to the options/selections available to the user	
B1.	PowerPlans/Care Sets	The set of orders that are grouped together to support a condition, procedure or process	
B1.1	*PowerPlan/Care Set added*	The addition of a set of orders grouped together	Two new district-wide 'Post-Operative Nausea and Vomiting' PowerPlans have been added
B1.2	*PowerPlan/Care Set removed*	The removal of a set of orders grouped together	Care Sets 'End of Life' and 'End of Life – Variable', will be permanently removed from eMM from the October 2018 release cycle

B1.3	*Component/s of a PowerPlan/Care Set modified*	Change made to a set of orders grouped together	The 'Analgesia Aliquots IV PACU' PowerPlan has been revised. Dose and dose intervals have been updated, and the display order has been modified
B1.4	*Use of PowerPlan/Care Set broadened*	The use of a set of orders grouped together has been made available to more staff or locations	Care Set has been renamed to 'Intubation Induction Medication' and will now be available at other hospital sites
B2.	Order sentences	A pre-written medication order with pre-filled values/components	
B2.1	*Order sentence/s added*	The addition of a pre-written medication order	'Nitrous Oxide Variable Dose Order' was made available to

			search and order hospital-wide and offers two order sentences
B2.2	*Order sentence/s removed*	The removal of a pre-written medication order	Morphine order sentence has been removed from Analgesia within the 'Intubation Induction Medication' Care Set
B2.3	*Component/s of an order sentence modified*	Changes made to a pre-written medication order	A PRN order sentence with a frequency of 'once' to a frequency of 'daily' with an order comment of 'once only during dressing change'
B2.4	*Filter added for order sentence/s*	Specific pre-written medication orders are visible based on patient specifications (e.g. age range)	Medication order sentences for commonly prescribed paediatric

			medications will be filtered according to the patient's age
B3.	Order form fields	A component of a medication order requiring a value to be inputted	
B3.1	*Field/s added*	The addition of a field requiring a value	Three new mandatory fields were added to capture 'Lot Number', 'Manufacturer' and 'Expiration Date' for immunizations
B3.2	*Field/s removed*	The removal of a field requiring a value	The field for documenting 'Blood Glucose Level' bedside in the Medication Administration Window has been removed

B3.3	*Field/s combined*	The combination of two or more fields requiring a value	'Dose' and 'Dose Unit' will be combined into a single 'Dose' field
B3.4	*Field/s modification restricted*	Restricting the ability to edit a field	'Modify' action no longer allows the drug 'Form' field to be changed
B4.	Lists	A series of preset values or items available for selection under a menu, folder or field	
B4.1	*Option/s added to list*	The addition of a value or item to a list	Two new frequencies, 'Therapy Day q12h' and 'Therapy Day Once', have been added for chemotherapy medication orders

B4.2	*Option/s removed from list*	The removal of a value or item to a list	'Self-administered' was removed from the drop-down list of reasons that a medication was 'Not Given'
B4.3	*Use of option/s broadened*	The use of a value or item has been made available to other medication order types	The taping dosing function option will now be available for all medication orders (not just selected orders)
B5.	Free text data entry (alphanumeric)	The input of a value (e.g. words) directly into a field without predefined choices	
B5.1	*Use of free text data entry broadened*	Character limits increased for the free text data entry of alphanumeric	The decimal point charting limit under 'Other Infusions' will increase from one to two

		values (e.g. increase decimal points, adding text box etc.)	decimal points in 'Intake and Output Band'
C.	Change to clinical decision support	The use of tools or information intelligently filtered or presented at appropriate times to guide user decisions	
C1.	Alerts	A 'pop-up' window notifying the user that an action or event is about to occur, providing relevant information, providing a recommendation, or warning of a potential risk	
C1.1	*Alert/s added*	The addition of a 'pop-up' window	Insulin orders prescribed at an interval of less than four hours

			will prompt an alert to review the order
C1.2	*Alert/s removed*	The removal of a ‘pop-up’ window	The severity of drug-drug interaction between Metoclopramide - Promethazine has been downgraded to ‘Moderate’ and the alert will no longer fire
C1.3	*Alert/s content modified*	Changes to the words or phrases used to describe something in a ‘pop-up’ window	The alert language for antimicrobials ordered with a ‘First Dose Date/Time’ of tomorrow has been modified to align with best practice standards

C1.4	*Alert/s use broadened*	The use of a ‘pop-up’ window is triggered by more situations (e.g. more patients, more clinical scenarios etc.)	The enhancement extends the alert to fire for patients with an age range of 0-16 years old
C2.	MPage/tab	A page on the eMR or web browser that imports specific data based on certain parameters to assist user decision-making	
C2.1	*MPage/tab added*	The addition of a page or tab	Requests for single and multiple medications can now be placed on the new ‘Medication Request Summary’ MPage
C2.2	*MPage/tab removed*	The removal of a page or tab	The current ‘Medication Request History’ MPage will be retired

C3.	Other	Other decision support	
C3.1	*Task automation or calculation*	Changes to software to modify the manual requirements of tasks	Pharmacists can now select 'Inpatient 03' as 'Dispense Category' during verify or modify action. This dispense category will calculate 3 day's doses for Pharmacy dispensing
D.	Adding a forcing function	A task that prohibits the user from proceeding until they have overridden or actioned a pop-up	
D1.	Forced review	A review of relevant information or results (e.g. allergies, blood results) must be completed prior to completing an action	Users will now be forced to review allergies that have been recorded prior to the current

			inpatient admission before prescribing
D2.	Forced selection	An appropriate selection must be made from the options presented (e.g. drug brand)	When ordering Hydromorphone by its generic name, the system will prompt with a window for users to select the corresponding brand required
E.	Improved information transmission	An improvement in the exchange of data between one or more health information systems	
E1.	Improved information transmission within eMR modules	Data exchange is improved between eMM module and other eMR components	A more accurate and up-to-date medication list will transfer across into the 'Discharge

			Medication' section of the 'Discharge Referral' PowerNote
E2.	Improved information transmission between eMM system and other health information systems	Data is exchanged between eMM and other health information systems	The PowerChart to iPharmacy (Pharmacy dispensing software) interface script was enhanced to correctly transmit PowerChart medication orders to the iPharmacy software
F.	Other	A change made that is not covered by other categories	
F1.	General eMM use broadened	eMM has been made available to other patients/wards	eMM prescribing turned on for 'Admission Transit Lounge' ward

F2.	Report added	New report presenting data on specific system use has been made available to relevant staff	A new report is available on the explorer menu that captures data on the completion of documented medication history, admission medication reconciliation and discharge medication reconciliation of discharged patients

Note: eMM = electronic medication management, eMR = electronic medical record, BGL = blood glucose level, DC = discontinue, LHD = local health district, IV = intravenous, PACU = post-anaesthesia care unit, PRN = pro re nata, q12h = every 12 hours

Chapter 7: Discussion and Conclusions

This thesis explored system-related errors associated with the use of EMM systems, with a specific focus on long-term error occurrence. The following chapter provides a project summary, overview of key findings, recommendations, strengths, limitations and suggestions for future research.

PROJECT SUMMARY

Overview

Overall, this program of research successfully identified and classified long-term system-related errors associated with the use of EMM systems. Importantly, a novel approach was undertaken by comparing long-term system-related errors with short and medium-term errors, specifically exploring how errors develop and change across time. A detailed and thorough depiction of system-related errors was uncovered by deconstructing each error type into the actions that led to these errors, the factors that contributed to error occurrence, and the consequences or outcomes of errors. This program of research was able to build upon existing knowledge by exploring approaches to detect system-related errors and propose methods for minimising the risks associated with system-related errors by investigating strategies for error mitigation, management, and prevention. This research program provides valuable insights on how organisations can successfully implement, configure, and design EMM systems to prevent long-term system-related errors from occurring.

The narrative review (Chapter 2) synthesised existing literature on system-related errors, with a specific focus on how errors change over time, and highlighted various factors that led to error occurrence, including specific design features (i.e., display layouts and default settings) and sub-optimal use of the EMM system. Results suggested that system-related errors persist with long-term use, however our

analysis identified a research gap, as no single study examined how system-related errors changed over time. Therefore, the studies in Chapters 3 to 5 investigated system-related errors over time using multiple methods including analysis of hospital incident reports and interviews with key stakeholders. An analysis of incident reports related to EMM (Chapter 3) revealed that system-related incidents continued to occur years after EMM implementation, and were influenced by EMM system design, user and organisational conditions. Although these factors contributed to reported incidents in varying degrees over time, the persistence of certain factors highlighted the need for continuous improvement of the EMM system (Chapter 6) and its use. Given the limited information provided in incident report descriptions, interviews with key hospital stakeholders in Chapters 4 and 5 provided a more in-depth qualitative analysis of system-related errors, including the consequences of errors, in addition to detection and mitigation strategies. Changes to the EMM system were identified as a key error management strategy and analysis of enhancements (Chapter 6) provided concrete examples of system changes to prevent errors and improve workflow. Based on the analysis of hospital incident reports (Chapter 3), stakeholder interviews (Chapters 4 and 5) and EMM enhancements (Chapter 6), this thesis generated significant new evidence on system-related errors, emphasising how errors develop with sustained EMM system use and highlighting key learnings on how organisations can manage system-related errors to promote optimal EMM system use.

KEY FINDINGS

System-related errors are difficult to detect

Prior research and the current research program provide evidence supporting the occurrence of system-related errors, but the narrative review highlighted

inconsistencies in the identification of system-related errors within existing research. Different system-related error types and rates were attributed to the variable features of different EMM systems, including the clinical decision support included, as well as differences in the way system-related errors were defined and conceptualised in studies. A previous review of systematic reviews on the impact of EMM systems on outcomes revealed that previous research often grouped system-related errors within the broad category of medication or prescribing errors, not as a separate category.[1]

As a result of the inconsistencies in defining system-related errors and not examining these errors in isolation from other medication errors, collating published evidence specific to system-related errors was a challenge, complicated further by the various terminologies employed for EMM (i.e. computerized provider order entry, electronic medical record) and system-related errors (e.g. technology induced errors, unintended consequences). These challenges highlight the need for distinct evidence on the types and rates of system-related errors, separate from the broader investigations of medication errors and EMM systems. This research program partly addressed this gap by exclusively investigating the types of system-related errors that occur when using an EMM system. Future research would benefit from employing uniform language and definitions when describing the types of system-related errors that occur, and standardising measures when assessing the rates of these errors.

Further, the exploration of system-related errors in the current research program was hindered by difficulties encountered in the detection of system-related errors, irrespective of methods applied to capture system-related errors (see ‘Strengths,

limitations and suggestions for future research' for an assessment of the qualitative methods in the current research program). Interviews with key stakeholders revealed that strategies to detect system-related errors relied heavily on front-line clinicians. Further, clinical staff voluntarily entered EMM-related incident reports into the incident management system, while interviews involved various hospital staff, particularly clinicians in both medical and supporting roles. Despite implementing a keyword search to identify incident reports associated with the use of EMM, clinicians are known to assign the source of medication errors to people, workflows and context,[2] potentially failing to recognise the system's contribution to incidents.

Although clinicians are the primary end-users of EMM and play a key role in system-related error identification, previous research has highlighted that many system-related errors go undetected by clinicians.[3,4] Interviews revealed the importance of proactive detection measures, such as EMM system monitoring through regular system reports and enhancement projects, and the value of trial environments to test EMM redesign prior to releasing updates in a clinical setting. The former approach, including using EMM system data to measure EMM system use, has been identified as vital to advancing the use of EMM systems and realising the full benefits of EMM system implementation.[5]

System-related errors are difficult to classify

A critical component of this research program was to classify long-term system-related errors and determine the factors that lead to their occurrence. An accident analysis approach was considered to be the most effective method, as this approach distinguishes between the cause, process and consequences of accidents (incidents or errors).[6] Reason's accident causation model was selected as it recognises that

multiple domains contribute to errors (e.g. unsafe acts, the local workplace, and the organisation) and that these domains are interrelated, rather than occurring independently.[7] Further, the model redirects the focus from the individual involved, towards the context or system within which the event, or error, occurred.[8]

Throughout this program of research, existing classifications of system-related errors were explored with the hope of adopting an existing tool for data analysis. However, we found the utility of classifications to be context specific (e.g. only suitable when using a specific data source) and determined that existing classifications limited the consideration of the multi-faceted nature of system-related errors and their contributing factors. During analysis of interviews, utilisation of existing classifications of system-related errors prevented us from ascertaining the factors leading to errors, as well as the actions or unsafe acts that contributed to error occurrence, and the consequence of errors (see Table 1 for key issues identified with existing classifications). Therefore, a new classification was iteratively developed from interview data, distinguishing between the different factors contributing to errors.

Table 1: A sample of the classifications we initially employed, including the key issues identified and an example.

Classification	Use	Key issues identified	Example
Mozaffar et al.[9]	Analysis of interviews	• Overlapping components (i.e., did not differentiate between description of unsafe acts, latent	The category 'inappropriate system use' included both actions taken by the

		conditions, and consequences)	user and contributing factors
Westbrook et al.[3]	Analysis of interviews	• The mechanism focused on processes, with insufficient consideration of underlying conditions • The manifestation focused on clinical errors rather than other types of consequences • Failed to capture the richness of interview descriptions	The categories 'selection errors' and 'editing errors' explain an action, but do not include latent conditions
Schiff et al.[10]	Analysis of incident reports	• Codes were overfitting for data (i.e., 101 codes for 'what went wrong' and 67 codes describing 'why errors occurred') • Overlapping components for why errors occurred (i.e.,	The category 'comments field free text confusing/confusion' includes both a design component and user factor

		did not differentiate between the latent conditions related to the EMM design, user and organisation) • Incident report descriptions • The refined version of the classification[11] was overly granular	
Van de Vreede et al.[12]	Analysis of incident reports	• Simplistic classification of conditions related to the EMM system, the user and the organisation • Certain categories were unclear from incident descriptions (i.e., 'site build error' and 'hardware malfunction')	The category 'system build' lacked specificity in identifying EMM design factors

Similar challenges were encountered when classifying incident reports and EMM enhancements. Numerous existing incident classifications were tested when analysing incident reports, yet categories were either too narrowly defined, particularly given the lack of information provided in incident descriptions, or too broad to effectively capture the range of contributory factors reported in incidents. For example, a classification developed to categorise medication and EMM-related incident reports relating to paediatric oncology patients was employed for a sample of incident reports and determined to be too broad to convey the particular aspects of the system and context that contributed to incident occurrence.[13] Therefore, the classification developed from stakeholder interviews was utilised when analysing incident reports. A similar approach was trialled when categorising EMM enhancements into the type of update made and the reason for each update. When no suitable classification was identified, a novel classification system was iteratively developed using cases as they emerged. By developing these novel classifications, our research was able to effectively communicate the richness of the data and provide a more nuanced analysis of system-related errors in each study, enhancing the overall depth and insight from our findings.

The human-computer interaction plays a critical role in system-related errors

The implementation of an EMM system is more than just the addition of new software. Instead, it is a complex procedure requiring the transformation of existing clinical practices into new and flexible workflow processes.[14,15] This research program highlighted that as a result of this workflow transformation, system-related errors are not solely derived from system malfunctions, but rather develop from issues relating to the human-computer interaction. Although system-related errors

can arise from system glitches or malfunctions, these error types are infrequent. A previous multisite study investigating medication-related incidents revealed that only 6% of EMM-related incidents were associated with the system or site build, while most system-related incidents had contributory factors associated with humans using the system.[12]

Incident reports and interviews with key stakeholders determined that unsafe acts performed by EMM users facilitated most system-related errors. Amongst 444 EMM-related incident reports, 410 reports described an unsafe act that had occurred. Reported incidents described commission errors, where the user performed an incorrect action on the system, most frequently. For example, a doctor mis-selecting the wrong order sentence when prescribing a medication. Similar findings were described in a recent study evaluating system-related prescribing errors associated with EMM in geriatric patients.[16] Results suggested that 96% of system errors were related to the human-computer interaction, and of these, 99% were commission errors. On the other hand, interview participants in the current research program most commonly described omission errors, or errors where the user failed to take a course of action. For example, a nurse failing to document a medication administration in the EMM.

The inconsistency between the most frequent type of unsafe act reported in incident reports and the most common type described in interviews likely reflects the capacity for each data source to capture certain error types. Namely, incident reports are typically structured forms that capture the specific details of incidents or errors that occur, making reports more likely to highlight commission errors where an action was taken, particularly as actions can result in immediate consequences.[17,18] On the

other hand, during interviews, clinicians may have had a better recollection of omission errors, as they reflected on their practice and recalled instances where they may have missed important steps or actions. Despite this discrepancy in the reporting of unsafe acts, both error types suggest that human-computer interactions play a critical role in facilitating system-related errors.[19-22]

Workarounds, or cases where the user deliberately circumvented the EMM system to achieve an intended outcome, were described in both incident reports and stakeholder interviews. The analysis of incident reports uncovered only a small number of workarounds, but in-depth stakeholder interviews revealed several workarounds not previous identified in existing literature, including ‘top boxing’ (i.e., user administering a high-risk medication changes the name of the witness to themselves, and the administrator to another nurse, to avoid the requirement for another nurse to double check the administration) and prescribing ‘unlisted’ medications (i.e., user manually prescribes a medication not preconfigured in the system's medication database, bypassing safety mechanisms). These intentional EMM workflow deviations indicate an incompatibility between the required tasks performed by users and the capabilities of the technology.[23] Our research provided new evidence on the types of workarounds that occur following the implementation of an EMM system, and established a link between workarounds and the occurrence of system-related errors.

The detection of workarounds, as well as commission and omission errors, highlighted the critical role of the human-computer interaction in generating system-related errors, emphasizing the importance of considering the compatibility or fit between the human and the system in the design and use of EMM systems. Further,

although analysis of EMM enhancements found that changes were most frequently made to prevent medication errors (24% of rationales for why changes were made), updates also sought to optimise workflow (22%) and replicate work as done on paper medication charts (16%). This finding suggests that clinical informatics staff recognised the need for the EMM system to promote the needs, goals and preferences of the users, in order to improve the efficiency, usability and safety of the system. Taken together, these results indicate that system-related errors are not independent events, but influenced by the interaction between humans and the EMM system.

System-related errors are the result of multiple factors

In the same way that the relationship between the user and the EMM system was shown to impact system-related errors, incident reports and interviews illustrated that system-related errors resulted from a combination of inter-related factors. These factors were associated with the design and functionality of the EMM system, the characteristics of users, and aspects of the organisation in which the system was used, such as the use of hybrid paper-EMM systems. Reported incidents described between zero and six latent conditions, with contributions from the EMM design, user and organisation being described in a similar proportion of reports (41% - 47%). Prior investigations of system-related errors have reinforced that errors result from the interaction between factors and can vary depending on the EMM system, workflow and setting.[24,25] This study went further than previous research by showing that across time and between the three hospitals, each category of latent condition was present, but varied in its contribution to the occurrence of system-related errors.

Interviews provided further evidence that system-related errors arose from multiple factors. Stakeholders reported various EMM design issues that contributed to error occurrence, including the cluttered display of information on the screen and additional navigation required on the system for information retrieval. However, user factors, such as clinicians being time poor or stressed, and organisational factors, such as downtime, were also said to have contributed to system-related errors. Further, as noted in the section above, factors or latent conditions did not occur in isolation, but occurred together and interacted with the unsafe acts undertaken by users. For example, stakeholders described omission errors in which users failed to check for duplicate orders when prescribing. This issue was exacerbated by the design of the EMM system, as the ordering screen did not display the current medications.

The finding that system-related errors are multifactorial is consistent with previous qualitative research in a large English hospital with an electronic prescribing system.[26] By also applying Reason's accident causation model, the researchers determined that three broad categories of latent conditions contributed to system-related errors; system functionality and design, the system's implementation and the users' behaviours when using the system. These latent conditions were found to generate conditions that facilitated prescribing errors, including those related to the work environment and team, and produced unsafe acts by the system users. The authors concluded that to improve prescribing safety when using an electronic system, consideration needs to be given to the usability of the system in the context of the wider environment.[26] The current research program added to this work by conducting interviews with a wider range of stakeholders (i.e., not just prescribers) and exploring different types of medication errors.

The traditional approach to incident or error management considers events in isolation, occurring primarily due to the actions of an individual or a single point of failure in a system.[7,8] Contemporary error management approaches take a more comprehensive and systemic view, with the goal of identifying and addressing the various causes of the error, rather than blaming individuals for their mistakes.[27-29] The current research findings, in the context of existing literature, reinforces that system-related errors are the by-product of multiple elements in a complex working environment and provides further evidence of what these elements are.

A standard, one-size-fits-all electronic medication management system design is not always the best approach

This research program supported existing views that a generic EMM system design is not the most effective product due to variations in healthcare settings, diverse patient needs, and specific medication management workflows. A previous review highlighted that EMM configuration can impact system usability, clinicians' prescribing behaviour and the types of medication errors that occur.[30] Further, a range of system features, such as the computer screen layout,[19,31] drop-down menus,[32] and default settings[33] have been associated with EMM-related prescribing errors.[3,20,34] Incident reports demonstrated variability in the proportion and nature of EMM design factors that contributed to reported incidents at different sites across time. This variability suggests that design aspects that are efficient, usable, and safe for one site may not necessarily translate to effective and safe use for another, as context can influence the outcomes of the system. A study comparing two EMM systems at two hospitals supported this view, with results showing that the types of system-related errors varied significantly between sites.[24] The authors attributed the

difference in error types to variations in system design and the distinct procedures associated with prescribing.

As was the case in this research program, hospitals can opt to implement a commercial EMM system procured from a third-party vendor that can support multiple organisations simultaneously and offers predefined features and functionality. Although commercial systems are typically pre-configured upon procurement, implementation across a health district usually occurs sequentially, with one site piloting the system followed by adoption by other hospitals.[35] This was the case in our research, facilitating a unique approach to explore EMM-related incidents reported at sites that had implemented an identical commercial EMM system but at different stages of system maturity. Lower rates of design issues were reported at the two hospitals that had implemented the system after it had been well established at the first site, suggesting that these sites had adopted an enhanced system where previous design issues had been identified and addressed. This finding highlights the value in sharing knowledge between sites to minimise future system-related errors.

Analysis of enhancements made to the EMM system to mitigate system-related errors, indicated that system refinement and improvement was an ongoing process, providing further evidence that the initial system design may not adequately address the unique needs of all patients, users, wards or hospitals. It is worth noting that the reviewed documents did not contain an exhaustive register of system changes, particularly as older documents were less detailed and structured than more recent reports. Yet, to our knowledge, analysing EMM enhancements to investigate system-

related errors has not been conducted before, presenting a novel research method to understand these errors.

One-hundred and forty-seven individual changes were documented across the 4-year time-period. Modifications ranged from the addition of alerts to prevent medication errors, to incorporating summary pages detailing pertinent clinical information to assist in decision making. The wide variety of changes demonstrated that there are many potential areas in the EMM system that could benefit from enhancements, and that considering organisation and user needs is essential to ensure the EMM system aligns with unique workflows. By identifying areas for enhancement and emphasizing the value of adaptability, this research contributes to the broader understanding of effective EMM system design and its potential to mitigate system-related errors.

Frequent flyers: Design problems that recur in system-related errors

While acknowledging the potential limitations of a uniform EMM system design, this research program highlighted certain design components that persistently contributed to system-related errors. System-related errors were associated with the display of information on the EMM and the configuration of the system (see Table 2).

Table 2: Design elements of the electronic medication management system that appeared to consistently contribute to system-related errors.

Design component	Explanation	Example
Display of information	The presentation or arrangement of data on the EMM system's interface is	Nursing and medical task tiles are indistinguishable from each other on the

	sub-optimal or creates inefficiencies for users	medication administration record
• Cluttered, unclear and/or confusing	The visual representation of information on screen is unclear or confusing	Long list of medications, including both prescribed and discontinued medicines, when completing medication reconciliation
• Limited or filtered display	The presentation or visibility of certain information related to medications, patients, or other aspects of the system is selectively shown or withheld from users	'Next task' view during medication administration limits full medication overview
• Lack of visual cues	The system does not provide clear or obvious visual indicators to guide users in medication management processes or decision-making	Inability for users to flag vital information with colour and text

Configuration of system	The setup of the EMM system is not optimised or aligned with the needs or requirements of the users or context	Clicking next patient or ‘forward’ does not take you to next patient
• Complex and/or inflexible	The system or its components are inflexible, rigid or overly complex. The EMM functions in a way that is not aligned with current workflow or practices.	Users cannot sign for medication more than one hour ahead of time
• Additional tasks required	The system requires additional steps that were not necessary on paper	Certain fields must be completed during prescribing before allowing the user to progress
• Additional navigation required	The system requires users to navigate to a different part of the EMM to retrieve information for clinical decision making	Users are unable to review the current medication chart or read consultation notes while prescribing

• Default settings	The system's default settings are incongruent with what is required by the user	Checking time for blood to clot automatically generates order for warfarin

The suboptimal display of information was the most frequent EMM design factor described in incident reports. Similarly, stakeholders stated that limitations in the visibility of information on the EMM system led to system-related errors. Supporting this, a systematic review reported that the computer screen display, as well as the wording of text, contributed to prescribing errors associated with the EMM system.[34] For example, the failure to display all orders on the EMM screen limited the user's ability to perform a full medication review, leading to duplication errors.[20,31]

Recent research has demonstrated that making information visible on the EMM system is an effective nudge, or behaviour change mechanism, to improve care delivery.[36] We found that changes to the visual display, including making extra information available on the EMM screen, was one of the most frequent EMM enhancements made across a four-year period. The addition of information on the EMM screen was mainly employed with optimising workflow and preventing errors in mind. Our finding adds to the previous research by suggesting that to enhance patient care, as well as prevent errors and improve workflow, optimising the visual display of information on the EMM system is an ongoing process, rather than a quick fix.

Interview participants also indicated that system-related errors could occur in response to the cluttered or confusing display of information on the EMM system, as

well as a lack of visual cues on the screen. These findings highlight the importance of not only ensuring vital information is visible to the user at certain points in the medication use process (i.e., prescribing to administration and monitoring), but that visual design elements, such as colour and layout, should be used to convey pertinent clinical information. For example, incorporating human factors design principles (i.e., alerts should be positioned within the visual field in order of importance) into the design of medication alerts in the EMM system has been shown to improve usability, and reduce perceived user workload and prescribing errors.[37] Our results suggest that utilising these design elements in other areas of the system are likely to also reduce the occurrence of system-related errors.

Additionally, the configuration of the system was found to be associated with system-related errors. EMM-related incident reports often showed that the configuration of the system did not support work, was complex or inflexible. The complexity of the EMM system was also referred to in interviews with key stakeholders. More specifically, it was reported that additional navigation was required on the EMM system to retrieve important clinical information. For example, participants expressed difficulties in simultaneously reviewing the current medication chart and reading consultation notes while prescribing medications. Consequently, to access and review this information during the prescribing process, they had to navigate between multiple screens.

Interview participants also referred to additional tasks required when using the EMM system; tasks that were not necessary on paper charts. For example, certain fields were deemed mandatory by the system, such as the brand name of a medication, requiring completion before users could proceed. This task example adds to the

existing research, which previously identified four other distinct task types mandated by the EMM system for prescribers.[3] These tasks, which were unnecessary with paper charts, were found to also be responsible for system-related errors. One such task is the requirement to change the default time and date of prescriptions. This has been linked to system-related errors in other research,[38] mirroring our finding that inappropriate default settings can lead to errors, and suggesting that configuration of defaults requires attention when setting up a system.

Of note, EMM system enhancements reviewed in this research program included numerous changes to both the display and configuration of the system, suggesting that these aspects of the system required ongoing review and maintenance to maintain safety and efficiency. By drawing attention to these specific areas in the EMM system, our findings contribute to the emerging development of design guidelines and heuristics associated with safer EMM systems.[39-41]

High-risk medications require particular attention when implementing and optimising an electronic medication management system

In documents detailing EMM enhancements, over a third of updates made to the EMM system targeted high-risk medications, demonstrating that medications with an increased risk of causing patient harm required specific consideration and attention within the EMM system. Previous research has highlighted the complexity of high-risk medication management in the EMM system, particularly for anticoagulants, insulin and chemotherapy medicines, and the need for an iterative, considered approach.[42-45] An Australian case study evaluated the management of anticoagulants in the EMM after implementation and found that specific interdisciplinary governance arrangements were required for each class of

anticoagulant (e.g. heparins, warfarin) and converting work processes to the EMM system was challenging, involving extensive consultation with clinicians and technical staff.[42] A series of digital strategies were developed for each anticoagulant prior to go-live, with further modifications made after EMM system implementation to address system shortcomings, illustrating the ongoing need for continuous improvement.

Our research added to this work by examining a broader range of high-risk medications (i.e., not focusing solely on anticoagulants), and by analysing enhancements over a longer time-period, beyond the initial 12-month period after the introduction of the EMM system. Analysis of EMM enhancements revealed that there did not appear to be a standard approach for ensuring safe use and management of different high-risk medication types, but rather the requirements for each medication were examined and thoughtfully addressed. Further, modifications directed towards high-risk medications frequently required multiple changes to the system, at different time points in the medication management process, and typically targeted different clinicians. In light of this, high-risk medication management in the EMM system must involve assessing existing paper-based workflows for each medication type, including the essential information required at each stage of the medication management process, and tailoring layered strategies in the EMM system in line with these assessments.

User unfamiliarity with the electronic medication management system persists over time

Participants who took part in interviews referred to user inexperience with the EMM system, as well as inadequate system training, as key contributors to the occurrence

of system-related errors. Similarly, incident reports established that unfamiliarity with the EMM system was a significant factor contributing to reported incidents related to system use, and that system-related errors associated with user unfamiliarity were persistent and widespread. Misunderstanding or unfamiliarity with the EMM system or workflow represented the most frequent user-related condition described in incident reports across all three hospitals during the data collection period and contributed to the greatest number of reports overall (25% of EMM-related incident reports). Although EMM unfamiliarity fluctuated in frequency over time and between sites, it remained a leading user factor reported in incident descriptions across all three hospitals, irrespective of time since EMM system implementation.

In keeping with this trend, insufficient training or education was the most frequent organisational condition described in incident reports at all three hospitals and persisted in incident descriptions across time, highlighting the recurring need to educate and support users in using EMM systems. Existing literature suggests that providing adequate resources and training to hospital staff is essential for successful implementation of an EMM system.[46-48] Interviews supported this, but also went further in highlighting that education is an effective strategy for minimising system-related errors, not only ensuring successful implementation of a system. Individual training was said to be provided on a case-by-case basis in response to specific incidents, while wider education to a particular cohort, ward or hospital was undertaken when system-related errors occurred more generally. This finding is novel, suggesting that various educational modalities are being rolled out in an effort to mitigate system-related errors.

A longitudinal study exploring the changing perceptions and experiences of nurses and doctors following EMM implementation found that during the first week of EMM system use, inexperience with the system was perceived to influence the time taken to complete tasks, as well as medication safety.[49] However, inexperience with the EMM system did not emerge as a theme during later data collection timepoints, suggesting that with increased knowledge and experience, users became more proficient in system use, reducing the impact of inexperience on performance and perceptions of safety. Adding to this work, our interviews highlighted that an increase in clinician confidence when using the system will not only increase efficiency and medication safety overall, but also has the potential to lead to fewer system-related errors.

However, the persistence of user unfamiliarity and EMM training inadequacies found in incident reports is at odds with the idea that unfamiliarity with an EMM and the need for EMM training should reduce after the initial implementation period.[49,50] As suggested by interview participants, this finding is likely due to the recruitment of new clinicians, and the rotation of staff across the local health district. Further, documents specifying EMM enhancements demonstrated that systems are continually changing, including the introduction of new functionalities, thus creating a need for ongoing education. Another finding from the interviews was that, to minimise system-related errors, users must be regularly informed of modifications made to the EMM, and provided with periodic, targeted training to adapt to these changes.

Hybrid environments lead to system-related errors in the short, medium and long-term

Hospitals often adopt hybrid paper-computer systems during a transitionary period in response to certain hospital areas or medication regimens remaining on paper.[48] The use of dual paper and EMM systems has been shown to result in medication errors, additional time spent on tasks and more work for users.[3,22,49,51] In incident reports and interviews, the simultaneous use of paper and EMM, as well as the transfer of information between the two, was shown to contribute to system-related errors. At the two hospitals with a more established EMM system, incident reports describing the simultaneous use of paper and the EMM system persisted across time, likely reflecting the continued use of paper-based systems in specific wards, such as the ICU, and for certain medications, like chemotherapeutic medications.

Interestingly, at the original hospital (i.e., the hospital with the EMM system in place for the longest time), the transfer of information between paper and the EMM system contributed to a significant number of incident reports in the first two years following hospital-wide implementation. Errors subsequently decreased in number. Reports describing incidents of information transfer between paper and the EMM system were infrequent or absent at the other two sites. Given that a hospital-wide EMM implementation strategy was adopted from the outset by these hospitals, minimising the hybrid use of paper and computers for medication related tasks during EMM system implementation may have eliminated opportunities for this type of error.

Incident reports and stakeholder interviews also highlighted that as the use of paper-based processes became more infrequent, new risks associated with hybrid clinical information systems emerged. A number of stakeholders noted the risks and increased likelihood of errors associated with using different clinical information systems between wards/units. In addition, EMM-related incident reports in a

paediatric oncology practice revealed challenges in transferring information between different electronic medication systems within the same hospital (i.e., between general and ICU wards).[13] The lack of a suitable interface between separate systems was suggested to have interfered with transfers between the two systems, and the processes surrounding the transfer were found to be error prone. In our review of incident reports, incidents related to the transfer of information between the EMM system and other clinical information systems arose two years after hospital-wide implementation at the first two hospitals compared to the third. The absence of transfer errors between electronic systems in the third hospital, which implemented the EMM system at a later stage, suggests the site potentially benefited from lessons learned and improvements made during the earlier implementations at the first two hospitals.

Although small in number, the emergence of transfer errors between electronic systems, together with the decrease in paper-computer errors, is likely to reflect the changing medication management landscape within hospitals. Our unique method of exploring system-related errors over time demonstrated the evolving risk associated with hybrid systems. As hospitals continue to adopt clinical information systems and reduce their use of paper, this novel finding highlights the need for organisations to be aware of this new type of system-related error.

Downtime remains a risk for system-related errors

While minimizing hybrid paper and EMM systems can mitigate the risks associated with dual systems, the complete elimination of paper may not be possible. In instances of system downtime, hospitals are likely to resort to paper-based systems, requiring users to possess adequate knowledge of these processes and be proficient

in downtime procedures. During interviews, planned and unexpected system downtime, when the system became inaccessible to users, was frequently described as an organisational factor that was disruptive to workflow and had the potential to cause system-related errors. In particular, the transfer of information between the EMM system and paper during downtime, was said to increase opportunities for transcribing errors.

A previous study exploring incident reports associated with EMM downtime found that 46% of reports were the result of absent downtime procedures or procedures not being followed.[52] Our findings from interviews adds to this research by emphasising that downtime procedures specifically targeting transcribing processes are necessary to mitigate system-related errors. Additionally, hospitals can minimise the risks associated with planned downtime by effectively communicating their occurrence to users, staggering the updates across a short period of time to minimise the sustained length of disruption, and scheduling the shutdown outside of busy work hours.[53,54]

Further, stakeholders explained that as paper-based medication practices are phased out, errors associated with the use of paper charts during EMM system downtime may grow. An explanation for this increase was that junior or less experienced clinicians may face difficulties when using paper charts due to their limited previous exposure to such documentation methods. Anecdotal evidence during a downtime event in the US suggested that junior doctors without prior paper-based training incorrectly completed prescriptions on discharge.[55] Our research provides evidence that stakeholders believe a lack of knowledge on paper-based systems can contribute to system-related errors during system downtime and

uptime. To enhance the efficiency and usability of paper-based systems, unnecessary components of the chart should be removed and these manual systems should be customised specifically for downtime events.[52]

Medication errors are not the only consequence of system-related errors

Numerous studies have examined the rates and types of medication errors that arise following the introduction of an EMM system, often assessing medication errors both pre and post-implementation.[24,56-60] Additionally, prior research has evaluated the unintended consequences of EMM system implementation, citing the occurrence of workflow disruptions, changes in communication practices between clinicians, and negative emotions experienced by users.[32,61,62] However, investigations assessing the consequences of system-related errors have largely focused on the potential and actual medications errors and adverse drug events that occur as a result of a system-related error.[31,63,64] In a seminal paper, Westbrook et al. (2013) examined system-related errors associated with two commercial EMM systems, and described the manifestations of these errors.[3] In this case, the manifestation of a system-related error was conceptualised as the consequence of the action taken by the user while interacting with the system and reported as clinical error types (i.e., wrong timing, wrong dose etc.).

Limited research has examined the consequences arising from system-related errors, beyond these medication-related incidents. Our research filled this gap by exploring the consequences of system-related errors outside of clinical errors. This research program determined that system-related errors could result in consequences to the patient (i.e., medication errors), but also significant consequences to the end-user and to the accuracy of documentation contained

within the EMM system itself. Stakeholder interviews revealed that system-related errors could lead to additional work and time on tasks for users. Supporting this finding, previous research has indicated that the introduction of EMM has coincided with perceived inefficiencies for staff, including increased time spent on medication-related activities and greater workloads.[65-67] Our research shows is that some of this additional time may be the result of system-related errors.

Another significant consequence of system-related errors was the misalignment between what occurred in reality (i.e., clinical practice) and what was documented on the EMM system. Although EMM systems have been associated with improved quality and completeness of documented medications,[68,69] non-compliance with appropriate EMM processes can occur in response to perceived system barriers,[70,71] with the potential to undermine accurate documentation. For example, interview participants described the workaround called ‘top-boxing’, which permitted nurses to mark off tasks as complete prior to actioning them. These findings suggest that reducing system-related errors could also result in more accurate documentation on the EMM system.

RECOMMENDATIONS

For organisations

Recommendation 1: Organisations should implement a robust and user-friendly system for clinicians to report system-related errors.

Users should be encouraged by the organisation to report system-related errors without fear or repercussions. To foster a safe and secure environment, data reported by users should remain confidential where possible. By establishing a

reporting mechanism for system-related errors, organisations can gather valuable feedback from users, identify areas of improvement, and implement measures to address system-related errors promptly.

Recommendation 2: Organisations should establish a feedback loop that provides timely and meaningful information back to clinicians following reports of system-related errors.

The feedback loop should involve clear and structured processes, including the investigation and analysis of reported errors, implementation of necessary improvements or actions (i.e., updates to the system, additional training required, or system limitations identified), and timely communication to end-users about the outcomes of reports. This ensures that end-users are informed of the organisation's response and facilitates a continuous learning cycle.

Recommendation 3: Organisations should ensure that strategies targeting system-related errors are multi-layered and complementary.

System-related errors result from multiple factors therefore a systems approach to error management should be adopted. A systems approach emphasises the identification and analyses of multiple underlying contributing factors and implements strategies to target these factors.

As this research program identified factors such as inadequate knowledge and training, communication breakdowns, hybrid systems and design deficiencies that led to errors, strategies and interventions should target these areas.

Further, error management strategies discussed in interviews included redesign of the system (see Recommendation 9), targeted education and minimising the use of hybrid systems.

Recommendation 4: Organisations should prioritise high-risk medication workflows, and ensure they are continuously monitored and optimised.

Particular attention should be paid to each individual high-risk medication to ensure that EMM workflows are effective, efficient, and safe. With ongoing EMM use, the use of high-risk medications should be monitored and evaluated, and updates to enhance the safe use of these medications should be implemented as needed.

Recommendation 5: Organisations should provide ongoing, targeted, and dynamic training to clinicians.

Organisations should ensure that training to clinicians is provided on a regular basis and includes information on the specific EMM system in use to orient the user to the system features, functionalities and workflows. Clinicians should also be informed of system-related errors and educated on new updates and enhancements as they are implemented.

Recommendation 6: Organisations should minimise the use of hybrid systems where possible.

During EMM system implementation, the use of hybrid paper-electronic systems should be minimised for medication-related tasks. In cases where this is not possible, standardised guidelines and processes should be implemented for hybrid workflows to ensure consistent and clear pathways for medication management. As paper-based systems are phased out, organisations should assess the feasibility of

integrating various electronic systems to create a more unified and streamlined way of working.

Recommendation 7: Organisations should implement clear planned and unexpected downtime procedures.

To mitigate the impact of downtime events, procedures should include effective communication, scheduling, and optimisation of paper-based systems. Those impacted by planned downtime should be notified well in advance, and where possible, downtime events should be scheduled outside of busy work hours (i.e., weekdays between 8am and 5pm). Paper-based systems should be simplified and tailored specifically for downtime events, and users should be trained on these processes.

For clinical informatics designers

Recommendation 8: Clinical informatics designers should co-design with end-users to ensure the system aligns with clinical workflow requirements and reduces the likelihood of system-related errors.

As human-computer interaction was shown to impact system-related errors, it is important to ensure that the needs and perspectives of clinicians, who will be using the system, are considered during the design and development of the system. Using a collaborative approach that involves active participation and feedback from end-users will result in a more user-friendly, efficient, and effective system that minimises system-related errors.

Recommendation 9: Clinical informatics designers should consider well-established principles of design when designing clinical informatics systems.

Ensure that the display and configuration of the system are well thought-out and considered when designing clinical informatics systems. Particular attention should be paid to elements such as the presentation and visual display of information on the screen, default settings, forcing functions, clinical decision support and navigational requirements. Using human factors design principles and co-designing systems with end-users (see Recommendation 8) can minimise the risk posed by poor designs.

Recommendation 10: Clinical informatics designers should carefully consider the appropriate methods to support the use and management of different high-risk medications, with extensive clinical consultation.

This consultation process should involve seeking input from a diverse range of clinicians, including physicians, pharmacists, and nurses, who possess a range of clinical expertise in medication safety. Through extensive clinical consultation, designers can gain valuable insights into the specific challenges and requirements associated with the various types of high-risk medications. Before developing appropriate solutions, it is crucial to have a clear understanding of the clinician workflow.

Recommendation 11: Clinical informatics designers should make a concerted effort to integrate new electronic systems with existing infrastructure.

Integration and interoperability ensure that the risks associated with hybrid electronic systems are minimised and are crucial for smooth data exchange, streamlined workflows, and effective collaboration across different departments/wards and healthcare systems.

STRENGTHS, LIMITATIONS, AND SUGGESTIONS FOR FUTURE RESEARCH

This program of research had several strengths and limitations. First, this research provided new evidence on system-related errors that emerged from long-term EMM system use. Investigating the same EMM system at three hospitals at different stages of implementation provided a longitudinal perspective and allowed for comparison across sites over time. However, the focus on a single health district may limit the generalisability of results to other settings and EMM systems. Exploring system-related errors associated with different EMM systems in a range of settings will bolster the current research findings. In particular, examining EMM systems that have been well established at a particular location can shed further light on long-term system-related errors.

Secondly, this research program utilised incident reports, stakeholder interviews and documents detailing EMM system enhancements to explore system-related errors. The use of multiple research methods enabled the triangulation of results from various sources and thus enhanced the validity of findings on system-related errors. For the purposes of exploring system-related errors in depth, these methods proved to be informative and complementary, with each approach providing a unique perspective. Yet, incident reports and qualitative data cannot be used to quantify the frequency with which system-related errors occur. Although previous research has quantified the occurrence of system-related errors,[38,57] understanding the degree to which latent conditions contribute to these errors would be useful, as would the quantifying the impact of system-related errors on the patient, user and the EMM system in the short-, medium-, and long-term.

It is also important to recognise that each data source used in this research program had their own limitations. Incident reports served as a valuable source for examining

general trends in the types of EMM-related incidents that were reported by staff over time and the factors that led to these incidents. However, given the voluntary nature of reports and the use of keyword searches, extracted EMM-related incidents were unlikely to be exhaustive and descriptions often contained insufficient information to determine why an incident had occurred. It is also possible that variations in reported incidents were influenced by external factors, such as changes in policy and updates to the EMM system, however we did not explore these relationships.

Interviews with key stakeholders, including both clinicians and staff involved in supporting EMM use, provided rich descriptions of system-related errors. From this data source, we were able to ascertain the actions and conditions that led to system-related errors and determine how these errors develop over time. Interviews also provided an opportunity to expand on previous research by exploring the consequences of system-related errors outside of clinical errors, revealing effects on the system and to the user. These finding lay the groundwork for further studies assessing how system-related errors impact the user and the system, as well as the wider organisation.

Approaches to detect and mitigate the risks associated with system-related errors were also explored through interviews. To our knowledge, our research was the first to examine how organisations detect system-related errors, and added to the emerging research on how these errors are overcome or managed once detected. However, as noted above, interviews were conducted with staff in one local health district, and therefore the identified detection and mitigation strategies are unlikely to represent all possible approaches taken. It would be valuable to expand our investigation to other organisations and healthcare settings. Additionally, conducting

further longitudinal studies could provide insights into the long-term effectiveness of these strategies to mitigate system-related errors.

Interview transcripts were analysed using a general inductive approach, where the subjective judgments of the researcher's may have influenced the interpretation of the data. However, we addressed this limitation by initially independently coding the data, and then regularly meeting to discuss themes and resolve any discrepancies. Further, incident reports and interviews relied heavily on clinicians to recognise, interpret and report system-related errors associated with the EMM system. Although clinicians are the primary end-users of EMM systems, and are critical to the system's evaluation and improvement, future research would benefit from exploring alternative measures to detect and understand system-related errors, such as workflow analysis.

Prior to our analysis of documents detailing EMM system enhancements, no prior research had systematically reviewed and classified changes made to an EMM system to mitigate risks and improve clinician workflow. We were able to provide clear examples of updates made to an EMM system and identify the underlying reasons why changes were made. However, we were limited by the quality of information contained in the reviewed documents. These documents were not exhaustive of all system changes made to the EMM system or provided comprehensive detail of the rationale behind them. Additionally, earlier documents were less detailed and structured than more recent records. This highlights an opportunity for organisations to maintain a more comprehensive and well-documented record of system changes, facilitating better analysis and understanding of their impact. Despite assessing the reason why updates were made, we did not

attempt to measure the outcomes of these updates. To our knowledge, this is an unexplored area, and research would benefit from evaluating the effectiveness of specific EMM system changes to improve the safety and usability of the system.

It is worth noting that this research took place during the COVID-19 pandemic. Consequently, we were limited in our ability to access hospitals for a period of time, which resulted in delays to data collection. The overall timeline of our research was impacted, and changes were made to the sequence in which the research was conducted (i.e., documents detailing EMM enhancements were analysed while interview collection was suspended), which may have altered the interpretation of results. In order to limit the influence of COVID-19 on our findings, data collection for incident reports and documents detailing EMM enhancements was concluded prior to the COVID-19 pandemic. However, interviews were conducted during and following the peak of COVID-19, therefore certain findings related to system-related errors, such as the consequences of these errors, may have been impacted.

Lastly, although this research adds to the growing body of evidence in this space, digital health is advancing at a rapid pace, and it is important to acknowledge that the findings may not fully capture the latest developments in the field. As such, references used throughout this program of research were based on current literature at the time of publication and may no longer be informed by the most up-to-date research. However, unpublished chapters have been reviewed and updated with recent research where possible.

CONCLUSION

Overall, this program of research found that system-related errors persisted with long-term EMM use, although the specific conditions that lead to their occurrence

varied over time. System-related errors are influenced by multiple factors, including the EMM system design, user actions and conditions, and the organisational context where the system is used. This research has identified strategies to reduce the risks associated with system-related errors and enhance the effectiveness of EMM systems. In Australia, eHealth New South Wales (NSW), the state's digital health service delivery and management agency, recently announced the procurement of a single digital patient record to unify all electronic medical records, medication management and pathology information systems across the state.[72] By offering insights from early to later phases of the EMM journey, we hope this program of research will provide knowledge and evidence to inform the state-wide implementation and long-term use of this unified system.

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