Identifying effective prescribing alerts to include in an electronic medication management system

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TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Hospitals in Australia are making vast investments in electronic medication management (EMM) systems; a major driver is the potential benefits of these systems to significantly reduce medication errors, particularly when systems incorporate clinical decision support (CDS).

Most EMM systems include a number of CDS alert categories to warn prescribers of potential medication errors, such as drug-allergy interactions, drug-drug interactions, exceeding a maximum dose range, and therapeutic duplication. Enabling multiple alert categories may reduce prescribing error rates further than any single alert category. However alert fatigue and high rates of alert override are well-recognised consequences of excessive interruptive alerts. Information is lacking on which prescribing alert category or categories to include in an EMM system to maximise the potential safety benefits of alerts, balanced against the risk of alert fatigue.

The overall aim of my research was to fill this evidence-gap by synthesising the literature, consulting with experts and then summarising this information to present evidenced-based guidance to Australian hospitals to assist in identifying effective prescribing alerts to include in hospital EMM systems.

The first aim of this thesis was to critically appraise the literature on interruptive medication prescribing alerts in hospital inpatient EMM systems. A systematic review identified twenty-three papers that met all the inclusion criteria. The review revealed that in 53% of studies, alerts improved prescriber behaviour or patient outcomes. The greatest volume of evidence arose from drug-condition interaction, drug-drug interaction and corollary order alerts, with drug-condition alerting having the greatest evidence of positive effect. There was no comparative research evidence indicating that a specific category of alerts is more effective than another, and little is known about the impact on prescribing or patients when alerts from multiple categories were incorporated within the same system.

With limited research evidence available to guide alert selection in EMM systems, the second aim of this thesis was to determine the process by which Australian hospitals make decisions about which alerts to include in the EMM systems, and the basis for these decisions. To do this, a standardised, semi-structured telephone survey was conducted on a purposive sample of key stakeholders involved in EMM implementation in Australian hospitals. This survey revealed that the three most frequently implemented alert categories were drug-allergy interaction alerts (100% of hospitals surveyed), drug-drug- interaction alerts (100% of hospitals surveyed), and dose range checking alerts (69% of hospitals surveyed).

Respondents reported that a high degree of customisation of the vendor out-of-the box functionality was required to improve sensitivity and specificity of alerts and to minimise alert fatigue. Configuration decisions appeared to have been influenced by a perception that alerts change prescriber behaviour and improve patient outcomes and may have been shaped by factors additional to those identified by respondents, such as alert experiences in pharmacy dispensing systems. Few hospitals had undertaken evaluation activities, and stakeholders were not confident that the perceived benefits of alerts are being achieved in their local settings. Despite this, stakeholders favoured optimising existing alerts rather than removing alerts.

In summary, this program of research has identified that while there is some evidence of the effectiveness of specific individual categories of alerts, there is little research evidence available to guide selection of the most effective combination of alert categories for inclusion in EMM systems. Yet implementers in Australian hospitals have actively embraced multiple categories of interruptive alerts and believe that there is published evidence which supports their use. Few hospitals have assessed alert effectiveness, and implementers harbour doubts about the likely effectiveness of their alerts locally.

The Australian experience offers guidance to new implementers on the most commonly used alerts, and lessons learned on designing and implementing effective interruptive prescribing alerts. There is a significant research gap on which alerts to include and exclude from an EMM system. Ongoing evaluation of the effectiveness of interruptive medication prescribing alerts is required, in particular the cumulative impact when different combinations of alert categories are incorporated within the same system.

PRESENTATION OF THESIS

This thesis is presented by publication, as a combination of one published systematic review and one published paper.

The review and paper describe the methods, results and discussion of the three research projects undertaken in this candidature.

Chapter 1 provides an introduction to electronic management systems with clinical decision support, and of the research project undertaken in this candidature.

Chapters 2-3 contain the following manuscripts. The candidate is the principal author for each of the papers.

> Chapter 2: **Page, N.**, M. T. Baysari, and J. I. Westbrook. *A systematic review of the effectiveness of interruptive medication prescribing alerts in hospital CPOE systems to change prescriber behavior and improve patient safety*. International Journal of Medical Informatics, 2017.105:22-30.

> Chapter 3: **Page, N**., M. T. Baysari, and J. I. Westbrook *Selection and use of decision support alerts in electronic medication management systems in Australian hospitals: A survey of implementors.* Under consideration by the Journal of Pharmacy Practice and Research (submitted November 2017).

Chapter 4 synthesises the findings from the separate studies and discusses the significance and contribution of the results in the light of existing research. The chapter draws conclusions from the research undertaken, describes the contribution of this research to decision support practice and offers directions for future research.

PUBLICATIONS

Page, N., M. Baysari, and J. Westbrook, A systematic review of the effectiveness of interruptive medication prescribing alerts in hospital CPOE systems to change prescriber behavior and improve patient safety. International Journal of Medical Informatics, 2017. 105: p. 22-30

Page, N., M. T. Baysari, and J. I. Westbrook (in press). *Selection and use of decision support alerts in electronic medication management systems in Australian hospitals: A survey of implementors.* Currently under consideration. Journal of Pharmacy Practice

PRESENTATIONS

March 2017   Invited Presentation: Determining Critical Prescribing Alerts to Include in eMM, *eMedication Management Conference 2017, Sydney, Australia*

DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed:

Date: 06 June 2018

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And to Roland and Ashwin, my reasons for everything, and my two favourite inquisitive minds. I dedicate this to both of you.

"The important thing is not to stop questioning. Curiosity has its own reason for existing"

– Albert Einstein

CHAPTER 1

Introduction

1.1. Medication use and error

Medications are the most prevalent health therapy in Australia [1]. And while medications often contribute to significant improvements in patient health, their frequent use means they are associated with more errors and adverse events than any other aspect of health care [1].

Medication errors have been defined as "a failure in the treatment process that leads to, or has the potential to lead to, harm to the patient" [2, p.1013], and "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" [3, p.4]. This latter definition recognises that medication errors are a potentially preventable cause of patient harm.

Medication errors can occur at any of the phases of the medication management cycle or within any of the system-wide background processes (see Figure 1). Errors have most commonly been reported during the prescribing, administration and dispensing stages [4].
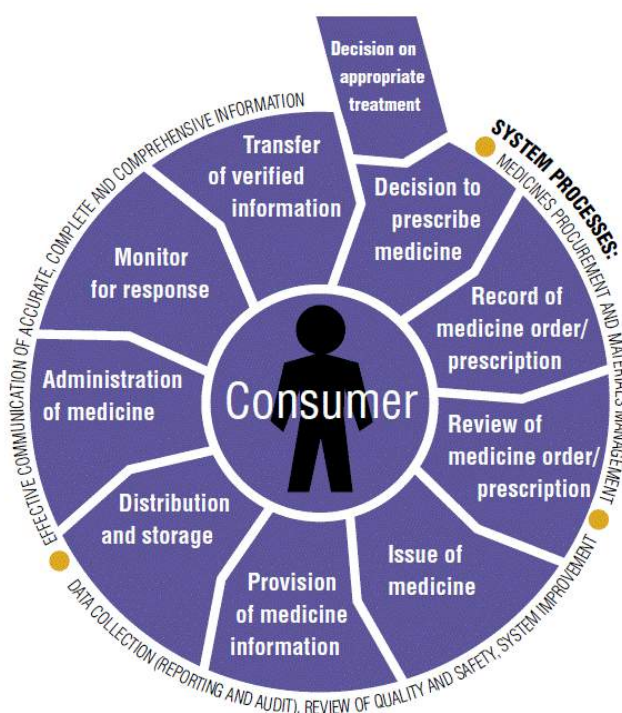

Figure 1. Medication Management Cycle [5]

1.2. Incidence of medication error and harm from error

A 2016 review of published literature on medication safety in the acute care setting in Australia reported several key findings on medication error and medication-related adverse events [6]. An estimated 230,000 Australian hospital admissions (2-3%) are due to medication-related problems costing an estimated AU$1.2 billion annually [6]. On admission to hospital, medication errors occur at the rate of two errors for every three patients, and on discharge the rate increases to up to two errors per patient [6]. Prescription errors in hospital occur at a rate of up to one error per patient [6].

Medication errors are not a unique problem to Australia and have been recognised as a significant global patient safety issue for more than a decade [7]. The seminal report 'To Err is Human', published byr The Institute of Medicine in 1999, estimated that at that time medication errors in the USA accounted for over 7,000 deaths annually, and called for efforts to improve the rate of error in health care [8]. In 2017, the World Health Organisation published their third Global Patient Safety Challenge, Medication Without Harm, with the global goal to reduce the level of severe, avoidable harm related to medications by 50% over the next five years [9].

International medication error rates are comparable to those reported in Australia. Between 2-5% of hospital admissions are related to problems with medicines [10, 11], and this appears to differ across age groups, with the rate higher in older adults in some studies (10-10.7%) [10, 12] compared with younger adults (6.3%) and children (2.9%-4.1%) [10, 13]. Up to 69% of medication-related hospital admissions have been shown to be preventable [11]. The rate of harm from medication error during hospital admission ranges from 0.7- 9.2% [11, 14-19], with up to 56.6% of events estimated to be potentially preventable [11].

Studies that analyse voluntary incident reports indicate that prescribing errors are reported more frequently than other medication error types [4, 19, 20], and have been described as potentially the most serious type of medication error [18, 20]. However, they are also reported as more likely to be intercepted than errors during other stages of the medication management cycle [20]. The majority of prescribing errors have been reported to occur while recording the medication order, with the most serious errors originating during the decision to prescribe [21].

A systematic review of prescribing errors concluded that while causes are often multifactorial, inadequate knowledge of the medication or the patient are the most common cause of prescribing errors in hospital inpatients [22].

1.3. Causes of medication error

Medication errors occur due to multiple, inter-related contributing factors, including human and system factors [23, 24]. There are many general theories of error that can be applied to medication error. Reason's theory of human error, also known as the 'Swiss Cheese Model', describes the human and system factors that contribute to error occurrence. It describes the error types as active failures (such as errors due to slips, lapses, mistakes and violations) and system factors as latent conditions (situations within the healthcare system likely to give rise to human error) [24].

Ferner and Aronson's psychological approach to error further defines the human factor element, describing an error as an action intended but not performed [2]. They classify these events into four broad error types (see Figure 2).
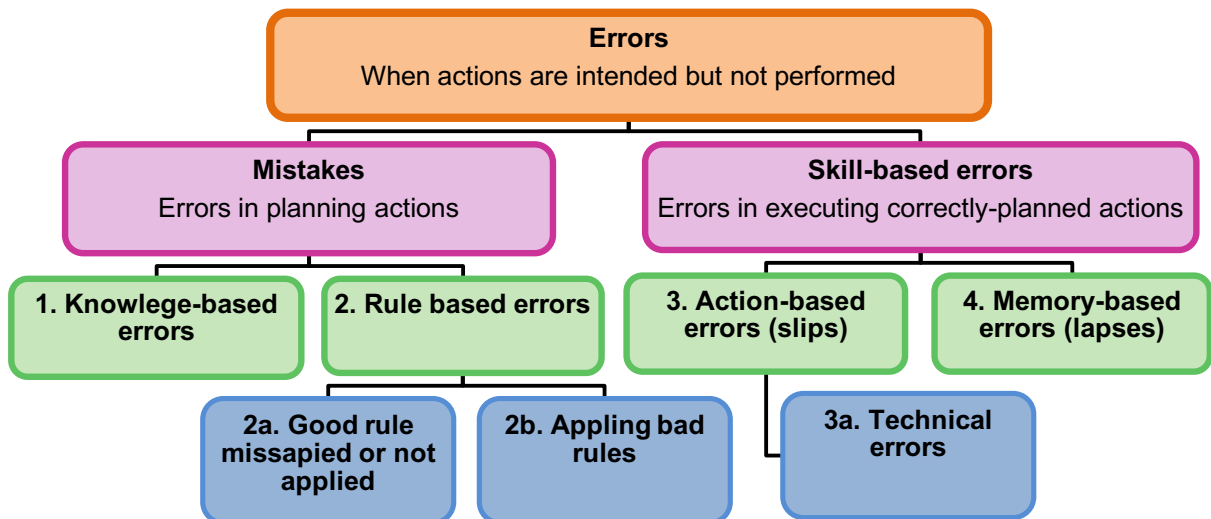
Figure 2. The classification of medication errors based on a psychological approach [2]

The classification of errors using an approach such as this can aid in the identification of appropriate strategies to reduce each category of medication error and will be further discussed in Section 1.6.

1.4. Medication safety in Australia

The National Safety and Quality Health Service Standards, developed by the Australian Commission on Safety and Quality in Health Care (ACSQHC), provide a description of the level of care that should be provided by Australian health service organisations and the systems that are needed to deliver such care [25]. All hospitals across Australia are required to implement and undergo assessment and accreditation against the NSQHS Standards. It is intended that these standards then drive the use of safety and quality systems and improve the quality of health service provision in Australia.

Standard 4: Medication Safety describes the systems and strategies to ensure clinicians safely prescribe, dispense and administer appropriate medicines [26]. To meet Standard 4, Australian hospitals have a clinical governance responsibility to enhance the safe and appropriate use of medicines; by understanding the risk of medication error and implementing strategies and systems known for reducing the potential for medication-related errors. Electronic medication management (EMM) systems have been advocated as one strategy to reduce medication errors.

1.5. Electronic medication management systems

An EMM system is defined by the ACSQHC as an integrated clinical information system that supports *the "entire electronic medication process from the prescriber's medication order, to the pharmacist's review of the medication order and supply of medicine, to the nurse's documentation of administration of the medicine, and all the processes in between"* [27, p.175].

EMM is a broad term that incorporates any electronic clinical information system, tool, or software application that is used to support the medicines management cycle, effectively replacing (or minimising) documentation on paper forms, enabling medication-related tasks to be completed and recorded electronically. Under this definition, EMM systems include prescribing systems (also known as computerised provider order entry systems, or CPOE), decision support systems, and medication administration records. EMM systems may be standalone systems, or one element of an integrated digitised clinical care system such as an electronic health record (EHR).

A high-level overview of medication order entry as performed in an EMM system is described in Figure 3.

```mermaid
graph TD
    A[Prescriber enters the medication name in the EMM search window] --> B[Prescriber selects an order from the search results]
    B --> C[Prescriber completes the required fields]
    C --> D[Prescriber electronically signs order]
```
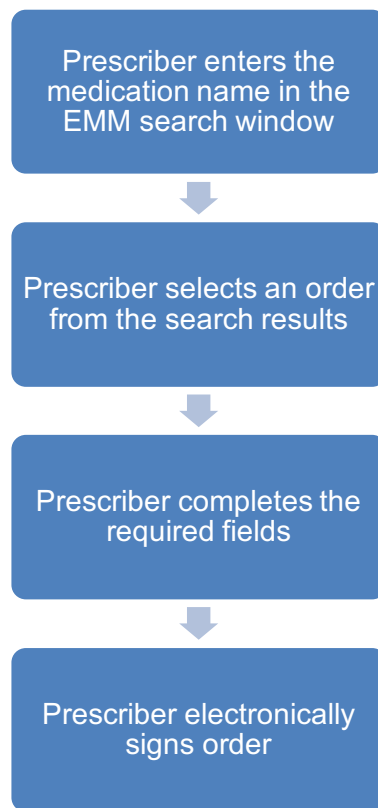
Figure 3. High level overview of medication order entry in an EMM system

The use of EMM systems within Australian hospitals is not widespread and few have more than 5 years' experience, but EMM use globally has been expanding since the introduction of the first home-grown systems over 30 years ago and commercial systems over 20 years ago. The literature reporting the impact of EMM systems on medication error is growing, and there are many demonstrations of EMM (in certain circumstances) reducing medication error rates [28-33].

EMM implementation is now endorsed by key Australian healthcare professional and government bodies [27], and all Australian state and territory Health Departments are actively implementing EMM systems in their major acute care hospitals. An EMM system is not necessary for accreditation against NSQHS Standard 4, however safe implementation of an EMM system within a robust clinical governance framework facilitates compliance with many of the standards, for example, via clear documentation and standardised terminology, patient information available at the point of care, prospective data collection for reports and analysis, and decision support tools.

1.6. Decision support for medication prescribing

Clinical decision support (CDS) can provide clinicians with "clinical knowledge and patient-related information, intelligently filtered and presented at appropriate times, to enhance patient care" [34, p.40]. It is an integral part of EHR systems and has the potential to reduce errors and improve quality of patient care through enhanced clinician decision making and the support of evidence-based practice [35]. A comprehensive taxonomy of CDS tools can be found in Appendix A).

CDS tools in EMM systems can support the various stages of the medication management cycle (Figure 4), and include order facilitation, protocol/pathway support, alerts/reminders, bar-coded patient or medication identification, provision of reference information, and disease management support.
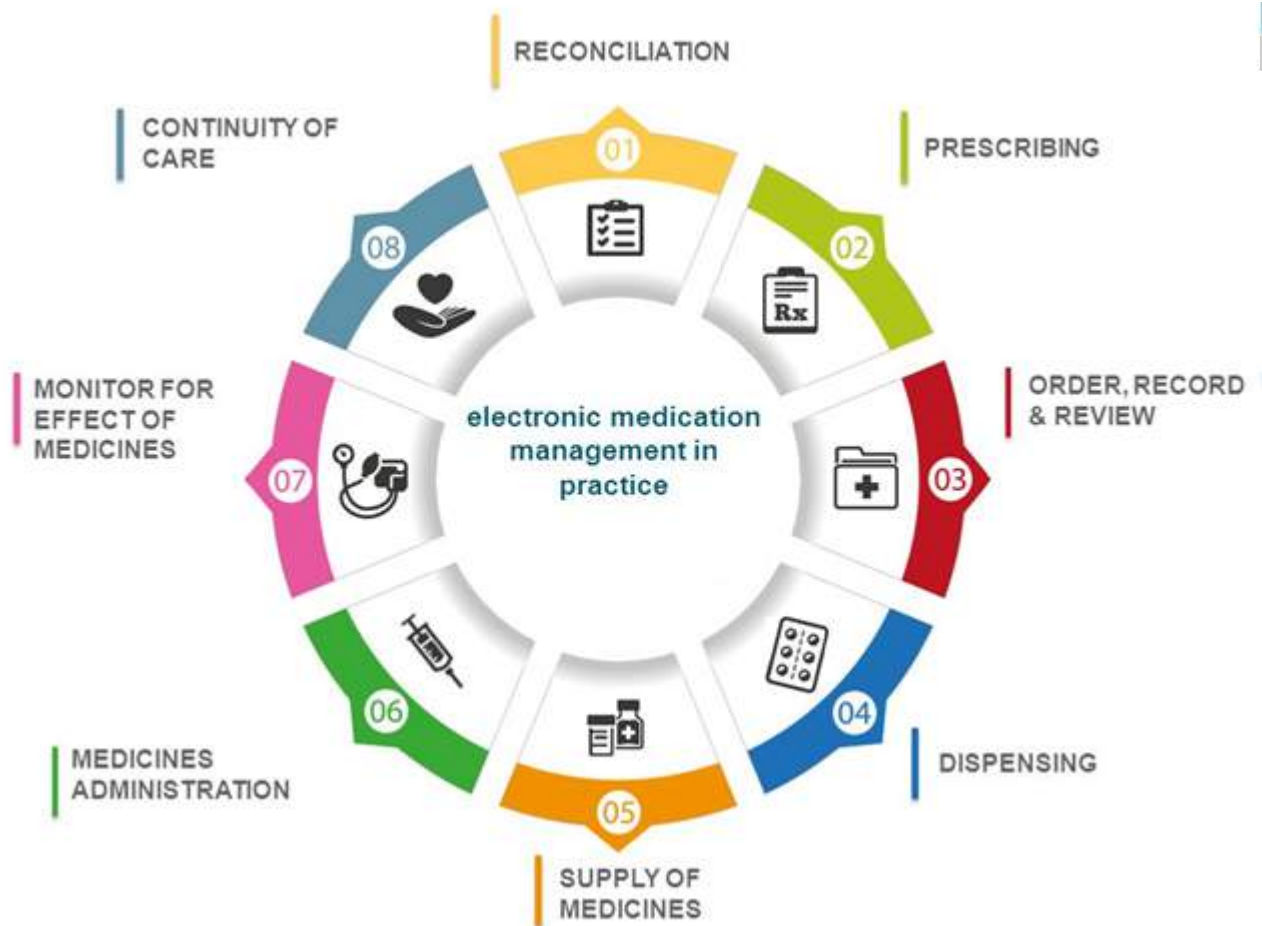
Figure 4. Modified medication management cycle to explain how EMM systems are being implemented to support the various stages in the process [36]

Order facilitation includes order sentences (Figure 5) where some or all of the order fields of a prescription (e.g. dose, route, frequency) have predefined default values [37], saving time and potentially preventing errors. Order sets (Figure 6) are multiple order sentences linked in sequences, supporting protocols and pathways by generating multiple orders rapidly for review and signature [37].

Figure 5. An example of prewritten medication order sentences in a commercial EMM system

Figure 6. An example of an order set of multiple prewritten order sentences in a commercial EMM system

CDS tools can be used to target specific known common causes [2] of medication errors. For example, CDS tools can reduce knowledge-based errors by presenting information to a prescriber that they may not have otherwise known, for example, information about a certain antibiotic containing a penicillin. CDS has the potential to reduce rule-based errors by providing pre-written medication order sentences, or interruptive alerts when a dose maximum is exceeded. Action based errors could be reduced by choosing medication order sentences for certain clinical indications from an order set. Interventions to reduce memory lapses could include prompting on a specified date to review a short-course medication.

Since prescribing errors are cited as the most frequent and preventable type of medication error [4, 18, 19], a major focus of CDS in commercial EMM systems is to support safe medication prescribing. One such CDS tool that assists prescribers in the construction of safe medication orders is interruptive alerts. These provide immediate notification of potential errors or safety risks to the prescriber at the time of electronic medication order entry. A high-level overview of medication order entry in an EMM system with CDS alerts is shown in Figure 7). Commonly available categories of interruptive medication prescribing alerts include drug-allergy interactions, drug-drug interactions (DDIs) (Figure 8), drug-condition

interactions (Figure 9), drug-laboratory interactions, dose range checking (DRC) (Figure 10), dose adjustment, therapeutic duplication (Figure 11), corollary orders, and formulary alerts [34, 38-40].
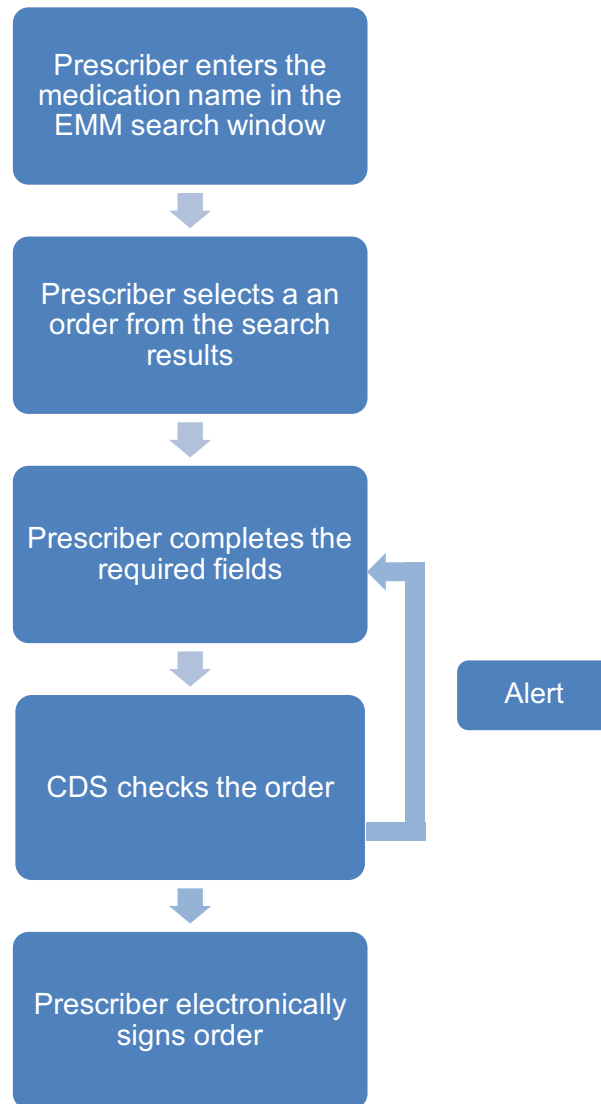
Figure 7. High level overview of medication order entry in an EMM system with CDS

Figure 8. An example of a DDI alert in a commercial EMM system

Figure 9. An example of a drug-condition alert in a commercial EMM system

Dose Range Alert

The following violation was found:

The ordered dose (400 mg Oral FOUR times a day) is OVER the suggested dose range for this medication(ibuprofen)

Suggested SINGLE DOSE range: 0 - 11 mg/kg. (0 - 330 mg for this patient's Weight measured (30kg) recorded on 28/03/2018 10:43.)

Comment: This dose range check is based on published paediatric prescribing guidelines - AMH CDC/ BNFc/ Micromedex/ MIMS/ circa August 2017. You may choose to override this alert at your discretion based on clinical judgement, specific patient factors or more up-to-date prescribing information.

Alert Action

- ○ Cancel Order
- ○ Override Alert
- ● Modify Order

Alert History   OK

Figure 10. An example of a dose range checking alert in a commercial EMM system

Figure 11. An example of duplicate order alert in a commercial EMM system

EMM systems with limited CDS are predominantly only effective at reducing lower risk errors, such as those that are procedural in nature (e.g. unclear, incomplete, or illegible orders) [41]. Alternatively, EMM systems with integrated CDS alerts have been shown, in certain circumstances, to be effective at significantly reducing medication errors [28-33].

However, CDS alerts may not always deliver on the potential to reduce error. Many studies show that excessive generation of alerts leads to alerts being ignored [42, 43]. As a result, the opportunity to avoid preventable errors can be missed [42-48], compromising the potential and desired safety impact of EMM with CDS [43, 49]. This unintended phenomenon is termed alert fatigue, with users not only ignoring alerts that have limited clinical significance, but also those that are clinically significant [50]. A consequence of alert fatigue is alert override (i.e. users moving past the alert without performing the action recommended by the alert [51]). A 2006 systematic review reported that 49-96% of medication-related CDS alerts were overridden by prescribers [43]. More recent studies indicate that this is an ongoing problem [52, 53]. So, whilst the concept of designing CDS is simple, achieving the desired outcome from interruptive alerts is very difficult.

13

1.7. Implementing effective medication prescribing alerts

EMM systems with integrated CDS are not 'plug and play' systems, and most commercial systems offer a limited range of customisation or tailoring of alerting to suit the setting. This customisation includes options such as selecting which alert type will be activated/deactivated; switching alerts from interruptive to non-interruptive; and alert filtering based on alert severity (i.e. filtering alerts and only displaying those of high severity that are most likely to cause harm).

There is increasing focus in the literature on the best way to optimise CDS alerts in EMM systems [47, 48, 50, 54-64], with leading international experts suggesting the need for standards on clinically relevant content for CDS alerts [57]. Including high-priority clinically significant alerts, while reducing interruptions resulting from low- and moderate-priority alerts should, in theory, target important prescribing errors whilst minimising alert fatigue. Following this agenda, the literature to date has focused on the content [43, 48, 50, 56, 58, 59, 61, 64], design [65-68], or context factors [69] of alert categories. Taking the example of drug-drug interaction (DDI) alerts, research has included optimising sensitivity and specificity via content such as determining high and low priority interacting medicines, [50, 56, 70] or changing the DDI severity classification for selected medications [71]; design elements such as tiering of DDI alerts by severity [48, 72] or according to patient-specific factors [70], or making certain DDI alerts interruptive or non-interruptive [56, 58]; and context factors such as displaying DDI alerts to certain users only, e.g. junior clinicians.

However, organisations rarely introduce a single CDS alert category on its own. Dozens of alert categories are often available in EMM and most systems allow a level of customisation of the chosen alerts, as described above. Despite many studies and systematic reviews performed on CDS alerts, there is limited evidence available reporting the effectiveness of prescribing alerts by alert category or comparing the effectiveness of different categories of medication prescribing alerts.

Information is lacking on which prescribing alert category or categories to include in an EMM system to maximise the potential safety benefits of alerts balanced against the risk of alert fatigue. Despite this lack of evidence, implementers must make decisions about the number and types of alerts to integrate into EMM systems. Little is known on how implementers make decisions on what alerts to include in EMM system in the absence of available evidence and guidelines.

1.8. Aims of this project

Clinicians undertake electronic prescribing in an EMM system within a context of multiple alert categories, however there are no standards or evidence-based recommendations from expert groups or government bodies on which combination of medication prescribing alert/s should be included in an EMM system.

The aim of this research was to identify evidence of the effectiveness of interruptive medication prescribing alerts to inform decisions about which combination to include in a hospital inpatient EMM system.

1.9. Research questions

The research program focussed on two core questions:

What is the evidence for the effectiveness of interruptive medication prescribing alerts to improve prescriber behaviour or patient outcomes in hospital EMM systems?

Which interruptive medication prescribing alerts have been selected for inclusion in EMM systems in Australian hospitals, and why?

To answer these questions, evidence was gathered from published research on alert effectiveness, and from the reported experiences and advice of key stakeholders involved in the implementation of EMM systems in Australian hospitals.

1.10. Chapter 1 References

1. Roughead, E.E., S.J. Semple, and E. Rosenfeld, *Literature Review: Medication Safety in Australia*, Australian Commission on Safety and Quality in Health Care, Editor. 2013, ACSQHC: Sydney.

2. Ferner, R.E. and J.K. Aronson, *Clarification of terminology in medication errors.* Drug safety, 2006. **29**(11): p. 1011-1022.

3. National Coordinating Council for Medication Error Reporting and Prevention *NCC MERP: The first ten years. Defining the problem and developing solutions*. 2005.

4. Leape, L.L., et al., *Systems analysis of adverse drug events. ADE Prevention Study Group.* JAMA, 1995. **274**(1): p. 35-43.

5. Australian Pharmaceutical Advisory Council, *Guiding principles to achieve continuity in medication management.* Canberra: Commonwealth of Australia, 2005: p. 57.

6. Roughead, E.E., S.J. Semple, and E. Rosenfeld, *The extent of medication errors and adverse drug reactions throughout the patient journey in acute care in Australia.* International journal of evidence-based healthcare, 2016. **14**(Medication Safety Issue: 3): p. 113-122.

7. Institute of Medicine *Preventing Medication Errors*, ed. P. Aspden, et al. 2007, Washington, DC: The National Academies Press. 480.

8. Kohn, L.T., et al. *To err is human: building a safer health system*. 2000, Washington, DC: National Academies Press.

9. World Health Organization, *Medication Without Harm - Global Patient Safety Challenge on Medication Safety*. 2017: Geneva.

10. Oscanoa, T., F. Lizaraso, and A. Carvajal, *Hospital admissions due to adverse drug reactions in the elderly. A meta-analysis.* European journal of clinical pharmacology, 2017. **73**(6): p. 759-770.

11. von Laue, N.C., D.L.B. Schwappach, and C.M. Koeck, *The epidemiology of preventable adverse drug events: a review of the literature.* Wiener Klinische Wochenschrift, 2003. **115**(12): p. 407-415.

12. Kongkaew, C., P.R. Noyce, and D.M. Ashcroft, *Hospital Admissions Associated with Adverse Drug Reactions: A Systematic Review of Prospective Observational Studies.* Annals of Pharmacotherapy, 2008. **42**(7-8): p. 1017-1025.

13. Smyth, R.M.D., et al., *Adverse Drug Reactions in Children—A Systematic Review.* PLoS ONE, 2012. **7**(3): p. e24061.

14. NHS Connecting for Health, *Electronic prescribing in hospitals. Challenges and lessons learned*. 2009: London.

15. Schedlbauer, A., et al., *What evidence supports the use of computerized alerts and prompts to improve clinicians' prescribing behavior?* Journal of the American Medical Informatics Association, 2009. **16**(4): p. 531-8.

16.   Lesar, T.S., *Prescribing errors involving medication dosage forms.* Journal of general internal medicine, 2002. **17**(8): p. 579-587.

17.   Jiménez Muñoz, A., et al., *Medication error prevalence.* International journal of health care quality assurance, 2010. **23**(3): p. 328-338.

18.   Bates, D.W., et al., *Relationship between medication errors and adverse drug events.* Journal of general internal medicine, 1995. **10**(4): p. 199-205.

19.   Winsterstein, A.G., et al., *Nature and causes of clinically significant medication errors in a tertiary care hospital.* American Journal of Health-System Pharmacy, 2004. **61**(18).

20.   Bates, D.W., et al., *Incidence of adverse drug events and potential adverse drug events. Implications for prevention. ADE Prevention Study Group.* JAMA, 1995. **274**(1): p. 29-34.

21.   Dean, B., et al., *Prescribing errors in hospital inpatients: their incidence and clinical significance.* Quality and Safety in Health Care, 2002. **11**(4): p. 340.

22.   Tully, M.P., et al., *The causes of and factors associated with prescribing errors in hospital inpatients: a systematic review.* Drug Safety, 2009. **32**(10): p. 819-36.

23.   Australian Commission on Safety and Quality in Health Care, *Australia joins international push to halve medication errors.* 2017, ACSCHQ.

24.   Reason, J., *Human error: models and management.* BMJ : British Medical Journal, 2000. **320**(7237): p. 768-770.

25.   Australian Commission on Safety and Quality in Health Care, *National Safety and Quality Health Service Standards.* 2012, ACSQHC: Sydney.

26.   Australian Commission on Safety and Quality in Health Care, *Safety and Quality Improvement Guide Standard 4: Medication Safety.* 2012, ACSQHC: Sydney.

27.   Australian Commission on Safety and Quality in Health Care, *Electronic Medication Management Systems — A Guide to Safe Implementation, 2nd edition.* 2012, ACSQHC: Sydney.

28.   Bates, D.W., et al., *Effect of computerized physician order entry and a team intervention on prevention of serious medication errors.* JAMA, 1998. **280**(15): p. 1311-1316.

29.   Bates, D.W., et al., *The impact of computerized physician order entry on medication error prevention.* Journal of the American Medical Informatics Association, 1999. **6**(4): p. 313-321.

30.   Coiera, E., J. Westbrook, and J. Wyatt, *The safety and quality of decision support systems.* Methods Inf Med, 2006. **45**(Suppl 1): p. 20-5.

31.   Garg, A.X., et al., *Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review.* Jama, 2005. **293**(10): p. 1223-38.

32. Kaushal, R., K.G. Shojania, and D.W. Bates, *Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review.* Arch Intern Med, 2003. **163**(12): p. 1409-16.

33. Nuckols, T.K., et al., *The effectiveness of computerized order entry at reducing preventable adverse drug events and medication errors in hospital settings: a systematic review and meta-analysis.* Systematic reviews, 2014. **3**(1): p. 1.

34. Osheroff, J.A., et al. *Improving Outcomes with Clinical Decision Support: An Implementer's Guide, Second Edition.* 2012, Chicago, IL: Healthcare Information and Management Systems Society (HIMSS).

35. Doebbeling, B.N., et al., *Integrating Clinical Decision Support into Workflow.* 2011.

36. Australian Commission on Safety and Quality in Health Care. *Electronic medication management (EMM). A guide for healthcare providers.* v1.01 2015, [cited 9 April 2018]; [Available from: https://www.safetyandquality.gov.au/wp.../Mapping-eMedications-Management.pptx.

37. Payne, T.H., et al., *Preparation and Use of Preconstructed Orders, Order Sets, and Order Menus in a Computerized Provider Order Entry System.* Journal of the American Medical Informatics Association : JAMIA, 2003. **10**(4): p. 322-329.

38. Kilbridge, P.M., E.M. Welebob, and D.C. Classen, *Development of the Leapfrog methodology for evaluating hospital implemented inpatient computerized physician order entry systems.* Qual Saf Health Care, 2006. **15**(2): p. 81-4.

39. Kuperman, G.J., et al., *Medication-related clinical decision support in computerized provider order entry systems: a review.* J Am Med Inform Assoc, 2007. **14**(1): p. 29-40.

40. Wright, A., et al., *Development and evaluation of a comprehensive clinical decision support taxonomy: comparison of front-end tools in commercial and internally developed electronic health record systems.* J Am Med Inform Assoc, 2011. **18**(3): p. 232-42.

41. Westbrook, J.I., et al., *Effects of two commercial electronic prescribing systems on prescribing error rates in hospital in-patients: a before and after study.* PLoS Med, 2012. **9**(1): p. e1001164.

42. Ash, J.S., P.Z. Stavri, and G.J. Kuperman, *A consensus statement on considerations for a successful CPOE implementation.* J Am Med Inform Assoc, 2003. **10**(3): p. 229-34.

43. Van Der Sijs, H., et al., *Overriding of drug safety alerts in computerized physician order entry.* Journal of the American Medical Informatics Association, 2006. **13**(2): p. 138-147.

44. Baysari, M.T., et al., *Failure to utilize functions of an electronic prescribing system and the subsequent generation of 'technically preventable' computerized alerts.* J Am Med Inform Assoc, 2012. **19**(6): p. 1003-10.

45. Chan, A.J., et al., *Order sets in health care: a systematic review of their effects.* Int J Technol Assess Health Care, 2012. **28**(3): p. 235-40.

46. Baysari, M.T., et al., *The influence of computerized decision support on prescribing during ward-rounds: are the decision-makers targeted?* J Am Med Inform Assoc, 2011. **18**(6): p. 754-9.

47. Smithburger, P.L., et al., *A critical evaluation of clinical decision support for the detection of drug–drug interactions.* Expert Opinion on Drug Safety, 2011. **10**(6): p. 871-882.

48. Chaffee, B.W. and C.R. Zimmerman, *Developing and implementing clinical decision support for use in a computerized prescriber-order-entry system.* American Journal Of Health-System Pharmacy: AJHP: Official Journal Of The American Society Of Health-System Pharmacists, 2010. **67**(5): p. 391-400.

49. Ranji, S.R., S. Rennke, and R.M. Wachter, *Computerised provider order entry combined with clinical decision support systems to improve medication safety: a narrative review.* BMJ quality & safety, 2014: p. bmjqs-2013-002165.

50. Phansalkar, S., et al., *Criteria for assessing high-priority drug-drug interactions for clinical decision support in electronic health records.* BMC Medical Informatics and Decision Making, 2013. **13**(1): p. 65.

51. McCoy, A.B., et al., *A framework for evaluating the appropriateness of clinical decision support alerts and responses.* J Am Med Inform Assoc, 2012. **19**(3): p. 346-52.

52. Beeler, P.E., et al., *Provider variation in responses to warnings: do the same providers run stop signs repeatedly?* Journal of the American Medical Informatics Association, 2015. **23**(e1): p. e93-e98.

53. Nanji, K.C., et al., *Overrides of medication-related clinical decision support alerts in outpatients.* Journal of the American Medical Informatics Association, 2014. **21**(3): p. 487-491.

54. Troiano, D., et al., *The need for collaborative engagement in creating clinical decision-support alerts.* American Journal Of Health-System Pharmacy: AJHP: Official Journal Of The American Society Of Health-System Pharmacists, 2013. **70**(2): p. 150-153.

55. Tiwari, R., et al., *Enhancements in healthcare information technology systems: customizing vendor-supplied clinical decision support for a high-risk patient population.* Journal Of The American Medical Informatics Association: JAMIA, 2013. **20**(2): p. 377-380.

56.   Phansalkar, S., et al., *Drug-drug interactions that should be non-interruptive in order to reduce alert fatigue in electronic health records.* Journal Of The American Medical Informatics Association: JAMIA, 2013. **20**(3): p. 489-493.

57.   Mulherin, D.P., C.R. Zimmerman, and B.W. Chaffee, *National standards for computerized prescriber order entry and clinical decision support: the case of drug interactions.* American Journal Of Health-System Pharmacy: AJHP: Official Journal Of The American Society Of Health-System Pharmacists, 2013. **70**(1): p. 59-64.

58.   Phansalkar, S., et al., *High-priority drug–drug interactions for use in electronic health records.* Journal of the American Medical Informatics Association, 2012. **19**(5): p. 735-743.

59.   Classen, D.C., S. Phansalkar, and D.W. Bates, *Critical Drug-Drug Interactions for Use in Electronic Health Records Systems With Computerized Physician Order Entry: Review of Leading Approaches. [Article].* Journal of Patient Safety June, 2011. **7**(2): p. 61-65.

60.   Bates, D.W., *Cpoe and clinical decision support in hospitals: Getting the benefits: comment on "unintended effects of a computerized physician order entry nearly hard-stop alert to prevent a drug interaction".* Archives of Internal Medicine, 2010. **170**(17): p. 1583-1584.

61.   Van der Sijs, H., et al., *Turning off frequently overridden drug alerts: limited opportunities for doing it safely.* Journal of the American Medical Informatics Association, 2008. **15**(4): p. 439-48.

62.   Troiano, D., et al., *The need for collaborative engagement in creating clinical decision-support alerts.* Am J Health Syst Pharm, 2013. **70**(2): p. 150-3.

63.   Coleman, J.J., et al., *On the alert: future priorities for alerts in clinical decision support for computerized physician order entry identified from a European workshop.* BMC Med Inform Decis Mak, 2013. **13**: p. 111.

64.   Phansalkar, S., et al., *Towards Meaningful Medication-Related Clinical Decision Support: Recommendations for an Initial Implementation.* Applied Clinical Informatics, 2011. **2**(1): p. 50-62.

65.   Mollon, B., et al., *Features predicting the success of computerized decision support for prescribing: a systematic review of randomized controlled trials.* BMC Med Inform Decis Mak, 2009. **9**: p. 11.

66.   Horsky, J., et al., *Design of decision support interventions for medication prescribing.* Int J Med Inform, 2013. **82**(6): p. 492-503.

67.   Horsky, J., et al., *Interface design principles for usable decision support: A targeted review of best practices for clinical prescribing interventions.* J Biomed Inform, 2012. **45**(6): p. 1202-1216.

68.   Roshanov, P.S., et al., *Features of effective computerised clinical decision support systems: meta-regression of 162 randomised trials.* BMJ, 2013. **346**.

69.   Riedmann, D., et al., *Development of a context model to prioritize drug safety alerts in CPOE systems.* BMC Medical Informatics and Decision Making, 2011. **11**: p. 35-35.

70.   Tilson, H., et al., *Recommendations for Selecting Drug-Drug Interactions for Clinical Decision Support.* American journal of health-system pharmacy : AJHP : official journal of the American Society of Health-System Pharmacists, 2016. **73**(8): p. 576-585.

71.   Horn, J.R., et al., *Customizing clinical decision support to prevent excessive drug-drug interaction alerts.* American Journal Of Health-System Pharmacy: AJHP: Official Journal Of The American Society Of Health-System Pharmacists, 2011. **68**(8): p. 662-664.

72.   Paterno, M.D., et al., *Tiering drug–drug interaction alerts by severity increases compliance rates.* Journal of the American Medical Informatics Association, 2009. **16**(1): p. 40-46.

CHAPTER 2

A systematic review of the effectiveness of interruptive medication prescribing alerts in hospital CPOE systems to change prescriber behaviour and improve patient safety

This chapter contains the systematic review titled *A systematic review of the effectiveness of interruptive medication prescribing alerts in hospital CPOE systems to change prescriber behavior and improve patient safety*, published in the International Journal of Medical Informatics 2017,105: 22-30. At the time of submission this paper had already been cited twice.

The purpose of this systematic review was to answer the question:

What is the evidence of the effectiveness of interruptive medication prescribing alerts to change prescriber behaviour and/or improve patient outcomes in the acute hospital inpatient setting?

Contributor	Statement of contribution*
Natalie Page	Development of research question
	Development of research protocol
	Conducted literature search
	Conducted article screening process
	Conducted data extraction
	Conducted data analysis
	Interpreted results
	Developed manuscript
Signature:	
Date: 06 June 2018	
Associate Professor Melissa Baysari	Aided development of research question
	Aided development of research protocol
	Aided article screening process
	Aided data analysis
	Aided result interpretation
	Aided manuscript development
Professor Johanna Westbrook	Aided development of research question
	Aided development of research protocol
	Aided data analysis
	Aided result interpretation
	Aided manuscript development

Pages 24-32 of this thesis have been removed as they contain published material. Please refer to the following citation for details of the article contained in these pages.

Page, N., Baysari, M. T., & Westbrook, J. I. (2017). A systematic review of the effectiveness of interruptive medication prescribing alerts in hospital CPOE systems to change prescriber behavior and improve patient safety. *International Journal of Medical Informatics*, 105, p. 22-30.

CHAPTER 3

Selection and use of decision support alerts in electronic medication management systems in Australian hospitals: A survey of implementors

This chapter contains the manuscript (in press) titled *Selection and use of decision support alerts in electronic medication management systems in Australian hospitals: A survey of implementors,* Journal of Pharmacy Practice and Research.

The second research question of this thesis was to investigate the experiences of Australian hospital EMM implementers with respect to interruptive medication prescribing alert utility, configuration, evaluation and governance. This study was approved by Macquarie University's Human Research Ethics Committee, and the approval letter can be found in Appendix F.

Contributor	Statement of contribution*
Natalie Page	Development of research question
	Development of survey
	Wrote ethics application
	Conducted survey
	Conducted data extraction
	Conducted data analysis
	Interpreted results
	Wrote manuscript
Signature:	
Date: 06 June 2018	
Associate Professor Melissa Baysari	Aided development of research question
	Aided development of survey
	Aided ethics application
	Aided thematic coding of results
	Aided data analysis
	Aided result interpretation
	Aided manuscript development
Professor Johanna Westbrook	Aided development of research question
	Aided development of survey
	Aided ethics application
	Aided data analysis
	Aided result interpretation
	Aided manuscript development

ABSTRACT

Background

Electronic medication management (EMM) systems provide the capacity to enable and configure front-end clinical decision support (CDS) tools to trigger medication-related prescribing alerts.

Aim

To determine how and why alerts were selected for inclusion in inpatient EMM systems in Australian hospitals.

Method

A semi-structured, cross-sectional survey containing multiple choice questions, scaled responses, and open-ended questions was conducted on a purposive sample of key stakeholders from Australian hospitals who had implemented an EMM system.

Results and Discussion

We interviewed fifteen participants, predominantly pharmacists, representing 26 Australian hospitals that had implemented an EMM system. All hospitals had implemented drug-allergy and drug-drug alerting, and 69% (n=18) dose range checking alerting. Implementers reported a high level of customisation of the vendor out-of-the box functionality in efforts to improve sensitivity and specificity of alerts and to minimise alert fatigue.

For the most frequently implemented alert categories most respondents reported that they believed there was research evidence to support the benefits of these alerts to improve prescribing behaviours and patient outcomes. Aside from drug-allergy alerts, less than 50% of EMM implementers reported that they thought alerts had improved prescriber behaviour in their hospitals. Few local evaluations of the effects of alerts had been conducted.

Conclusion

The results of this survey provide implementers with new insights into the experiences of Australian hospitals to inform the design and implementation of effective medication prescribing alerts. They also highlight the urgent need for robust evaluations of prescribing alerts in Australian healthcare contexts.

Keywords

- E-Health
- Electronic prescribing
- Computerised Decision Support

1. Introduction

Electronic medication management (EMM) system adoption in Australia is on the rise; one of the major drivers being the potential benefits of these systems to significantly reduce medication errors, particularly when systems incorporate computerised alerts. EMM with integrated clinical decision support alerts can provide prescribers with "clinical knowledge and patient-related information, intelligently filtered and presented at appropriate times, to enhance patient care" [1, p.40]. However, interruptive alerts may not always deliver on this potential. Alert fatigue and high rates of alert override are well-recognised consequences of the excessive generation of interruptive alerts; one systematic review reported that 49–96% of interruptive medication prescribing alerts were overridden by prescribers [2]; more recent papers maintain that this is an ongoing problem [3, 4]. As a result, the opportunity to avoid preventable errors is missed, and consequently, there is increasing focus on the best way to design and customise alerts to achieve the potential and desired safety benefits.

Most commercial EMM systems offer a range of customisation or tailoring of alerting to suit the setting, such as selecting which alert categories (e.g. drug-allergy alerts, drug-drug interaction alerts) will be activated/deactivated; switching alerts from interruptive to non-interruptive; and the filtering of alerts by differing severity levels.

EMM implementers are faced with the question of what alert categories should be included in their EMM system, and how they should be customised to maximise the potential safety benefits of alerts while balancing the risk of alert fatigue. In our recent systematic review, we found no evidence to support the inclusion of one particular category or categories of alerts over others in EMM [5]. The review identified no studies which investigated the impact of alerts when alerts from multiple categories were incorporated within the same system [5].

With limited research evidence available to guide alert selection in EMM systems, we set out to determine how and why alerts were selected for inclusion in EMM systems in Australian hospitals.

2. Method

2.1. Study context and design

We performed a cross-sectional in-depth interview survey of key stakeholders (see 2.3 Participants) known to be involved in the implementation of inpatient EMM systems in Australian public and private hospitals. The survey was administered via telephone to maximise the response rate and allow the interviewer to clarify any ambiguous or unclear responses. Hospitals were categorised according to the Australian Institute of Health and

Welfare (AIHW) public hospital peer group classification [6]. With no formal statistics available, the authors estimated, based on consultation with a range of key informants, that approximately 35 Australian hospitals had implemented an EMM system at the time the survey was performed.

The study was approved by the Macquarie University's Human Research Ethics Committee.

2.2.   Survey development

The survey questions were developed based on surveys and questionnaires sourced from the literature and an unpublished survey conducted by one of the investigators. The survey tool was pilot tested amongst the research team (n=3) and by a participant matching the survey selection criteria who was also interviewed for detailed feedback. The survey was then refined. Alert category terminology for the survey was classified using the taxonomies described by Wright *et al.* [7] and Kuperman *et al.* [8].

The survey (Table 1) was structured into six key question areas: hospital demographics, hospital governance and evaluation, use and experience with specific alert categories, personal beliefs and opinions, and lessons learned.

The survey consisted of a combination of question types: dichotomous and multiple-choice questions were predominantly used to ask hospital-specific questions; open-ended questions were used to collect opinions on interruptive medication prescribing alerts. Scaled responses were used to collect the level of agreement to belief statements, with respondents ranking their agreement using a seven-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = somewhat disagree, 4 = either disagree nor agree, 5 = somewhat agree, 6 = agree, 7 = strongly disagree).

2.3.   Participants

The study was carried on a purposive sample of key stakeholders known to be involved in the implementation of EMM systems in Australian hospitals. Potential participants were identified via key informants (including government officials, and informants' and investigators' networks), and were contacted by direct email (where known to the investigators) and/or via message on member-only Australian EMM discussion forums (e.g. SHPA). Snowball sampling was utilised where if the initial contact within an organisation was unsuitable or unavailable, they were invited to recommend an alternative participant. Participants were required to have had direct involvement in the implementation of an EMM system in an Australian public or private hospital (e.g. in a project role involved in design and

configuration or training), and/or have knowledge of their hospital's configuration decisions, evaluation and governance (e.g. in an executive role, or relevant committee membership). Given that the vast majority of EMM implementations in Australia have occurred in public hospitals [9], the number of potential respondents from private hospitals was low.

The sample size was limited by the number of Australian hospitals who had implemented (or were imminently implementing) an EMM system. A maximum of one participant from each hospital was recruited for interview.

Participants were eligible to complete multiple questionnaires on behalf of more than one hospital if they had been involved in implementations that occurred across multiple hospitals within a local hospital network (LHN) or state/territory-wide EMM implementation (henceforth described as a 'network'). Those respondents completed multiple questionnaires, responding to sections 1-4 on each questionnaire for each hospital, but completing the personal opinions and beliefs questions (sections 5-6) on only one questionnaire.

2.4.   Data collection and analysis

The interviews were conducted via telephone and were audio-recorded. Following completion of the telephone survey, the audio-recording was transcribed verbatim and then destroyed.

Descriptive statistics were calculated for the closed ended questions. Responses to the open-ended questions were reviewed by two reviewers (NP, MB) who applied a general inductive approach [10] to code the data manually according to themes. Any discrepancies between reviewers were resolved by consensus.

Results were expressed as the number or percentage of hospitals or individuals that responded to the question. Where a hospital had not implemented a specific alert category, the hospital or respondent were removed from the denominator for that question, i.e. the denominator only included those hospitals or respondents with experience with that alert category; the exception being the frequency of alert categories used in Australian hospitals with an EMM system.

3. Results

3.1. Participants

Fifteen participants completed the survey, representing 75% (26/35) of the estimated number of Australian hospitals that had implemented EMM systems. Participants came almost exclusively from a pharmacist background (n=14), with one participant from a health information management background.

3.2. EMM systems

As shown in Figure 1, most hospitals had implemented an EMM system in the last five years. The hospitals in our sample were predominantly public hospitals (n=25, 96%), with one response from a private (acute group D) hospital (n=1, 4%). Of the public hospitals, responses were largely from principal referral hospitals (n=7, 27%), but also represented smaller acute hospitals (n=14, 54%), children's hospitals (n=2, 8%), and rehabilitation (n=1, 4%) and psychiatric hospitals (n=1, 4%).

All EMM systems were commercial products; systems and vendors included MedChart, CSC (n=13, 50%), Millennium, Cerner (n=7, 27%), Sunrise, Allscripts (n=4, 15%), Trakcare, Intersystems (n=1, 4%), and Willow Inpatient, EPIC Systems (n= 1, 4%).

Less than half of the hospitals surveyed had implemented the EMM system across their entire hospital (n=12, 46%), requiring hybrid medication management in some clinical areas. Reasons for incomplete utilisation included ongoing implementation, EMM functionality not suitable to a specialty clinical area, or another established clinical information system was in use in a specialty clinical area (e.g. ICU system).

3.3. Alert categories in use in Australian hospitals

As shown in Figure 2, all hospitals had implemented drug-allergy alerts and drug-drug interaction (DDI) alerts. Half of the hospitals (n=13, 50%) had developed a localised list of interacting DDI pairs due to a concern that adopting the vendor's commercial drug knowledge database would result in excessive alerting. The remainder of the hospitals (n=13, 50%) used the vendor-supplied functionality (however one site had modified the severity level of some interacting pairs within the vendor database). Dose range checking (DRC) was utilised by 69% of hospitals (n=18). The remaining eight categories were utilised by less than 50% of hospitals. All hospitals had implemented more than one alert category; the range of alert categories in place was 2-7 (mean 5).

3.4. Alert governance models in place

All hospitals had an established governance model for alert decision-making, either through e-health governance committees (e.g. EMM committee) (n= 21, 80%), or via an existing medication governance group such as a Drug and Therapeutics or Quality Use of Medicines Committee (n=5, 20%).

Participants responding on behalf of multiple hospitals described a range of governance approaches across a hospital network. Examples of these included a lead site testing an alert before rollout to other sites (e.g. a renal alert tested in the tertiary renal hospital within the network); alerts selectively implemented dependent on the hospital-specific factors (e.g. a pregnancy alert switched off at an aged care hospital; dose range checking limits higher at a specialty hospital) or alerts applying to all hospitals within the network with no customisation between hospital sites. The approach was dependent on whether the governance model required a single alert configuration for all hospitals within the network; or a more flexible model with a network recommendation but local hospital decision on whether to adopt the recommended configuration.

3.5. Evaluation of alerts in the local setting

In response to a yes, no question about whether any evaluations of alerts had been undertaken, seven hospitals (27%) indicated that they had performed some evaluation of their alerts. Six (23%) hospitals reported that this had been on an ad-hoc basis. All had assessed the rate of interruptive medication prescribing alerts (n=7, 100%), with some also examining rates of alert override (n=3, 43%), the impact of alerts on prescriber behaviour (n=4, 57%), and/or the impact on patient outcomes. We did not ascertain whether evaluations had been comprehensive. Respondents for two hospitals (8%) reported that their alert evaluations had been published in the scientific literature.

Twenty-one hospitals (81%) had solicited end-user feedback on alerts (at least at one point in time), either via user groups (n=6, 29%), surveys (n=5, 24%), via a feedback mechanism embedded within the EMM system (n=4, 19%), during the go-live period (n=2, 10%), or via staff forums (n=1, 5%).

3.6. Respondents' beliefs about alert evidence and benefits

We asked individual respondents to indicate their agreement with five belief statements in relation to the effectiveness of different alert categories to improve medication safety. The

results from these questions for the top five alert categories are shown in Table 2. The full results for all alert categories are available are available upon request.

Generally, across all belief statements, agreement was highest for the top three most frequently implemented alert categories: drug-allergy, DDI and DRC. For these three alert categories there was high agreement among respondents that evidence exists in the literature to support their use (mean agreement 93%, range 80%-100%), and for improving prescriber behaviour (mean agreement 85%, range 88-93%) and patient outcomes (mean agreement 91%, range 88-93%).

There was strong agreement that drug-allergy had resulted in improvements to prescriber behaviour (93% agreement) and patient outcomes (93% agreement) at a local level, but only moderate agreement for other alerts including DDI and DRC (43%- 50% agreement).

3.7. Respondent's opinions on factors influencing alert configuration decisions

We asked respondents to nominate which of 11 possible variables had influenced their hospital or network's decision to implement each of the alert categories, with nomination of more than one influence possible. Local governance group recommendations were reported to have the greatest influence (n=31, 31%), followed by perceived usefulness (n=25, 25%), vendor recommendations (n=12, 12% of influences; cited across six categories), and beliefs about evidence (n=12, 12%). Hospitals with greater experience using EMM and local research were rarely cited as influences (n=3, n=2).

3.8. Respondents' opinions on alert benefits and problems

In an open-ended question we asked respondents to describe any benefits realised following implementation of an alert category in their hospital or network. Respondents identified eight benefit types, and each respondent identified at least one benefit. The most frequently perceived benefits included reduced prescribing errors (n=16, 50%), improved prescriber knowledge (n=6, 19%), and improved prescriber behaviour (n=3, 9%). Drug-allergy alerting was the category with the greatest number of reported benefits (n=10, 64% of respondents using this alert category reporting one or more benefit), followed by DDIs (n=7, 50%), DRC (n=4, 57%), and corollary orders (n=3, 75%).

Similarly, we asked respondents to identify any problems which had resulted following implementation of an alert category in their hospital or network. Nine problem types were identified across 15 respondents.

Compared with benefits, a greater number of perceived problems were described by respondents (n=43 vs. n=32). More than 80% of problems were attributed to four alert categories (n=26): drug-allergy interactions (n=16, 28% of respondents using this alert category report one or more problem), DDIs (n=9, 64%), therapeutic duplication (n=7, 100%), and DRC (n=4, 57%).

Half of all problems described related to specificity (n=11, 26%) and sensitivity (n=10, 24%) of alerts. Perceived specificity problems included the clinical accuracy of medication class categorization used for allergy and DDI checking, DDI pairs, and the local configuration for DDI severity level. Sensitivity problems were reported to be due to errors in documentation (e.g. uncoded allergies, allergy versus intolerance), and alert logic (e.g. checking not specific to the current inpatient encounter, failing to recognise intentional duplication such as split/divided dosing). The other key problem described was alert fatigue (n=7, 20%).

3.9. Changes to alert configuration

Most respondents (65%) reported that alerts had remained unchanged from the original go-live configuration. We asked about post-implementation changes that had been made to improve their alerts, and respondents described 23 changes. Participants could report more than one change to each alert category. Changes were categorised into four key areas: general enhancements (n=13, 57%), specificity (n=4, 17%), sensitivity (n=3, 13%), and activating a previously inactivate alert (n=3, 13%). The greatest number of configuration changes were made for DDIs (n=6 changes, 36% of respondents using this alert category had changed the alert post-implementation), drug-allergy interaction (n=4, 29%), and DRC (n=4, 57%). The most frequent single change initiated was to improve DDI alert specificity (n=4, 17%).

3.10. Lessons learned

In response to an open-ended question about lessons learned, participants were keen to share their experiences with the Australian EMM community to avoid '*reinventing the wheel'*. There was a wide range of responses (n=42) across five themes: alert design (n=28, 67% of responses), evaluation and reporting (n=5, 12%), workflow (n=3, 7%), governance (n=3, 7%), and knowledge sharing (n=3, 7%).

The most common design advice was to start with a small number of well-designed alerts (n=10, 24%). Respondents elaborated, commenting that: *No alert is better than a poorly - designed alert*, *Get alert design right the first time* and *Do not lose the end user's trust in*

alerts. Respondents also shared a common insight that governance groups are often reluctant to endorse the removal of an alert once it has been implemented – even if users are dissatisfied.

Another common lesson learned was that a structured evaluation and monitoring program for EMM medication alerts is critical for continual refinement of alerts. Respondents reported that getting the right data out of the system is critical to enable evaluation and that implementers should consider the reporting capabilities when deciding which alerts to implement.

4. Discussion

This study, the first national survey of interruptive EMM medication prescribing alerts in Australian hospitals, revealed that EMM systems have been implemented in a range of different hospital types and sizes, and across almost all clinical specialties. Despite these differences, Australian hospitals are consistent in the types of interruptive medication prescribing alerts implemented and approaches to customisation.

Hospitals have adopted on average five alert categories in their EMM system. Despite limited evidence to indicate that any specific category of alerts is more effective than another [5], all hospitals implemented DDI alerts and drug-allergy alerts, with many also adopting DRC alerts. These alert categories were perceived to result in the greatest local benefits. However, they were also reported to have resulted in the highest number of local problems and required the most changes in local configuration.

While a recent systematic review showed that approximately only half of the studies on interruptive medication prescribing alerts reported a statistically significant beneficial effect [5], the majority of respondents believed that evidence exists to support the use of these alerts and these beliefs are likely to have influenced configuration decisions. However, hospital respondents rarely reported that published evidence had an influence on alert decisions.

The survey attempted to identify whether hospitals had made independent decisions, knowing that while vendors often keep confidential their clients' decisions about alert selection and configuration, clients using the same vendor system will often share their experiences. Respondents cited that local influences (such as governance groups and perceived usefulness) had a greater impact on alert selection than a third-party such as the vendor or other hospitals using EMM. However, given the consistency across hospitals it is

possible that these external influences were underestimated, or that influences other those provided to respondents by multiple choice could have been a factor in decision making.

Respondents were not confident that at a local hospital level they had realised the benefits from alerts that they believed existed in the literature. This uncertainty is likely to be due to the limited evaluation undertaken at the local hospital level. Few hospitals had undertaken an evaluation of their medication prescribing alerts, although most had sought user feedback on alerts on at least one occasion. Despite this, most hospitals had not made any changes to alert configuration post-implementation.

Respondents reported that sensitivity and/or specificity of alerts were the main problems they experienced with alerts. The desire to improve these and reduce excessive alert generation and alert fatigue were the primary drivers for changes to alert configuration. While all hospitals had implemented DDI alerts, half did not use the out-of-the-box vendor functionality due to concerns of poor sensitivity and/or specificity, instead developing a custom list of interacting medication pairs for alerting, or customising the severity of interactions in the vendor-supplied commercial drug knowledge database. Customisation has been previously identified as an expensive and resource-intensive process [11].

The most common lesson learned was to start with a small number of well-designed alerts.

4.1. Limitations

Only 15 respondents representing 26 Australian hospitals participated in the survey, although this group is estimated to represent the majority of hospitals with experience of EMM in Australia. Non-responders did not seem to be overly represented by hospital type (noting few private hospitals have implemented EMM systems) or vendor system. Due to the small sample size, we were unable to determine whether the responses varied depending on the hospital type, vendor system used, or length of time EMM had been in place. Although purposive sampling was used to identify relevant participants, respondents represented most Australian states and territories, used a variety of commercial systems, and had varying experience with EMM systems, resulting in a diverse range of experience, opinions and beliefs. Our small sample size of predominantly pharmacists may limit the conclusions that can be drawn with respect to opinions and beliefs on EMM alerts – respondents' views may not represent those of other clinicians, the broader attitude at each hospital or in the wider EMM user community.

5. Conclusion

EMM systems in Australian hospitals include a number of interruptive medication prescribing alert categories, the most common being drug-allergy, DDI, and DRC alerts. Implementers, predominantly EMM pharmacists, reported high customisation of the vendor out-of-the box functionality in an attempt to improve sensitivity and specificity of alerts to minimise alert fatigue. The most common lesson learned was to start with a small number of well-designed alerts. Alert configuration decisions in Australian hospitals may have been fueled by a perception that alerts change prescriber behaviour and improve patient outcomes. However, evaluations at a local level have been limited and as a result, stakeholders were less convinced about benefits in their local setting. The results of this survey provide implementers with new insights into the experiences of Australian hospitals to inform the design and implementation of effective medication prescribing alerts. They also highlight the urgent need for robust evaluations of prescribing alerts in Australian healthcare contexts.

6. Chapter 3 References

1.   Osheroff, J.A., et al. *Improving Outcomes with Clinical Decision Support: An Implementer's Guide, Second Edition.* 2012, Chicago, IL: Healthcare Information and Management Systems Society (HIMSS).

2.   Van Der Sijs, H., et al., *Overriding of drug safety alerts in computerized physician order entry.* J Am Med Inform Assoc, 2006. **13**(2): p. 138-147.

3.   Nanji, K.C., et al., *Overrides of medication-related clinical decision support alerts in outpatients.* J Am Med Inform Assoc, 2014. **21**(3): p. 487-91.

4.   Beeler, P.E., et al., *Provider variation in responses to warnings: do the same providers run stop signs repeatedly?* J Am Med Inform Assoc, 2015.

5.   Page, N., M. Baysari, and J. Westbrook, *A systematic review of the effectiveness of interruptive medication prescribing alerts in hospital CPOE systems to change prescriber behavior and improve patient safety.* International Journal of Medical Informatics, 2017.

6.   Australian Institute of Health and Welfare (AIHW), *Primary health care in Australia*, AIHW, Editor. 2017: Canberra.

7.   Wright, A., et al., *Development and evaluation of a comprehensive clinical decision support taxonomy: comparison of front-end tools in commercial and internally developed electronic health record systems.* J Am Med Inform Assoc, 2011. **18**(3): p. 232-42.

8.   Kuperman, G.J., et al., *Medication-related clinical decision support in computerized provider order entry systems: a review.* J Am Med Inform Assoc, 2007. **14**(1): p. 29-40.

9.   Pedersen, B., *EMR in Australia: the state of the nation*, in *Health Informatics Conference*. 2017: Brisbane, Australia.

10.   Thomas, D.R., *A general inductive approach for analyzing qualitative evaluation data.* American journal of evaluation, 2006. **27**(2): p. 237-246.

11.   Phansalkar, S., et al., *Towards meaningful medication-related clinical decision support: recommendations for an initial implementation.* Appl Clin Inform, 2011. **2**(1): p. 50-62.
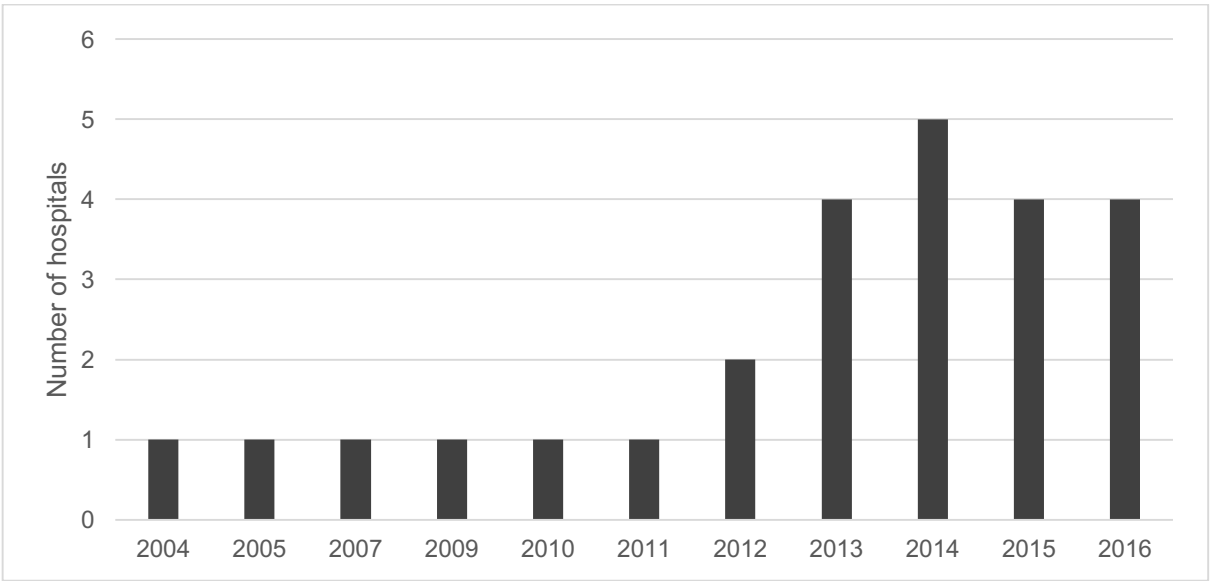
7. Chapter 3 Figures

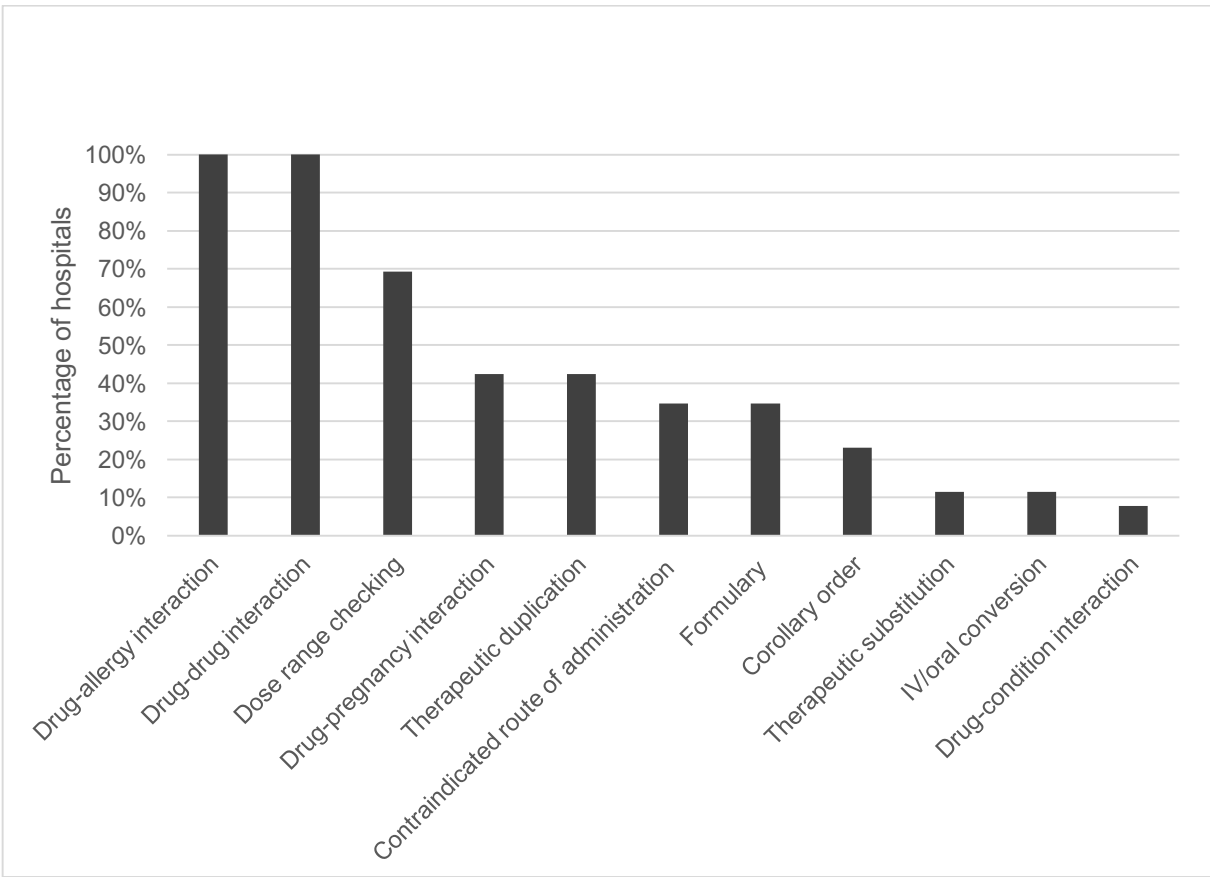Figure 1 Year EMM was first introduced (including pilots) in 26 Australian hospitals with an EMM system

Figure 2. Frequency of alert categories used in 26 Australian hospitals with an EMM system, expressed as a percentage of respondents that implemented the alert category at their hospital/s

8. Chapter 3 Tables

Questions	Response type
Section 1: Hospital Demographics	
1. State/territory of the hospital in which you have worked on an EMM project	Multiple options
2. AIHW Hospital classification	Multiple options
Section 2: EMM system	
3. Have you implemented or are you in the processes of implementing an EMM system?	Multiple options
4. Year first introduced, including pilots	Open-ended
5. Is it currently used hospital wide?	Yes/No
6. Locations currently used	Multiple options
7. What is the location scope for future budgeted rollout?	Multiple options
8. EMM System used (Product, Vendor)	Multiple options
Section 3: governance	
9. Are the prescribing alerts in the EMM system at your site managed (created, modified, evaluated) at a local, health service, or state/territory-wide level?	Multiple options
10. Did you convene a specific governance group to consider issues related to prescribing alerts?	Multiple options, Open-ended
11. Governance decision making a. What clinician roles were involved?	Multiple choice
b. Was decision making shared amongst these roles, or did one (or more) clinician role have greater input?	Open-ended
12. Does your organisation solicit feedback regarding specific prescribing alerts from clinicians?	Yes/No
13. Does your organisation collect metrics on the use of prescribing alerts?	Yes/No, Open ended
Section 4: Medication prescribing alerts **For EACH medication prescribing alert category implemented**	
14. Is this alert type utilised in your system?	Yes/No
15. If responded yes above, please describe your build/configuration	Open-ended
16. Which of the following had the greatest influence/s over your build/configuration?	Multiple options
17. Can you please describe any benefits your organisation has realised as a result of this alert type?	Open-ended
18. Can you please describe any problems your organisation has faced as a result of this alert type?	Open-ended
19. Have you made any changes to this functionality/configuration since go-live? If so, why?	Yes/No, Open ended
20. Do you have any immediate plans to change this functionality/configuration? If so, why?	Yes/No, Open ended
Section 5: Beliefs. Based on YOUR experience please indicate how much you agree with the following statements: **For EACH medication prescribing alert category implemented**	
21. I believe there is evidence in the scientific literature to support utilisation of this alert type.	Scaled response
22. I believe there is evidence in the scientific literature that this alert type has a positive impact on improving prescriber outcomes (e.g. cancelling an order or prescribing a new appropriate order).	Scaled response
23. I believe there is evidence in the scientific literature that this alert type has a positive impact on improving patient outcomes (e.g. clinical signs or symptoms suggesting potential and/or actual harm).	Scaled response
24. I feel that this alert type has had a positive impact in my organisation on improving prescriber outcomes (e.g. cancelling an order or prescribing a new appropriate order).	Scaled response
25. I feel that this alert type has had a positive impact in my organisation on improving patient outcomes (e.g. clinical signs or symptoms suggesting potential and/or actual harm).	Scaled response
Section 6: Lessons learned/future research	
26. Has your organisation undertaken any evaluation on the impact of medication prescribing alerts? If yes,	Yes/No
a. Have these been published in the scientific literature?	Yes/No
b. Have you evaluated any of the following outcomes?	Multiple options
27. If you could remove one alert type from your current alert suite, which type would you remove, and why?	Open-ended
28. If you could add one alert type from your current alert suite, which type would you add, and why?	Open-ended
29. Is there anything else about your experience with prescribing alerts that you'd like to share with other Australian implementers?	Open-ended

Table 1. Survey questions

Alert category	I believe there is published evidence to support utilisation of this alert category			I believe there is published evidence that this alert category improves prescriber behaviour			I believe there is published evidence that this alert category improves patient outcomes			I believe this alert category has improved prescriber behaviour in my hospital/network			I believe this alert category has improved patient outcomes in my hospital/network		
	Agree	Neither	Disagree	Agree	Neither	Disagree	Agree	Neither	Disagree	Agree	Neither	Disagree	Agree	Neither	Disagree
Drug-allergy interaction	100% (15)	0% (0)	0% (0)	93% (14)	0% (0)	7% (1)	93% (14)	0% (0)	7% (1)	93% (13)	0% (0)	7% (1)	93% (13)	0% (0)	7% (1)
Drug-drug interaction	80% (12)	0% (0)	20% (3)	73% (11)	7% (1)	20% (3)	93% (14)	0% (0)	7% (1)	43% (6)	43% (6)	14% (2)	50% (7)	50% (7)	0% (0)
Dose range checking	100% (8)	0% (0)	0% (0)	88% (7)	0% (0)	13% (1)	88% (7)	13% (1)	0% (0)	43% (3)	57% (4)	0% (0)	43% (3)	57% (4)	0% (0)
Drug-pregnancy interaction	50% (3)	17% (1)	33% (2)	67% (4)	17% (1)	17% (1)	33% (2)	33% (2)	33% (2)	33% (2)	67% (4)	0% (0)	50% (3)	33% (2)	17% (1)
Therapeutic duplication	75% (6)	13% (1)	13% (1)	50% (4)	0% (0)	0% (4)	50% (4)	25% (2)	25% (2)	43% (3)	29% (2)	29% (2)	43% (3)	29% (2)	29% (2)

Table 2. Responses to five belief statements for the five most commonly used alert categories in relation to the effectiveness of different alert categories to improve medication safety, as a percentage of hospitals who indicated that they had implemented that alert category.

CHAPTER 4

Discussion and conclusions

4.1. Discussion

The aim of this research program was to identify evidence of the effectiveness of interruptive medication prescribing alerts, to inform decisions about which combination of alerts to include in hospital inpatient EMM systems. In addressing this aim, two questions were answered: what is the evidence for the effectiveness of interruptive medication prescribing alerts in hospital EMM systems, and which interruptive medication prescribing alerts have been selected for inclusion in EMM systems in Australian hospitals, and why?

The review of alert effectiveness studies revealed that there is some evidence that specific categories of alerts provide benefit. Just over half of the studies reported a statistically significant beneficial impact on prescriber behaviour from an intervention alert, but there were also many cases where no significant effect was found. The most common alert categories studied were drug-condition interaction, DDI, and corollary order alerts. Only for drug-condition alerts did the majority of studies report positive effects. No studies investigated the impact on patient or prescriber outcomes when alerts from multiple categories were incorporated within the same EMM system. There have been no comparisons of the relative effectiveness of individual alert categories, for example the relative effectiveness of DDI alerts compared to allergy alerts in terms of, for example, reducing harm to patients. The results of this review indicate that implementers have limited evidence to inform the selection of alerts in EMM systems. An underlying assumption that might be drawn from the available literature is that including multiple alert categories will provide a cumulative benefit, however current evidence to confirm this assumption is not available.

With limited research evidence available to guide alert selection in EMM systems, the second aim of this thesis was to determine how and why interruptive medication prescribing alerts were selected for inclusion in EMM systems in Australian hospitals. Using a standardised, semi-structured telephone survey it was found that the three most frequently implemented alert categories were drug-allergy interaction, DDI and DRC alerts. Stakeholders reported that a high degree of customisation of the vendor out-of-the box functionality was required to improve the sensitivity and specificity of their alerts in an attempt to minimise alert fatigue among users. Participants held the view that there is research evidence to show that interruptive medication prescribing alerts change prescriber behaviour and improve patient

outcomes. Few hospitals had undertaken evaluation activities to determine the effects of their alerts on outcomes, but anecdotally, stakeholders had limited confidence that the potential benefits of alerts were being achieved in their local hospital. Despite this, stakeholders favoured optimising existing alerts rather than removing alerts. These results are consistent with published research that shows that whilst users would like to reduce EMM alerts, it is difficult to reach consensus on what alerts can be safely removed [1, 2].

Interestingly, the survey revealed that drug-condition interaction alerts have been infrequently utilised by Australian EMM implementers to date, yet the systematic review revealed that studies of this alert category reported the largest proportion of positive effects (5 out of 6 studies). Hospitals could give greater consideration to this alert category, however, there would be multiple issues for implementers to take into account with drug-condition alerts. Firstly, this alert category may not be standard functionality in all commercial EMM systems, and so its use may require considerable resourcing to develop and maintain. Secondly, a drug-condition alert must be relevant to the hospital's patient population (e.g. inappropriate medications in the elderly are most valuable in a hospital with a large number of older adult patients). And thirdly, a drug-condition alert may require a problem list (e.g. QT prolongation) or results from another EHR system (e.g. laboratory results for a renal alert). This may not be within the scope of a standalone EMM system, and within our sample around 50% of Australian hospitals currently utilise a standalone EMM system.

Despite the limited evidence to indicate that any specific category of alerts is more effective than another [3], Australian hospitals have been consistent in the types of medication prescribing alerts implemented in their EMM systems. The survey sought to identify factors influencing their choice of alerts. Respondents cited local influences (such as governance groups and perceived usefulness) as having a greater impact on alert selection than third-parties such as vendors or other hospitals. However, given the consistency across hospitals it is possible that these external influences were underestimated, or that influences other than those provided to respondents in the multiple-choice survey options could have played a role in decision making.

DDI and drug-allergy alerts were implemented by all Australian hospitals. These alerts have been standard in pharmacy dispensing software for decades, and their use in these systems precedes their use in EMM systems. It has been suggested that CDS tools in EMM systems "are often little more than pharmacist-friendly systems that have been retrofitted for physician use" [4, p.2], and indeed pharmacy and EMM systems generally use the same (limited number of) third party medication knowledge databases to support this CDS alerting [5]. Pharmacists are very accustomed to these alerts, and this familiarity is likely to have influenced pharmacists' contributions to the selection of alerts to be incorporated in the EMM

systems. Pharmacists are key players in EMM implementation and influential in governance groups, and their support for DDI and drug-allergy alerts may have also been a factor in the governance group determination, leading to support for the use of these alerts.

Despite being in use for several decades very few evaluations of CDS alerts in pharmacy dispensing systems have been performed. A 2013 [6] systematic review included five studies evaluating alerts triggered at the point of dispensing that resulted in a statistically significant reduction in the dispensing of prescriptions containing medication errors. This small body of evidence suggests that pharmacy CDS alerts generally improve medication safety. No studies investigated the impact of CDS on patient outcomes. Most of the literature on pharmacy CDS is concentrated on DDI alerting. Several studies have revealed poor sensitivity and specificity of pharmacy CDS [5, 7]. Variability in the performance of CDS systems has been noted [5] as each of the third-party knowledge databases supporting alerting uses their own proprietary system for determining alert content and severity. This leads to inconsistencies in alert severity ratings between systems and a failure to alert users to clinically important DDIs in some systems [5, 7]. These problems with inconsistencies in DDI references and DDI alerts have been well described [8-14], and have led international experts to advocate the need for standards on clinically relevant content used to trigger CDS alerts [15]. Because of poor sensitivity and specificity, the rates of alerts experienced by pharmacists is high (but potentially not as high as prescriber alerts). One study of CDS in Dutch community pharmacies found that one or more alerts were generated in 42.9% of prescriptions. The most common alerts were DDI alerts, (15% of all prescriptions), drug–condition interaction alerts (14%), duplicate medication alerts (13%), and dose adjustment alerts (7%) [16]. A Swiss study reported that even when configured to only display severe alerts 36.7% of potential DDIs were manually overridden without the pharmacist taking further action [17]. A study of a pharmacy CDS in a large tertiary Dutch hospital found that of all alerts presented, only 3.6% were deemed clinically relevant, and concluded that improvements in alert effectiveness were required [7]. So, while DDI alerts are common in pharmacy systems, as with EMM systems, there is limited evidence to demonstrate their effectiveness, and studies suggest the vendor out-of-the box functionality needs to be configured to optimise sensitivity and specificity. So, whilst the evidence is mixed, pharmacists' familiarity and long-term experience with these types of alerts is likely to have influenced their support for the introduction of these alerts within EMM systems.

There are no clinical recommendations on alerts for EMM systems, but there have been recommendations for the purposes of financial incentives (the United States CMS EHR Incentive Program, also known as Meaningful Use, now superseded) [18] and accreditation purposes (the HIMSS EMRAM) [19]. Both recommended DDI and drug-allergy checking as the baseline medication CDS alerts to be implemented within an integrated EHR. No robust

evidence to support this particular combination of alerts could be identified. It is possible that these recommendations were developed largely based on the CDS capabilities of early EMM systems, and hence may also have been influenced by CDS in the pharmacy setting.

DDI alerts have been the focus of a considerable number of EMM studies, however most studies showed no significant effect. The potential consequences of the administration of a medication known to cause DDIs varies from negligible to catastrophic. A review of case reports of significant adverse drug events published from 1976-97 reported 120 instances of death, permanent disability, or a threat to life as a result of a DDI [20] but a recent systematic review concluded that evidence of the prevalence of harm from DDIs is limited [21]. DDIs are generally considered predictable and, therefore preventable [22-25], making them suitable candidates for CDS alerts. Hospitals wishing to undertake accreditation against HIMSS EMRAM would be required to implement DDI alerting. Since assessment for DDIs is an essential step when prescribing a new medication [26], and the limited evidence for DDIs is either positive or neutral, this alert category should be considered by EMM implementers but with thorough review of the vendor-supplied medication pairs that trigger a DDI alert to minimise alert fatigue. In this undertaking implementers should look to guidance in the published literature on effective customisation of DDI alerts [27-30].

Drug-allergy alerting is another alert category utilised by all Australian implementers, and as with DDIs its use may be influenced by this alert category's inclusion in pharmacy dispensing systems. Results in the EMM literature on the effectiveness of drug-allergy alerting are mixed, with one study showing a positive effect on prescriber behaviour, but another showing high rates of alert overrides. This effect is often attributed to the inability of the CDS tool to distinguish between trivial intolerances such as gastrointestinal upset and potentially life threatening immune mediated allergic and hypersensitivity reactions. A 2015 observational of study of a decade of drug-allergy alerting in EMM systems reported an overall rate of overrides of 87.6%, and found that alerts for immune mediated and life-threatening reactions were also overridden at high rates, though significantly less frequently than other reaction types (72.8% and 74.1% of the time) [31]. Given the potential benefit of alerting to drug-allergies, this alert category should be considered by EMM implementers. But hospitals looking to achieve effective drug-allergy alerts should investigate means of focusing the sensitivity of these alerts to ensure accurate alerting. Hospitals wishing to undertake accreditation against HIMSS EMRAM would also be required to implement drug-allergy alerting.

Vendor influence was cited as the third most common influence in the survey results, but this was possibly less explicitly apparent to implementers and understated. Vendors require implementers to use CDS and share their experiences, evaluation, and opinions to enable

the vendor to continue to make enhancements of the both the system functionality and the knowledge database that drives CDS tools. This collaboration is essential for continual refinement of CDS alerts. There is no available research on the influence of EMM vendors on implementers, however the marketing techniques employed by pharmaceutical companies to influence doctors prescribing habits are well described [32] and it is possible that EMM vendors are exerting a greater influence over alert implementers in the design and configuration of alerts than recognised.

4.2. Contribution of this research program and future directions

This research program has provided a synthesis of the available evidence applying a new lens which re-focusses attention from the effectiveness of individual alerts, to the potential cumulative effects of multiple alerts within an EMM system. In this way the research has shed light on a significant research gap.

The analysis of the literature and the survey of EMM implementers has also demonstrated the lack of evidence-based recommendations available for implementers to guide alert selection in EMM systems. Several previous systematic reviews have been conducted on CDS in EMM [33-40], and specifically on alerts [41-46], however there was a need to revisit the current evidence subsequent to the growth in the literature in the past ten years. Previous reviews have generally looked at other outcome measures, aggregated decision support to make overall assessments of its effectiveness or examined alerts in other care settings (e.g. primary care). However, caution should be taken in generalising the results from such reviews to hospital EMM systems because of the potential lack of transferability to hospital interruptive medication prescribing alerts. Additionally, research to date has not reported whether papers focused on individual alert categories or combinations of alerts from multiple categories, which is important in understanding the benefits derived relative to the additional cognitive burden that multiple alerts place on users.

This thesis has made a further contribution through the conduct of a survey of practitioners which reported the experiences and views of those faced with decisions about the selection of alerts within hospital EMM systems. The results provide new information about what and why alerts are selected for inclusion and provide insights into possible influencing factors. The survey was the first Australian study to investigate the utility, configuration, evaluation and governance of EMM alerting, providing valuable information to what is a limited area of international research [27, 28]. There have been several surveys undertaken on EMM and CDS alerts [29-40], but these have generally focused on adoption and the user experience rather than on design and configuration. The survey is the first to provide implementers with

accounts of the experiences of Australian hospitals. The results indicate that groups charged with decisions about the selection of alerts to be included in EMM systems should give due consideration to the fact that there is limited evidence of the cumulative benefit of multiple alerts. Thus, if multiple alerts are included within systems, a heightened importance should be placed on evaluation of the effects of these on desired outcomes such as prescriber behaviour, reduced medication errors and associated harm to patients. This requires both adequate alert reporting capabilities and resourcing of evaluation activities. The results of the survey highlighted the lack of evaluation of interruptive medication prescribing alerts in Australia, emphasising the urgent need for robust research in this area. This absence of evidence to inform ongoing decisions about not only the inclusion of new alerts within EMM systems, but also the removal of ineffective alerts was apparent from the survey results. Despite respondents often reporting their perceptions that alerts had limited effectiveness in their local settings, they were reluctant to consider removing alerts from the system. The challenges of gaining agreement to remove alerts from EMM systems have been highlighted by other researchers [1, 2]. However, the long-term effectiveness and sustainability of EMM systems will be dependent upon opening up the decision-making dialogue to not only include questions of inclusion but also removal of alerts. Obtaining robust evidence of alert effectiveness is an important element to support this broadening focus for hospitals.

4.3. Conclusions

Interruptive medication prescribing alerts in EMM systems have the potential to change prescriber behaviour and improve patient outcomes, but alert fatigue and high rates of alert override from the excessive generation of interruptive alerts are common problems. This thesis investigated the scientific literature and experiences of Australian implementers and showed that there remains a paucity of evidence to inform the selection of effective interruptive medication prescribing alerts in hospital EMM systems. There is some evidence that specific categories of alerts within an EMM system provide benefit, but no evidence of the impact of multiple alerts and whether these provide a cumulative benefit.

Australian hospitals have been consistent in their implementation of particular alert categories but appear to hold a false belief there is evidence available in the literature to support their selections. The fact that implementers made similar choices indicates that decisions could have been shaped by factors additional to those identified by respondents, such as alerts in pharmacy dispensing systems. The Australian experience offers guidance to new implementers on the most commonly used alerts, and lessons learned on designing and implementing effective interruptive prescribing alerts, including the difficulty in removing alerts from an EMM system.

There is a significant research gap on which alerts to include and exclude from an EMM system. Continuing evaluation of the effectiveness of interruptive medication prescribing alerts on desired outcomes is required, including assessing the cumulative impact when different combinations of alert categories are incorporated within the same system.

4.4. Chapter 4 References

1. Baysari, M.T., et al., *Identification of strategies to reduce computerized alerts in an electronic prescribing system using a Delphi approach.* Stud Health Technol Inform, 2013. **192**: p. 8-12.

2. Van der Sijs, H., et al., *Turning off frequently overridden drug alerts: limited opportunities for doing it safely.* Journal of the American Medical Informatics Association, 2008. **15**(4): p. 439-48.

3. Page, N., M. Baysari, and J. Westbrook, *A systematic review of the effectiveness of interruptive medication prescribing alerts in hospital CPOE systems to change prescriber behavior and improve patient safety.* International Journal of Medical Informatics, 2017. **105**: p. 22-30.

4. Wolters Kluwer Medispan. 2011. *Overcoming Clinician Resistance to Medication Decision Support within CPOE* [Online]. Wolters Kluwer Health. [cited 23 April 2018]. Available from: www.wolterskluwercdi.com/sites/default/files/documents/white-papers/Medi-Span_PhysicianResistance_WhitePaper_HiRes_FIN.pdf+&cd=1&hl=en&ct=clnk&gl=au&client=firefox-b.

5. Saverno, K.R., et al., *Ability of pharmacy clinical decision-support software to alert users about clinically important drug-drug interactions.* J Am Med Inform Assoc, 2011. **18**(1): p. 32-7.

6. Ojeleye, O., et al., *The evidence for the effectiveness of safety alerts in electronic patient medication record systems at the point of pharmacy order entry: a systematic review.* BMC Med Inform Decis Mak, 2013. **13**: p. 69.

7. de Wit, H.A., et al., *Evaluation of clinical rules in a standalone pharmacy based clinical decision support system for hospitalized and nursing home patients.* Int J Med Inform, 2015. **84**(6): p. 396-405.

8. Hines, L.E., et al., *Critical issues associated with drug–drug interactions: Highlights of a multistakeholder conference.* Am J Health Syst Pharm, 2011(68): p. 941-946.

9. Hazlet, T.K., et al., *Performance of community pharmacy drug interaction software.* Journal of the American Pharmaceutical Association (1996), 2001. **41**(2): p. 200-204.

10. Hansten, P.D., *Drug interaction management.* Pharmacy World and Science, 2003. **25**(3): p. 94-97.

11. Amkreutz, J., et al., *Clinical decision support systems differ in their ability to identify clinically relevant drug interactions of immunosuppressants in kidney transplant patients.* Journal of clinical pharmacy and therapeutics, 2017. **42**(3): p. 276-285.

12. Kheshti, R., M. Aalipour, and S. Namazi, *A comparison of five common drug–drug interaction software programs regarding accuracy and comprehensiveness.* Journal of Research in Pharmacy Practice, 2016. **5**(4): p. 257-263.

13. Reis, A.M. and S.H. Cassiani, *Evaluation of three brands of drug interaction software for use in intensive care units.* Pharm World Sci, 2010. **32**(6): p. 822-8.

14. Sweidan, M., et al., *Quality of drug interaction alerts in prescribing and dispensing software.* Medical Journal of Australia, 2009. **191**(6): p. 358.

15. Mulherin, D.P., C.R. Zimmerman, and B.W. Chaffee, *National standards for computerized prescriber order entry and clinical decision support: the case of drug interactions.* American Journal Of Health-System Pharmacy: AJHP: Official Journal Of The American Society Of Health-System Pharmacists, 2013. **70**(1): p. 59-64.

16. Heringa, M., et al., *Nature and frequency of drug therapy alerts generated by clinical decision support in community pharmacy.* Pharmacoepidemiol Drug Saf, 2016. **25**(1): p. 82-9.

17. Indermitte, J., et al., *Management of drug-interaction alerts in community pharmacies.* J Clin Pharm Ther, 2007. **32**(2): p. 133-42.

18. Centers for Medicare Medicaid Services HHS, *Medicare and Medicaid programs; electronic health record incentive program. Final rule.* Federal register, 2010. **75**(144): p. 44313.

19. HIMSS Analytics. 2011. *EMR Adoption Model (EMRAM)* [Online]. [cited 9 April 2018]. Available from: https://www.himssanalytics.org/emram.

20. Kelly, W.N., *Potential risks and prevention, Part 4: Reports of significant adverse drug events.* Am J Health Syst Pharm, 2001. **58**(15): p. 1406-12.

21. Zheng, W.Y., et al., *Drug-drug interactions and their harmful effects in hospitalised patients: a systematic review and meta-analysis.* European journal of clinical pharmacology, 2017: p. 1-13.

22. Juurlink, D.N., et al., *Drug-drug interactions among elderly patients hospitalized for drug toxicity.* Jama, 2003. **289**(13): p. 1652-1658.

23. McDonnell, P.J. and M.R. Jacobs, *Hospital Admissions Resulting from Preventable Adverse Drug Reactions.* Annals of Pharmacotherapy, 2002. **36**(9): p. 1331-1336.

24. Greenberger, P.A., *Drug allergy.* Journal of Allergy and Clinical Immunology. **117**(2): p. S464-S470.

25. Horn, J.R., et al., *Customizing clinical decision support to prevent excessive drug-drug interaction alerts.* American Journal of Health-System Pharmacy, 2011. **68**(8): p. 662-664.

26. De Vries, T., et al., *Guide to good prescribing: a practical manual.* 1994.

27. Horn, J.R. and P.D. Hansten, *Customization of Drug Interaction Software: Caution Is Warranted.* Pharmacy Times, 2011. **77**(8): p. 38-38.

28. Phansalkar, S., et al., *Criteria for assessing high-priority drug-drug interactions for clinical decision support in electronic health records.* BMC Medical Informatics and Decision Making, 2013. **13**(1): p. 65.

29.   Phansalkar, S., et al., *High-priority drug–drug interactions for use in electronic health records.* Journal of the American Medical Informatics Association, 2012. **19**(5): p. 735-743.

30.   Phansalkar, S., et al., *Drug-drug interactions that should be non-interruptive in order to reduce alert fatigue in electronic health records.* Journal Of The American Medical Informatics Association: JAMIA, 2013. **20**(3): p. 489-493.

31.   Topaz, M., et al., *Rising drug allergy alert overrides in electronic health records: an observational retrospective study of a decade of experience.* Journal of the American Medical Informatics Association, 2015. **23**(3): p. 601-608.

32.   Association of American Medical Colleges. 2008. *Industry funding of medical education: Report of an AAMC task force* [Online]. Washington, DC: AAMC. [cited 23 April 2018]. Available from:
        https://www.aamc.org/download/157370/data/industry_funding_report.pdf.

33.   Kaushal, R., K.G. Shojania, and D.W. Bates, *Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review.* Arch Intern Med, 2003. **163**(12): p. 1409-16.

34.   Kawamoto, K., et al., *Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success.* Bmj, 2005. **330**(7494): p. 765.

35.   Chaudhry, B., et al., *Systematic review: impact of health information technology on quality, efficiency, and costs of medical care.* Ann Intern Med, 2006. **144**(10): p. 742-52.

36.   Ammenwerth, E., et al. *The effect of electronic prescribing on medication errors and adverse drug events: a systematic review (Structured abstract)*. Journal of the American Medical Informatics Association, 2008. **15**, 585-600.

37.   Wolfstadt, J.I., et al., *The effect of computerized physician order entry with clinical decision support on the rates of adverse drug events: a systematic review.* Journal of General Internal Medicine, 2008. **23**(4): p. 451-8.

38.   Pearson, S.-A., et al., *Do computerised clinical decision support systems for prescribing change practice? A systematic review of the literature (1990-2007).* BMC health services research, 2009. **9**(1): p. 154.

39.   Weir, C.R., N. Staggers, and S. Phansalkar, *The state of the evidence for computerized provider order entry: a systematic review and analysis of the quality of the literature.* Int J Med Inform, 2009. **78**(6): p. 365-74.

40.   Chan, A.J., et al., *Order sets in health care: a systematic review of their effects.* Int J Technol Assess Health Care, 2012. **28**(3): p. 235-40.

41. Eslami, S., A. Abu-Hanna, and N.F. de Keizer, *Evaluation of outpatient computerized physician medication order entry systems: a systematic review.* J Am Med Inform Assoc, 2007. **14**(4): p. 400-6.

42. Eslami, S., N.F. de Keizer, and A. Abu-Hanna, *The impact of computerized physician medication order entry in hospitalized patients--a systematic review.* Int J Med Inform, 2008. **77**(6): p. 365-76.

43. Schedlbauer, A., et al., *What evidence supports the use of computerized alerts and prompts to improve clinicians' prescribing behavior?* Journal of the American Medical Informatics Association, 2009. **16**(4): p. 531-8.

44. Langemeijer, M.M., L.W. Peute, and M.W. Jaspers, *Impact of alert specifications on clinicians' adherence.* Stud Health Technol Inform, 2011. **169**: p. 930-4.

45. Garg, A.X., et al., *Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review.* Jama, 2005. **293**(10): p. 1223-38.

46. Wong, K., S.K. Yu, and A. Holbrook, *A systematic review of medication safety outcomes related to drug interaction software.* J Popul Ther Clin Pharmacol, 2010. **17**(2): p. e243-55.

47. Wright, A., et al., *Development and evaluation of a comprehensive clinical decision support taxonomy: comparison of front-end tools in commercial and internally developed electronic health record systems.* J Am Med Inform Assoc, 2011. **18**(3): p. 232-42.

APPENDICES

Appendix A. Clinical decision support taxonomies
Adapted from [47]

CDS type	CDS description	Example
Medication dosing support (7 features)		
1. Medication dose adjustment	Assistance with adjusting or calculating medication doses based on patient characteristics such as age, weight, or renal or hepatic function.	An algorithm that automatically suggests that if CrCl<50 mg/min, reduce frequency of administration of a particular medication to every 24 h.
2. Formulary checking	Check medication orders against hospital or payer formularies and suggest more cost-effective therapies.	Suggest omeprazole as a more cost effective alternative to pantoprazole.
3. Single dose range checking	Checking to see whether a single dose of a medication falls outside of an allowable dose range	Alert on a single dose of acetaminophen 1 g.
4. Maximum daily dose checking	Checking to see whether the combined daily dose of a medication exceeds a specified maximum daily dose. In the case of combination products (such as hydrocodone/acetaminophen), systems should check each ingredient for maximum daily dose in combination with other medications the patient is receiving.	Alert on a total daily dose of acetaminophen 4 g.
5. Maximum lifetime dose checking	Checking to see whether the combined lifetime dose of a medication exceeds a specified maximum lifetime dose.	Alert if the total cumulative dose of doxorubicin over _ a patient's lifetime exceeds 550 mg/m^2.
6. Default doses/pick lists	Providing common doses of a medication for a provider to choose from.	Providing a list of 100 mg, 200 mg, 300 mg, 400 mg, _ 600 mg, and 800 mg doses for ibuprofen with a default of 400 mg.
7. Indication-based dosing	Adjusting default medication doses based on indications entered by ordering provider.	Order 7.5 mg methotrexate once weekly for rheumatoid _ arthritis, but 1500 mg/m^2 every 4 weeks (with leucovorin rescue) for gastric cancer.
Order facilitators (9 features)		
1. Medication order sentences	Complete statements of orders which a provider can order as a single unit	Allowing the provider to order 'Digoxin 0.25 mg PO QD' as a single unit.
2. Subsequent or corollary orders	Suggesting or automatically ordering something based on or in response to another order	Order liver function tests after starting a statin.
3. Indication-based ordering	Suggesting orders based on the indication entered by the ordering provider	Suggesting a low-dose thiazide diuretic for a patient with hypertension.
4. Service-specific order sets	Order sets (collections of common orders) based on the service a patient is being admitted to.	Intensive care unit (ICU) admission order set _
5. Condition-specific order sets	Order sets (collections of common orders) based on a disease or problem that a patient has.	Rule out myocardial infarction order set
6. Procedure-specific order sets	Order sets (collections of common orders) based on a procedure or clinical state (post-operative, post-partum, post-procedure, etc.) of a patient.	Post total knee replacement order set

7.	Condition-specific treatment protocol	A treatment protocol for a specific condition. Protocols are characterized by complex or temporal logic, in comparison to order sets which are usually simpler	Hypothermia treatment protocol
8.	Transfer order set	Order sets (collections of common orders) based on the services a patient is being transferred from and to	ICU-to-medicine transfer order set
9.	Non-medication order sentence	Complete statements of non-medication orders which a provider can order as a single unit.	Allowing the provider to order 'Call HO for T >101, SBP >180, SBP <90, _ HR >120, HR <50, RR >30, RR <10, OT sats <92%' as a single unit.
Point-of-care alerts/reminders (14 features)			
1.	Drug-condition interaction checking	Checking medication orders against the patient problem list for possible contraindications.	Alert when a provider orders propranolol for a patient with asthma.
2.	Drug-drug interaction checking	Checking medication orders and the medication list for possible contraindications.	Alert when a provider orders sildenafil for a patient with nitroglycerin on the medication list.
3.	Drug-allergy interaction checking	Checking medication orders against the allergy list for possible contraindications, including both direct allergies, allergies to drug classes or ingredients, and cross-sensitivities.	Alert when a provider orders amoxicillin for a patient with a documented penicillin allergy
4.	Plan of care alerts	Time-based alerts relating to plans of care.	Reminders to reassess the need for restraints and reorder if necessary at least every 24 h.
5.	Critical laboratory value checking	Comparing laboratory results to reference ranges and alerting providers to critical (panic) values.	Page the covering provider when pH>7.60.
6.	Duplicate order checking	Checking active medication orders and the medication list for possible duplication.	Alert when a provider orders metoprolol in a patient with an active order for atenolol or when it is already
7.	Care reminders	Reminders to order a diagnostic or therapeutic procedure based on patient parameters, including preventive care reminders, chronic disease reminders, or palliative care reminders.	Order an HbA1c every 6 months for patient with diabetes.
8.	Look-alike/sound-alike medication warnings	Warn providers when they order a medication whose name looks or sounds like another drug	Warn providers ordering Zyrtec (cetirizine) or Zyprexa (olanzapine) to ensure that they have chosen the drug they intended.
9.	Ticklers	Time-based alerts that an order has not been fully carried out.	Alert a provider when a mammogram has been ordered but not scheduled or performed after 14 days.
10.	Problem list management	Alerts, reminders, and automated documentation tools that help providers maintain an accurate problem list.	When ordering ritonavir, ask the provider if he/she would like to add HIV to the problem list if not already documented.
11.	Radiology ordering support	Assistance in selecting appropriate radiology studies based on patient conditions	Order a foot (rather than an ankle) x-ray if there is any pain in the midfoot zone and the patient is unable to weight bear both immediately and in the emergency department

12. Intravenous to oral conversion	Conversion of patients from IV agents to PO agents when clinically appropriate and cost-effective.	Convert patient from IV metronidazole to PO metronidazole when patient is no longer nil by mouth
13. High-risk state monitoring	Alerting the provider to high-risk states	Alert the provider to order contact precautions for patients with known MRSA colonization
14. Polypharmacy alerts	Alerting the provider when patients are on a high number of medications	Alert the provider that a patient is on >8 medications and suggest consult pharmacy
Relevant information display (5 features)		
1. Context-sensitive information retrieval	Information retrieval based on patient characteristics and clinical context (sometimes called info buttons).	Allow the provider to link directly to prescribing information for a medication at the time of ordering.
2. Patient-specific relevant data displays	Show relevant patient-specific information at appropriate times within information system workflows	Display recent potassium levels when ordering digoxin.
3. Medication/test cost display	Show the cost of a medication or test at the time of ordering.	Indicate that a complete blood count costs $66 at the time of ordering
4. Tall man lettering	Vary the case of look-alike medication names to show critical differences	Show hydralazine and hydroxazine as HydrALAZINE _ HydrOXYzine in a pick list.
5. Context-sensitive user interface	Provide special user interfaces for particular clinical scenarios.	Provide a special interface for chemotherapy order entry, which might include relevant data display, special facilities for ordering complex or time-based protocols, and reference information
Expert systems (11 features)		
1. Antibiotic ordering support	Antibiotic suggestions based on patient history, hospital antibiogram, culture results, and patient characteristics	Suggest vancomycin for empiric antibiotic therapy for patients with suspected MRSA
2. Ventilator support	Ventilator suggestions based on patient-specific blood gas readings and current condition	Unless the FiO_2 is already at 1.0, suggest increasing the FiO_2 by 0.1 if the PaO_2 is >50 but <60 mm Hg in patients with acute respiratory distress syndrome
3. Diagnostic support	Differential diagnosis suggestions based on patient signs and symptoms (e.g., Isabel, DxPlain, QMR)	Suggest a differential diagnosis of appendicitis, diverticulitis/osis or kidney stones in patients with lower abdominal pain
4. Risk assessment tools	Tools and calculators to estimate disease risks based on patient characteristics	Calculate 10-year cardiovascular disease risk for a patient based on the Framingham risk score
5. Prognostic tools	Tools to estimate the survival of patients with cancer or other potentially life-limiting conditions based on diagnostic criteria and procedures performed	Estimate survival for cancer patients based on tumor type, location, staging, and procedures performed

6.	Transfusion support	Recommendations regarding the appropriateness of transfusions and suggested products and dosing based on clinical indications	Suggest fresh frozen plasma for patients with a high INR and taking warfarin.
7.	Nutrition ordering tools	Tools, calculators, guidelines, and protocols for ordering total parenteral nutrition (TPN), enteral nutrition or other alimentation procedures	Suggest increased protein in TPN for patients with active infection.
8.	Laboratory test interpretation	Interpretative information for laboratory results. This may include reference range information, correlation among several results, or calculations (such as the anion gap).	Based on ABG values, report that a patient has high anion gap metabolic acidosis.
9.	Treatment planning	Computer tools to assist in the planning of interventional procedures (i.e., surgery or radiation therapy).	An image-guided treatment planning system used for radiation _ oncology
10.	Triage tools	Tools for determining urgency of clinical problems and sorting patients on the basis of need and available resources.	A computer prompt that recommends that a patient with facial numbness and slurred speech, as documented by a triage nurse, be seen immediately to rule out stroke
11.	Syndromic surveillance	Direct or surrogate monitoring of disease conditions over a geographic area	City-wide reporting and monitoring of emergency department chief complaints in order to detect norovirus outbreaks.

Workflow support (7 features)

1.	Order routing	Rule-based routing of orders to various functional areas	Route order for albuterol nebulizer to pharmacy and respiratory therapy.
2.	Registry function	Actionable interventions on multiple patients	Send a letter to all patients with diabetes who are overdue for an HbA1c
3.	Medication reconciliation	Tools for reconciling medication lists across transitions in care (admissions, discharges, and transfers).Upon admission, automatically generate a pre-admission medication list _ based on outpatient medication orders and pharmacy dispensing data.	
4.	Automatic order termination	Automatic termination of orders after a set period of time.	Automatically terminate antibiotic orders after the conclusion of the _ order duration.
5.	Order approvals	Apply logic and route orders for special approval based on order type, ordering provider, or patient characteristics	Send all human growth hormone (HGH) orders to endocrinology for _ review/approval
6.	Free-text order parsing	Parsing tools to translate free-text orders into structured representations.	Allow the user to enter the text 'amox 500 mg QID 10d' and translate that to a complete, structured amoxicillin order that can be automatically processed by the pharmacy system.
7.	Documentation aids	Templates and tools for documenting care in structured or unstructured forms.	Totals (absence of '_' indicates response of N (no), NA (not applicable), or (blank)). Structured documentation template for a primary care asthma visit that _ has checkboxes for common symptoms, etc.

Appendix B. Survey Questions

Section 1: Hospital Demographics

1. State/territory of the hospital/project in which you have worked on an EMM project

Australian Capital Territory	New South Wales	Northern Territory	Queensland	South Australia	Tasmania	Victoria	Western Australia

2. Hospital classification[1]

Section 2: EMM system

3. Have you implemented or are you in the processes of implementing an EMM system?

    ☐ Implemented

    ☐ In the processes of implementing (but have not gone live as of the date of this interview)

    → *skip to Question 7*

4. Year first introduced, including pilots _____

5. Is it currently used hospital wide?   ☐ Yes   ☐ No

---

[1] AIHW 2015. Australian hospital peer groups. Health services series no. 66. Cat. no. HSE 170. Canberra: AIHW

7. Locations currently used

   Inpatient

☐	Medical wards
☐	Surgical wards
☐	Chemotherapy treatment
☐	Emergency department
☐	Haemodialysis
☐	Hospital in the home
☐	Intensive care
☐	Maternity
☐	Mental health
☐	Neonatal special care/intensive care unit
☐	Operating theatres
☐	Paediatrics
☐	Palliative care
☐	Rehabilitation care

☐ Outpatients   ☐ Community Health

8. What is the location scope for budgeted rollout?

   Inpatient

☐	Medical wards
☐	Surgical wards
☐	Chemotherapy treatment
☐	Emergency department
☐	Haemodialysis
☐	Hospital in the home
☐	Intensive care
☐	Maternity
☐	Mental health
☐	Neonatal special care/intensive care unit
☐	Operating theatres
☐	Paediatrics
☐	Palliative care
☐	Rehabilitation care

☐ Outpatients   ☐ Community Health

9. EMM System

   Product:
   _____

   Vendor:
   _____

Section 3: Governance

10. Are the prescribing alerts in the EMM system at your site managed (created, modified, evaluated) at a local, health service, or state/territory-wide level?

    ☐ local   ☐ health service   ☐ state/territory-wide level

    ☐ other (please specify)_____

11. Did you convene a specific governance group to consider issues related to prescribing alerts?

    ☐ Yes   ☐ No

    If no, why?

    _____

    _____

    _____

12. Decision making
    a. What clinician roles were involved?

    ☐ Pharmacist   ☐ Medical   ☐ Nursing

    ☐ Other (please specify) _____

    b. Was decision making shared amongst these roles, or did one (or more) clinician role have greater input?

    _____

    _____

    _____

13. Does your organisation solicit feedback regarding specific prescribing alerts from clinicians?

☐Yes   ☐No

If yes, how?

_____

_____

_____

14. Does your organisation collect metrics on the use of prescribing alerts?

☐Yes   ☐No

If yes, which metrics do you collect?

_____

_____

_____

Section 4: Medication prescribing alerts

For <u>EACH</u> medication prescribing alert category (See Figure 1):

Medication Dosing Support
Dose adjustment
Single dose range checking
Maximum daily dose range checking
Maximum lifetime dose checking
Order facilitators
Corollary order
Indication-based ordering
Point of care alerts/reminders
Drug-condition interaction
Drug-drug interaction
Drug-allergy interaction
Therapeutic duplication
IV/oral conversion
Drug-food interaction
Drug-pregnancy interaction
Drug-laboratory test interaction
Contraindicated route of administration
Formulary alert
Therapeutic substitution alert
IV compatibility

Figure 1. Medication prescribing alert categories

15. Is this alert type utilised in your system? If so, describe your build/configuration.

16. Which of the following had the greatest influence/s over your build/configuration?

- [ ] Vendor recommendation
- [ ] Beliefs about evidence
- [ ] Perceived usefulness
- [ ] EMM governance group recommendation
- [ ] Medication safety group recommendation
- [ ] Local incidents
- [ ] Area health service/state-wide policy
- [ ] Individual EMM governance group member
- [ ] Individual clinician
- [ ] Other (please specify) _____

17. Can you please describe any benefits your organisation has realised as a result of this alert type?

_____

_____

_____

18. Can you please describe any problems your organisation has faced as a result of this alert type?

_____

_____

_____

19. Have you made any changes to this functionality/configuration since go-live?

- [ ] Yes   - [ ] No

If yes, why?

_____

_____

20. Do you have any immediate plans to change this functionality/configuration?

☐Yes ☐No

If yes, why?

_____

_____

_____

Section 5: Beliefs

For <u>EACH</u> medication prescribing alert category (See Figure 1):

Based on YOUR experience please indicate how much you agree with the following statements:

21. I believe there is evidence in the scientific literature to support utilisation of this alert type.

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree

22. I believe there is evidence in the scientific literature that this alert type has a positive impact on improving prescriber outcomes (e.g. cancelling an order or prescribing a new appropriate order).

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree

23. I believe there is evidence in the scientific literature that this alert type has a positive impact on improving patient outcomes (e.g. clinical signs or symptoms suggesting potential and/or actual harm).

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree

24. I feel that this alert type has had a positive impact in my organisation on improving prescriber outcomes (e.g. cancelling an order or prescribing a new appropriate order).

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree

25. I feel that this alert type has had a positive impact in my organisation on improving patient outcomes (e.g. clinical signs or symptoms suggesting potential and/or actual harm).

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree

Section 6: Lessons learned/future research

26. Has your organisation undertaken any evaluation on the impact of medication prescribing alerts?

☐ Yes   ☐ No

If yes,

a. Have these been published in the scientific literature?

☐ Yes   ☐ No

b. Have you evaluated any of the following?

☐ Alert rate   ☐ Alert override rate

☐ Impact on prescriber outcomes   ☐ Impact on patient outcomes

27. If you could **remove** one alert type from your current alert suite, which type would you remove, and why?

_____

_____

_____

28. If you could **add** one alert type from your current alert suite, which type would you remove, and why?

_____

_____

_____

29. Is there anything else about your experience with prescribing alerts that you'd like to share with other Australian implementers?

_____

_____

_____

Appendix C. Survey information and consent form

**CENTRE FOR HEALTH SYSTEMS
AND SAFETY RESEARCH**
*Faculty of Medicine
and Health Sciences*
Australian Institute of Health Innovation

**An invitation to participate in a survey on
Electronic Medication Management (EMM) system prescribing alerts**

Participant Information Form

You are invited to participate in the first national survey of computerised prescribing alerts in electronic medication management (EMM) systems in Australian hospitals. The aim of the study is to determine the use, configuration, evaluation and governance of EMM decision support prescribing alerts.

The study is being conducted by Natalie Page as part of her Master of Philosophy degree at Macquarie University, under the supervision of Professor Johanna Westbrook (telephone 02 9850 2402, email Johanna.Westbrook@mq.edu.au) and Dr Melissa Baysari of the Centre for Health Systems and Safety Research.

The purpose of this research is to understand:
- EMM systems used across Australian public and private hospitals, and scope of usage/rollout
- What prescribing alert types have been implemented (and what local customisation occurred)?
- Local governance around prescribing alert configuration decisions
- Alert benefits and problems

If you decide to participate, please complete the following consent form and return by email to ＿ . You will then be asked to participate in a telephone survey to seek information relating to an EMM implementation you have been involved with. No identifiable information is being collected as part of this study (i.e. your name or hospital's name will not be recorded). With your permission, the telephone survey will be audio-recorded. The audio recording will then be transcribed and the recording destroyed. The typed transcript of your survey will be reviewed for analysis.

Any information or personal details gathered in the course of the study are confidential, except as required by law. Only investigators involved in this survey will have access to the data. A summary of the results of the data is available to you on request by contacting Natalie Page (telephone , email).

Participation in this study is entirely voluntary: you are not obliged to participate and if you decide to participate, you are free to withdraw at any time without having to give a reason and without consequence. We ask you to consider recommending other suitable participant/s if you believe you are unable to provide us with information about computerised alerts in EMM.

An invitation to participate in a survey on

Electronic Medication Management (EMM) system prescribing alerts

Participant Consent Form

I,   *(participant's name)*   have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to participate in this research, knowing that I can withdraw from further participation in the research at any time without consequence. I have been given a copy of this form to keep.

Participant's Name:_____

(Block letters)

Participant's Signature: _____   Date:_____

Investigator's Name:_____

(Block letters)

Investigator's Signature: _____ __ Date:_____

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics & Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

(INVESTIGATOR'S [OR PARTICIPANT'S] COPY)

Appendix D. Survey invitation - email

From:

To:

Subject: An invitation to participate in an Australian survey on hospital EMM prescribing alerts

Dear colleague,

I am writing to request your participation in the first national survey of interruptive computerised prescribing alerts in electronic medication management (EMM) systems in Australian hospitals. The aim of the study is to understand more about the way in which decision support within EMM is currently being used, configured, evaluated and governed. One of the anticipated outcomes of this research is that by drawing on experiences across multiple hospitals, lessons learnt and effective approaches to decision support can be identified and shared.

I am conducting this survey as part of my Master of Philosophy degree at Macquarie University, under the supervision of Professor Johanna Westbrook and Dr Melissa Baysari of the Centre for Health Systems and Safety Research, Australian Institute of Health Innovation.

The interview survey will be conducted via telephone and will take approximately 40-60 minutes to complete (depending on the number of alerts in your EMM system). No identifiable information is being collected as part of this study (i.e. your name or hospital's name will not be recorded).

Participation in this study is entirely voluntary: you are not obliged to participate and if you decide to participate, you are free to withdraw at any time without having to give a reason and without consequence. We ask you to consider recommending other suitable participant/s if you believe you are unable to provide us with information about computerised alerts in EMM.

Please find attached an information sheet and consent form.

If you would like to participate or would like more information, please do not hesitate to contact me.

I hope that you will consider being a part of this important project and sharing your knowledge and expertise. Thank you in advance for your time and contribution.

Warm regards,

Natalie Page

Pharmacist Advanced - Electronic Medication Management, Children's Health Queensland
Former Lead Pharmacist, Electronic Medication Management, ACT Health
Master of Philosophy candidate Macquarie University
Email:
Telephone:

Appendix E. Survey invitation - internet forum

Dear colleagues,

I am writing to request your participation in the first national survey of computerised prescribing alerts in electronic medication management (EMM) systems in Australian hospitals.

The aim of the study is to understand more about the way in which decision support within EMM is currently being used, configured, evaluated and governed. By drawing on experiences across multiple hospitals, lessons learnt and effective approaches to decision support can be identified and shared.

The interview survey will be conducted via telephone and will take approximately 40-60 minutes to complete. No identifiable information is being collected as part of this study (i.e. your name or hospital's name will not be recorded).

If you would like to participate or would like more information, please do not hesitate to contact me via the forum or by the email listed below.

I hope that you will consider being a part of this important project and sharing your knowledge and expertise. Thank you in advance for your time and contribution.

Warm regards,

Natalie Page

Pharmacist Advanced - Electronic Medication Management, Children's Health Queensland
Former Lead Pharmacist, Electronic Medication Management, ACT Health
Master of Philosophy candidate Macquarie University
Email:
Telephone:

Appendix F of this thesis has been removed as it may contain sensitive/confidential content