THE USE OF MODELING TECHNIQUES TO INFORM E-PRESCRIBING

THE USE OF PROCESS AND SIMULATION MODELING TO INFORM THE DESIGN OF ELECTRONIC PRESCRIBING SYSTEMS

By AHMAD GHANY B.H.Sc.

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree Master of Science in Electronic Health

McMaster University MASTER OF SCIENCE (2012) Hamilton, Ontario (Electronic Health)

TITLE: The Use of Process and Simulation Modeling to Inform the Design of Electronic Prescribing Systems

AUTHOR: Ahmad Ghany, B.H.Sc. (McMaster University)
SUPERVISOR: Dr. Anne Holbrook, MD, PharmD, MSc, FRCPC
NUMBER OF PAGES: xii, 94

ABSTRACT

Objectives: (1) to assess whether computer simulation modeling or process modeling have improved medication management systems, including informing the design of e-prescribing systems for Canada, and (2) to build and validate a workflow diagram of the handwritten medication management process in the community setting for Canada and use it to obtain feedback from stakeholders.

Methods: A systematic review was conducted to assess whether the modeling techniques have improved medication management systems. A workflow diagram was developed and used to obtain feedback from stakeholders as to where problems exist in the current paper-based process and where information technology might be of help. Analyses were descriptive and qualitative.

Results: The systematic review identified 13,376 citations, 8 of which were included in the full data extraction. The review revealed that simulation models of e-prescribing systems have been developed, but their accuracy and usefulness has not been established. One process model had been used to analyze a Canadian medication management system, but no evidence was found that process models had any positive impact on e-prescribing development in Canada.

Fifteen stakeholders, including 5 physicians, 5 pharmacists, and 5 members of the public provided feedback using the workflow diagram. All stakeholders agreed that the diagram was a realistic representation of the actual handwritten medication management process, suggesting face validity. The majority of stakeholders identified the most problematic

processes as generating the prescription by the physician (9/15 (60.0%)) and drug checking by the physician (6/15 (40.0%)).

Conclusions: There is a lack of published evidence on simulation models and process models, and the studies that exist do not suggest any benefit in informing e-prescribing design. We developed and established face validity for a workflow diagram of the paper-based medication management cascade. Stakeholders believed that generating the prescription and drug checking by the physician could be improved by e-prescribing.

ACKNOWLEDGEMENTS

I would like to thank all those who made the completion of my thesis possible. In particular, I would like to thank my supervisor, Dr. Anne Holbrook, for providing me with guidance and assistance throughout my research, for being a valuable resource, and for ensuring that my research was focused and relevant to the field of e-health. I would also like to thank the rest of my thesis committee members for their assistance: Dr. Karim Keshavjee for inspiring me to develop a process model for my thesis, for being a valuable resource in developing the process model, and for arranging interviews with key stakeholders; Dr. Ann McKibbon for her valuable insights on my search strategy and stakeholder feedback and for always directing me to the proper sources of information; and James Bowen for his valuable insights on modeling and analyzing stakeholder feedback, for ensuring that my research was focused, and for being a valuable resource whenever I required assistance. I would like to thank Kaitryn Campbell, who ensured that my systematic review search strategy was comprehensive and complete. I would also like to thank Jason Lam for being a second reviewer and assisting with screening and data extraction. Finally, I would like to thank all the stakeholders who took the time to provide feedback.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ADE	Adverse Drug Event
BPMN	Business Process Modeling Notation
CHI	Canada Health Infoway
CPOE	Computerized Physician (or Provider) Order Entry
DIS	Drug Information System
E-health	Electronic Health
EHR	Electronic Health Record
EMM	Electronic Medication Management
EMR	Electronic Medical Record
E-prescribing	Electronic Prescribing
FMEA	Failure Mode and Effects Analysis
IT	Information Technology
MD	Physician
pADE	Preventable Adverse Drug Event
Rx	Prescription

DECLARATION OF ACADEMIC ACHIEVEMENT

All members of my thesis committee (Dr. Anne Holbrook, Dr. Ann McKibbon, James Bowen, and Dr. Karim Keshavjee) assisted in deciding the topic and the scope of my thesis.

I prepared search strategies for the systematic review with the assistance of Kaitryn Campbell. Search strategies were peer-reviewed by members of my thesis committee to ensure completeness. I searched electronic databases and the grey literature. I screened studies based on title, abstract, and full text. A second reviewer, Jason Lam, screened a sample of studies by abstract and full text. I completed data extraction for all included studies. The second reviewer, Jason Lam, completed data extraction for a sample of the included studies. I analyzed the results from the systematic review and wrote the systematic review. My supervisor, Dr. Anne Holbrook, provided me with advice on methodology, feedback and assisted with multiple edits of the systematic review.

I built the workflow diagrams in PowerPoint and Arena. My primary sources of information for building the models were Dr. Karim Keshavjee and Dr. Anne Holbrook, both very experienced e-health and prescribing researchers. Dr. Keshavjee and I developed criteria for evaluating modeling software and each of us evaluated 10 modeling software products. Dr. Keshavjee also assisted in arranging interviews with stakeholders. All members of my thesis committee and myself developed the questionnaire to be used for stakeholder feedback. I interviewed all 15 stakeholders and collected data from each

interview. The data that were collected included (a) paper versions of the workflow diagrams with the ratings of each stakeholder, and (b) the audio recordings of the interviews. I analyzed the data from the interviews by tabulating the results from the ratings of stakeholders and presenting the results in a table. I transcribed all interviews, coded verbalizations from the interviews, and tabulated the verbalizations. I also selected quotations from the interviews to include in the paper. All members of my thesis committee advised me on the best approach for analyzing the data obtained from stakeholders. I analyzed the data from stakeholders and drafted the workflow diagram paper. Dr. Anne Holbrook advised on methodology, provided me with regular feedback and assisted with multiple edits of the workflow diagram paper.

CHAPTER 1: INTRODUCTION

1. BACKGROUND AND THE PROBLEM

The traditional outpatient medication management process consists of two primary phases, drug prescribing followed by the dispensing of the medication. The handwritten medication management process usually involves a physician writing out a prescription by hand, giving the prescription to the patient, who then takes it to a pharmacy for it to be reviewed, entered into the pharmacy computer system and dispensed by the pharmacy technicians and pharmacists. The complete medication management process includes prescribing, transmission, dispensing, counseling, administering (for the inpatient setting), and monitoring (Bell et al., 2004). Medication errors and adverse drug events (ADEs) have been associated with the medication management process (Kohn et al., 1999). Medication errors are defined as errors that occur at the different stages of the medication management process (Kaushal et al., 2001). ADEs are defined as drug-related injuries that result from medical interventions (Bates et al., 1995). Preventable adverse drug events (pADEs) are defined as ADEs that are attributed to medication errors (Thomsen et al., 2007).

A systematic review examining the types of medication errors that caused pADEs found that 64.7% of the reported pADEs originated from errors in the drug prescribing phase (Thomsen et al., 2007). Other research has also found the most common source of ADEs to be prescribing errors (Koppel et al., 2005). Research in the hospital setting has found that although errors that result in pADEs occur at various stages of the medication

management process, they are most frequent (56%) in the ordering phase (Bates et al., 1995). This could be the case simply because the prescribing phase has been studied more than the other phases of medication management (McKibbon et al., 2011). A comprehensive systematic review on medication management found that of the 428 studies included in the review, 174 studied the prescribing phase while only 9 studied the dispensing phase (McKibbon et al., 2011). Thus, errors and ADEs occurring at other phases of medication management are likely going undetected.

2. ELECTRONIC PRESCRIBING AS A PROPOSED SOLUTION

Because of the errors and ADEs associated with the paper-based medication management process, solutions have been proposed that involve the use of information technology (Aspden et al., 2007). Electronic prescribing (e-prescribing) is a technology that would make the medication management process electronic (Cusack, 2008), and has been proposed to eliminate or reduce the errors and ADEs found in the paper-based medication management process (Aspden et al., 2007).

3. THE STATE OF E-PRESCRIBING IN CANADA

Canada Health Infoway (CHI) has a goal of implementing a national electronic health record (EHR) system by 2016. A key component of the national EHR system proposed by CHI is a drug information system (DIS) that would allow for a patient's medication profile to be viewed online by physicians and pharmacists, decision support for drug checking, prescriptions to be generated electronically and sent electronically to a

pharmacy of the patient's choosing, and integration between the DIS and electronic medical records (EMRs) and the DIS and pharmacy information systems (Canada Health Infoway, 2010). CHI has called this future DIS the Generation 3 Drug Information System (Canada Health Infoway, 2010). As this system does not yet exist, CHI has claimed several benefits from Generation 2 DISs, which CHI classifies as systems that allow for a patient's electronic medication profile to be viewed locally by physicians or pharmacists and/or systems that allow for drug interaction checking to be performed locally by either physicians or pharmacists (Canada Health Infoway, 2010). The benefits claimed by CHI include an increase in provider productivity, a reduction in ADEs, and improved patient compliance (Canada Health Infoway, 2010). However, the evidence of actual benefit is not clear, as estimations from evaluation studies, interviews, the literature and surveys were used to determine benefit. Furthermore, these claimed benefits are being attributed to systems that do not have DISs and are not complete e-prescribing systems, as the electronic transmission of prescriptions to community pharmacies and integration between EMRs, pharmacy information systems and DISs are not currently in place.

4. EVIDENCE TO DATE ON E-PRESCRIBING

A major issue for e-prescribing is the lack of evidence of important clinical benefit. Research to date suggests that the benefits of e-prescribing have been minor and that studies are usually of poor quality (Eslami et al., 2008; Reckmann et al., 2009; Ammenwerth et al., 2008), systems have introduced new types of errors and problems

(Reckmann et al., 2009; Eslami et al., 2007), and that further research is needed to demonstrate the benefits of e-prescribing (Wolfstadt et al., 2008). Furthermore, unintended consequences typically emerge after implementing medication management information technologies (McKibbon et al., 2011). Research examining these unintended consequences has found that they can be major, some are considered to be positive while others are clearly negative consequences, including the introduction of new types of errors, decline in workflow efficiency, alert fatigue, and the system not being flexible (McKibbon et al., 2011). Analyzing existing workflow patterns before implementing an e-prescribing system may help with implementation of the system (Johnson & FitzHenry, 2006).

5. SIMULATION MODELING

Before an e-prescribing system can be implemented and replace the paper-based system in Canada, an analysis of the entire paper-based medication management process and its shortfalls is required. One of the main components of this research is to explore the use of computer simulation modeling and process modeling in analyzing medication management systems. Computer simulation modeling uses a computerized model to attempt to imitate the behaviour of the real system from which it is derived and the model's potential response to intervention (Lepley, 2001; van Sambeek et al., 2010; Kelton et al., 2010). It is a method of analysis that is especially useful when other methods of analysis using the real-life system are too expensive, difficult, or not possible to perform (Lepley, 2001; Kelton et al., 2010). Simulation modeling can be used to

measure the performance of real-life systems and makes it possible to determine what improvements, if any, need to be made to the system (Mo & Mahmoudi, 2008). Simulation modeling can also be used to model systems that do not yet exist and makes it possible to design a system and measure how a system might perform before the system is actually built (Mo & Mahmoudi, 2008). Other reasons why simulation models are used include testing proposed changes to a system without actually having to make actual changes to the system; reconstructing certain parts of a system so that it can be analyzed in detail to determine why the system performs the way that it does; determining bottlenecks in the system and diagnosing any problems; and helping in the understanding of how a system really works (Banks, 1999). The first component of the thesis aimed to determine from the literature whether any computer simulation models of e-prescribing systems have been developed, and if there was evidence that they were helpful in design or enhancement of systems. The results could guide future research on developing a computer simulation model of an e-prescribing system for Canada and could help to determine whether there is any benefit to exploring this area of research.

6. PROCESS MODELING

Process of workflow modeling is a technique used to visually display the operations of an organization or a system (Bandara et al., 2005). Process modeling is used to represent entities and activities while showing the relationships between them (Bandara et al., 2005). Process modeling is commonly used by organizations to reduce complexity and increase both knowledge and awareness of business processes (Bandara

et al., 2005). The first component of the thesis also aimed to determine from the literature whether any process models or workflow diagrams of Canadian medication management systems have been developed, and if there was any evidence that they were helpful in informing the design of an e-prescribing system for Canada. The second component of this thesis and research was to develop, validate, and use a workflow diagram of the handwritten medication management process in Canada in the community/outpatient setting to obtain feedback from key stakeholder groups. A workflow diagram of Canadian medication management in the community could help clarify the shortcomings in the paper-based process and where technology might help. This workflow diagram could inform the design of an e-prescribing system.

7. OVERVIEW OF THESIS CHAPTERS

Chapter 2 is a systematic review prepared for publication. The objective of this chapter is to determine whether computer simulation modeling or process modeling have improved medication management systems, including informing the design of an e-prescribing system for Canada. This chapter outlines the search strategy for the review and how studies were selected. It then goes on to discuss the results of the review, specifically what was learned in terms of research to date on e-prescribing simulation models and process models of Canadian medication management systems.

Chapter 3 of this thesis is a paper prepared for publication. This chapter discusses the methodology of how a workflow diagram of the paper-based medication management process was developed, validated, and used to obtain feedback from 15 stakeholder

representatives, including physicians, pharmacists, and members of the public. The results from stakeholder feedback as to where they perceived errors to be present in the current paper-based system and where they perceived information technology as being helpful are also discussed.

Chapter 4 provides an overall summary of what was learned from this research and discusses conclusions and future research.

CHAPTER 2: THE USE OF MODELING TECHNIQUES TO IMPROVE MEDICATION MANAGEMENT SYSTEMS: A SYSTEMATIC REVIEW

ABSTRACT

Background: Modeling tools, if properly developed and validated, may be of value in the analysis of medication management systems including the development of e-prescribing.

Objectives: To assess whether computer simulation modeling or process modeling have improved medication management systems, including informing the design of an e-prescribing system for Canada.

Methods: MEDLINE, EMBASE, CINAHL and grey literature were searched from 1975 to December 2011 using terms such as "computer simulation OR systems analysis" AND "electronic prescribing OR drug prescriptions". Records were screened by title and abstract by one reviewer with a second reviewer screening a sample (11.4%) of these. Full text articles were screened by one reviewer with a second reviewer screening a sample (13.0%) of these. Studies that met eligibility criteria were included in a qualitative synthesis.

Results: A total of 13,376 citations were screened, 301 full text articles were reviewed, and 8 studies were included in the full data extraction. Five of these were simulation model studies and three were process model studies. All 5 simulation models included studied the impact that implementing an e-prescribing system might have on certain factors, such as process times and the number of medication errors. Only 1 of the 3

process model studies analyzed a Canadian medication management process; the other 2 studies simply developed process models and did not use them for analysis. None of the simulation model studies validated their model predictions by comparing with data from the real system and none of the process model studies validated their models prior to use. All of these studies were of low or medium quality.

Conclusions: Simulation modeling and process modeling have both been tried as tools to analyze medication management systems, however we found no evidence that the simulation model predictions were accurate and no evidence that either type of model had any impact on e-prescribing development.

1. INTRODUCTION

Medication management refers to the processes involved in the prescribing, dispensing and monitoring of a medication, which includes prescribing, transmission, dispensing, counseling, administering (for the inpatient setting), and monitoring (Bell et al., 2004). The paper-based medication management process has been scrutinized over the years, especially since the report *To Err is Human* brought to light the incidence and impact of medication errors and adverse drug events (ADEs) occurring at the various stages of the medication management process (Kohn et al., 1999). Medication errors are errors occurring at various stages in the medication management process (Kaushal et al., 2001) which may result in (ADEs) (Bates et al., 1995). Although medication errors and ADEs result from multiple factors in the medication management system and are not the result of a single individual or factor (Aspden et al., 2007), there has been an emphasis on studying and preventing errors in the prescribing phase (McKibbon et al., 2011). For example, a systematic review found that 64.7% of all ADEs that were determined to be preventable originated from errors in the prescribing phase (Thomsen et al., 2007). When a prescriber writes out a prescription by hand, he/she may not have access to rapid patient-specific feedback on dose, contraindications, or possible drug interactions, and this lack of information may increase the risk of medication errors or ADEs (Buckley, 2002). The impact that medication errors and ADEs could have is significant considering that 483 million prescriptions are filled annually in Canada (Kondro, 2010).

Electronic prescribing (e-prescribing) is a system that would make the entire medication management process electronic without the use of any intermediaries such as

paper printouts or faxes (Cusack, 2008). E-prescribing has been proposed to reduce the medication errors and ADEs found in the paper-based medication management system (Aspden et al., 2007). The Canadian government has invested $2.1 billion in Canada Health Infoway (CHI) (Canada Health Infoway, 2009), which is helping to fund the development of an e-prescribing system (Canada Health Infoway, 2010). Hospitals are slowly implementing computerized physician (or provider) order entry (CPOE) (Jha et al., 2008), which often include an e-prescribing capability (Kuperman & Gibson, 2003).

A substantial amount of work and research is still needed before a fully functioning e-prescribing system exists in Canada. One of the reasons for this is that the evidence regarding the benefits of e-prescribing systems internationally is mixed. Evidence to date suggests that the benefits of e-prescribing have been minor and inconsistent (Koppel et al., 2005; Reckmann et al., 2009), current systems have produced harm in the form of several types of unintentional errors (including increased mortality) and faulty design (Campbell et al., 2006; McKibbon et al., 2011), and the costs of implementing such systems are much higher than expected (Cusack, 2008). As unintended consequences associated with the implementation of e-prescribing systems are consistently found after implementation (McKibbon et al., 2011), it has been suggested that analyzing existing workflow patterns *prior* to implementing e-prescribing systems would be an important component to ensuring successful implementation of the system (Johnson & FitzHenry, 2006). One way to perform this analysis is by using modeling techniques.

One modeling technique known as computer simulation modeling uses a computerized model to attempt to imitate the behaviour of the real system and its potential response to intervention (Lepley, 2001; van Sambeek et al., 2010; Kelton et al., 2010). The model is built by first identifying the elements of the system, their relationships, and data values (Anderson, 2002). Some possible sources of data include logs of the system, questionnaires, interviews, opinions of experts, and work sampling (Anderson, 2002). The model is then simulated using simulation software, which uses underlying mathematical algorithms and equations to perform simulations (Anderson, 2002). The simulation model simulates variations of the real processes in the system at an accelerated rate (van Sambeek et al., 2010). Variations can be made to the initial conditions, inputs, capacity, and the structure of the system (Anderson, 2002). For example, the number of prescriptions going through an e-prescribing system can be varied to determine what impact it would have throughout the system. The simulation model output is a simple spreadsheet, and this output is used to measure the performance of the system (van Sambeek et al., 2010; Mo & Mahmoudi, 2008). Performance is measured by examining variables of interest in the output report, such as process times, and determining how they were impacted by the variations to the system that were simulated. Simulation models can be used to model existing or planned systems (Banks, 1999). There are several different types of simulation models. Examples include discrete-event simulation modeling, which is suitable for systems where variables change at distinct moments in time (Lim et al., 2012); system dynamics, which is suitable for models of continuous processes where feedback loops are present (Sweetster, 1999); and

agent-based modeling, which is suitable for modeling systems that involve autonomous agents (i.e. users) that are directed by certain rules and interactions (Lim et al., 2012). Simulation modeling has been useful in analyzing process design, scheduling, and capacity problems for both the inpatient and outpatient setting (van Sambeek et al., 2010).

Another modeling technique known as process modeling or workflow modeling, allows for the visual representation of the operations of an organization or a system (Bandara et al., 2005). A process model or workflow diagram displays a network of processes or activities and the order in which these processes are performed (White, 2004), but does not involve any simulation. Process modeling uses a structured approach to describe a set of related processes or activities (Hook, 2011). Process models are typically developed by a top-down approach, where high-level processes are first mapped out and then broken down into greater levels of detail (White, 2004). Once the model or diagram is complete, it can be used to communicate different levels of detail (e.g., only certain parts of the model or the complete model) to different types of audiences (e.g., user groups or management) (White, 2004). Process modeling has been useful in analyzing process design problems in the hospital setting (van Sambeek et al., 2010).

The objective of this review was to assess whether computer simulation modeling or process modeling have improved medication management systems, including informing the design of an e-prescribing system for Canada.

2. METHODS

2.1 Eligibility Criteria

We included all types of studies as long as they were either original research or a systematic review. Editorials and commentaries were not considered for inclusion. We only considered reports that were published in the English language and published from 1975 onwards. By 1975, computerized pharmacy information systems had begun to proliferate in Canada, later versions of which support current medication management.

2.1.1 Screening Criteria

System

Computer simulation models were eligible for inclusion if they were intended to inform an e-prescribing or CPOE system in any country. CPOE systems were included as they often include electronic ordering of medications. Process models were eligible for inclusion only if they modeled a medication management system in Canada. For both types of models, we required studies to at least discuss the prescribing and dispensing phases of medication management.

Intervention

Any type of computer simulation model was eligible for inclusion (e.g., discrete-event, system dynamics, agent-based) as long as it was used to inform the design of or analyze an e-prescribing system. All types of process models were eligible for inclusion (e.g., workflow models, workflow diagrams) as long as an actual model was developed

and/or used to analyze a medication management system. For a comprehensive list of search terms refer to Appendix 1.

Control

We considered any comparison group that was included, including if the comparison group was the system prior to the intervention (e.g., historical controls in a before-after study).

Outcomes

For both types of models the outcomes of primary interest were workflow efficiency and patient important outcomes.

Setting

For both types of models, we considered all studies that were in the inpatient or outpatient setting.

2.2 Data Sources and Search Strategies

2.2.1 Electronic Databases

The literature was searched from 1975 until December 2011 (week 3) using the electronic databases MEDLINE (using OVID), EMBASE (using OVID), and CINAHL (using EBSCO). AG developed all search strategies with the assistance of a research librarian and search strategies were peer-reviewed prior to the actual searches.

The search strategies were as follows:

(a) Computer simulation modeling and related terms (Computer Simulation OR Systems Theory OR Systems Analysis) were combined with electronic prescribing and related terms (Electronic Prescribing OR Computer-Assisted Drug Therapy OR Computerized Medical Records Systems) using "AND".

(b) Process modeling and related terms (Systems Analysis OR Process Assessment [Health Care] OR Quality Assurance, Health Care) were combined with electronic prescribing, paper-based prescribing, and related terms (Electronic Prescribing OR Drug Prescriptions OR Computer-Assisted Drug Therapy) and (Canada OR Provinces OR Territories) using "AND".

(a) and (b) were then combined using "OR". The full search strategy for each electronic database with a complete list of terms that were searched is presented in Appendix 1.

2.2.2 Grey Literature

An extensive search of the grey literature was also performed using a combination of terms such as electronic prescribing simulation model, drug prescribing process model Canada, and drug prescribing model. The full search strategy for each source of grey literature that was searched is presented in Appendix 2.

2.3 Study Selection

All records were first screened by title only by AG to determine if they were concerning medication management and modeling. Duplicates and irrelevant records

(e.g., clearly not about medication management and modeling) were excluded. All remaining records were screened by title and abstract by AG to determine if they were concerning medication management, and process or simulation modeling. A second reviewer (JL) screened a random sample (11.4%) of the records in retrospect by title and abstract to obtain a measure of agreement. All identified citations meeting the inclusion/screening criteria, including studies where eligibility for inclusion based on title and abstract alone could not be determined, were further reviewed by obtaining the full text and reviewed by AG. JL screened a random sample (13.0%) of the studies in retrospect by full text to obtain a measure of agreement. Studies meeting the inclusion criteria were then included in the analysis. Bibliographies of all included studies were also searched to identify any other studies that met the inclusion criteria. The detailed screening criteria for the review are outlined in Appendix 3. Selection of studies from the grey literature was performed independently by AG by screening by title first, then abstract, and then full text. Inter-rater agreement for screening was calculated using an online Kappa calculator (GraphPad Software Inc., 2012).

2.4 Data Collection Process and Synthesis

Data were extracted from all included studies using a predefined data extraction form, which included study setting, the type of system being modeled, details of the intervention, outcome measures, whether validation occurred, and the results. The data extraction form is found in Appendix 4. Data extraction was performed independently by AG. JL performed data extraction independently for a sample (62.5%) of the included studies to obtain a measure of agreement. The level of inter-rater agreement for a sample

of the 5 key items found in the data extraction form was calculated using the same online Kappa calculator mentioned above. Results of studies were summarized.

2.5 Assessment of Quality

2.5.1 Quality of Simulation Model Studies

We assessed the quality of each simulation model study based on four factors, which were adapted from Robinson (1997) and Sargent (2005):

(A) *Was the simulation model validated prior to use*? Several validation techniques could be used to validate simulation models before they are used. White-box validation and black-box validation are used to determine if the components of the model or the overall model, respectively, are representative of the real-world system to a satisfactory degree of accuracy (Robinson, 1997). These correspond to face validity, meaning that at face value, those who are knowledgeable about e-prescribing systems believe that the simulation model appears to be an accurate representation of the real system. Another method of validation is to use historic data, if available, run these data through the simulation model, and then compare the results from the simulation model to the existing system to determine if the model is running correctly (Sargent, 2005). If a model was validated prior to its use by any of these validation methods, the study was given a score of 1, otherwise given a score of 0.

(B) *What quality of data was used to populate the simulation model*? Several sources of data could be used to populate simulation models, all of which are of different levels of quality. Poor quality or inaccurate data could result in inaccurate model predictions

(Robinson, 1997). If actual data were used to populate the simulation model (e.g., from system logs, work sampling, chart review), the study was given a score of 1. If the data used to populate a simulation model were based solely on opinions and estimation, the study was given a score of 0.

(C) *Was sensitivity analysis performed before the model was used*? Sensitivity analysis involves varying the inputs of the simulation model to determine the effects on the model's output (Sargent, 2005). Those parameters that cause substantial changes to the model's output are considered to be sensitive and need to be adjusted before the model is used (Sargent, 2005). If sensitivity analysis was performed before the model was used, the study was given a score of 1, otherwise given a score of 0.

(D) *Were model predictions tested to see if they were accurate*? This means the model *predictions* are compared to the actual system's behavior (i.e. once the changes have been made to the system or the new system has been implemented) to determine if they are the same and if the model was indeed accurate (Sargent, 2005). If model predictions were tested, the study was given a score of 1, otherwise given a score of 0.

A total quality score of 0-1 was considered low quality, a score of 2-3medium quality, and a score of 4 high quality.

2.5.2 Quality of Process Model Studies

We assessed the quality of each process model (i.e., workflow diagram) study based on two factors:

(A) *Was the process model validated prior to use*? If the model was validated for face validity (i.e. at face value, those with knowledge of the process believed the model to be

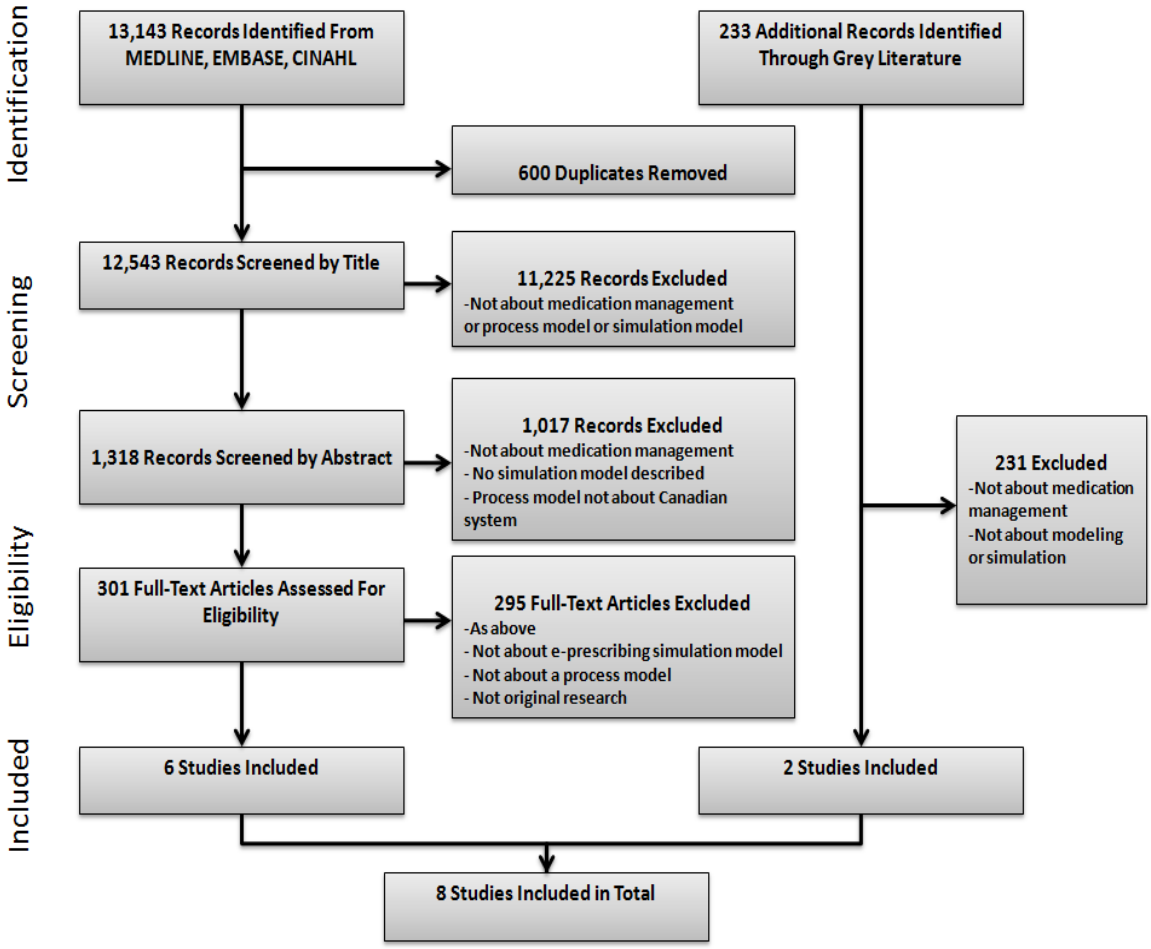
representative of the actual process), it was given a score of 1, otherwise given a score of 0.

(B) *Were the models built with the flexibility of dealing with regular workarounds*? If the model demonstrated any degree of flexibility to deal with workarounds, such as the computer system not functioning properly, it was given a score of 1, otherwise given a score of 0. If a study scored the maximum score of 2, it was considered to be of high quality. If it scored 1, it was considered to be of medium quality. If it scored 0, it was of low quality.

3. RESULTS

A search of MEDLINE, EMBASE and CINAHL on January 26th, 2012 yielded 13,143 records. An additional 233 records were identified through the grey literature. Figure 1 illustrates the study selection process. After removing duplicates (n=600), 12,543 records were screened by title. 1,318 records remained and were screened by abstract (Kappa = 0.307 fair). The main reasons for exclusion were not about medication management, no simulation model described, or the process model was not about a Canadian system. Three hundred and one studies remained for full text screening (Kappa= 0.304 fair). After applying the eligibility criteria to the full texts, 8 remained for qualitative synthesis. The main reasons for exclusion of full texts were as above, plus not about an e-prescribing simulation model, not about a process model, and not original research (e.g., editorials, commentaries). The level of inter-rater agreement for the data extraction form was Kappa=0.273 (fair).

Figure 1. Study Selection Flow Diagram



Five of the included studies described a simulation model of an e-prescribing system; 3 studies described a process model of a Canadian medication management system. All 8 studies were published between 2001 and 2008. A summary of these 8 studies is found in Table 1.

Table 1. Characteristics of Included Studies

Study, Design, Setting, Country	Phases of Medication Management Process Modeled	System(s)/ Process(es) Modeled	Intervention	Outcomes
A. Simulation Studies				
Anderson et al. (2002) Descriptive Inpatient (U.S.A.)	Prescribing, transmission, dispensing	One simulation model was developed of a CPOE system that was partially electronic, partially manual 5 changes to the system were tested using the model, 3 of them were different aspects of a CPOE system	Simulation model of: (a) a complete electronic system with decision support and order entry (i.e. all stages of medication management are electronic), (b) computerized prescribing with decision support (i.e. making the prescribing stage electronic), (c) physician order entry system that allows physicians to enter orders directly into the hospital information system	Changes to medication errors, adverse drug events, additional days of hospitalization and additional hospital costs
Bell et al. (2007) Descriptive Outpatient community practice (U.S.A.)	Prescribing, transmission, dispensing, monitoring	Complete Electronic prescribing system from prescribing to dispensing	Simulation model testing the implementation of 3 features for e-prescribing: (a) formulary and benefit feature - displays formulary information and the cost to the patient at the time the drug is being prescribed; (b) medication history feature - displays the history of medications filled and allows for safety alerts; and (c) electronic prior authorization feature - allows for completion of drug prior authorization requests online	Changes to healthcare provider times for task completion and pharmacist call back rate to physician prescriber due to implementing 3 e-prescribing features

Study, Design, Setting, Country	Phases of Medication Management Process Modeled	System(s)/ Process(es) Modeled	Intervention	Outcomes
Clancy (2006) Descriptive Inpatient (U.S.A.)	Prescribing, dispensing	CPOE system with decision support, electronic documentation, and pharmacy information system	Simulation models of implementing a CPOE system with embedded guidelines and without embedded guidelines	Changes to the annual number of medication orders and the total annual hours for healthcare providers to process medication orders
Dean et al. (2001) Descriptive Inpatient (U.K.)	Prescribing, transmission, dispensing	Handwritten prescribing system was modeled - e-prescribing was one intervention that was tested in this model (defined as a system that allows for real-time data link to pharmacy)	Simulation model of the introduction of e-prescribing into the existing system at the hospital	Changes to the medication administration error rate related to non-availability (U-MAE) - medication not available at the designated administration time (wards stocked a selection of drugs that were enough to provide 80% of all doses needed)
Wong et al. (2003) Descriptive Inpatient (Canada)	Prescribing, transmission, dispensing	CPOE system that allows for electronic ordering, dispensing, and administration of medications	Simulation model of a CPOE system	Changes to turnaround time from medication order to delivery of medication to wards, as well as errors associated with medications not being available

Study, Design, Setting, Country	Phases of Medication Management Process Modeled	System(s)/ Process(es) Modeled	Intervention	Outcomes
B. Process Model Studies				
Nickerson et al. (2008) Descriptive Inpatient (Canada)	Prescribing, transmission, dispensing	Handwritten prescribing	Failure Mode and Effects Analysis (FMEA) conducted using a process model to identify (a) potential failure modes in the medication ordering process (b) the causes and effects of those failure modes, and (c) potential solutions	Number of failure modes (in the process or design), criticality (importance) score for each failure mode, the causes and effects of those failures, and potential solutions to those failures
Abrams and Carr (2005) Descriptive Inpatient (Canada)	Prescribing, transmission, dispensing	2 systems modeled - Handwritten prescribing system - CPOE system that is electronic from ordering to dispensing, and includes electronic documentation of administration of medications	Developing two process models to show workflow before and after implementing an actual CPOE and EMM (electronic medication management) system	Two process models developed. Process models not used for analysis

Study, Design, Setting, Country	Phases of Medication Management Process Modeled	System(s)/ Process(es) Modeled	Intervention	Outcomes
Zamora et al. (2006) Descriptive Inpatient (Canada)	Prescribing, dispensing	CPOE system that involved electronic order entry with decision support and electronic documentation of administration of medications	Very basic process model of medication ordering process developed	Process model of the medication ordering process developed. Process model itself not used for analysis

3.1 Simulation Model Studies

Three simulation model studies (Anderson et al., 2002; Bell et al., 2007; Wong et al., 2003) were of low quality and two simulation model studies (Clancy, 2006; Dean et al., 2001) were of medium quality. Details of quality, interventions, outcomes, and results for each simulation model study are found in Table 2.

All five simulation model studies used a simulation model as a tool to estimate the impact that implementing an e-prescribing system would have on one or more variables that were of interest to help support the development of a *de novo* model. The models predicted that implementing e-prescribing systems would have a positive, negative, or no impact on the variables. The results from each study are discussed below according to variables related to workflow efficiency and patient important outcomes.

3.1.1 Workflow Efficiency

Three simulation model studies (Bell et al., 2007; Clancy, 2006; Wong et al., 2003) used simulation models to measure process times. Wong et al. (2003) predicted that the turnaround time from when a medication is ordered to its delivery to the wards would decrease by approximately 50% after implementing the proposed CPOE system. Bell et al. (2007) predicted that implementing 3 different e-prescribing system features would either (a) increase process times for the prescriber (this was for the formulary and benefit feature, which displays formulary information at the time of prescribing), (b) have a minimal effect on process times for healthcare providers and pharmacists (this was for the medication history feature, which displays the history of medications filled and allows

for safety alerts), or (c) decrease process times for prescribers and other staff (this was for the electronic prior authorization feature, which allows for requests regarding the approval of a prescription's coverage by a health plan to be completed online). Clancy (2006) predicted that (a) work time for physicians would increase by 87.8% and work time for nurses and pharmacists would decrease significantly after implementing a CPOE e-prescribing system with guidelines, and (b) work time for physicians would increase by 136.4% and work time for nurses would decrease after implementing CPOE without embedded guidelines.

Anderson et al. (2002) estimated that the number of additional days of hospitalization and associated costs would either decrease (for the comprehensive, completely electronic system) or remain about the same (for the other 2 CPOE interventions). Bell et al. (2007) predicted that the number of call backs from pharmacists to prescribers for clarification or issues with a prescription would be reduced after implementing the formulary and benefit, medication history, and electronic prior authorization features.

3.1.2 Patient Important Outcomes

Four simulation model studies (Anderson et al., 2002; Clancy, 2006; Dean et al., 2001; Wong et al., 2003) used simulation models to measure surrogates of patient outcomes, such as the number of medications, errors, and ADEs. Clancy (2006) predicted that the number of medications administered annually would be reduced by almost half after implementing a CPOE system with imbedded guidelines, as the embedded guidelines only allowed for a certain number of prescriptions to be prescribed and, if

exceeded, would require a consultation with a specialist. Dean et al. (2001) predicted that introducing e-prescribing would reduce by more than two thirds the unavailability-related medication error (U-MAE) rate (defined in Table 1); however, the authors did not detail how this reduction in error rate would take place and only mentioned that the system would allow for a real-time data link to the pharmacy. Wong et al. (2003) predicted that after implementing a CPOE system there would be a reduction in failures that occur when medications are not delivered to the ward on time or not administered in time (referred to as pharmacokinetic and 'tight' failures by Wong et al.). This reduction in failures was predicted because the proposed CPOE system would streamline the medication ordering process, which would result in fewer steps, and would eliminate problems such as illegibility of medication orders, which would result in fewer call backs to physicians by pharmacists. Overall, this was predicted to result in a reduction in the time it takes to deliver medications to wards and administer medications. Anderson et al. (2002) predicted that medication errors and ADEs would decrease after implementing only 1 of the 3 e-prescribing interventions - the comprehensive, completely electronic system – as this proposed system would detect as well as prevent errors and ADEs by providing the prescriber with patient and medication history at the time of prescribing, allowing for direct order entry, and performing drug checks.

Table 2. Details of Simulation Model Studies

Study, Method of Assessing Outcome Measure	Quality of the Study		Model Specific Results	
	Quality Score	**Comment**	**Baseline Values**	**Simulation Predictions**
Simulation Studies				
Anderson (2002) (Anderson et al., 2002) Simulation Model Output	Total Score: 1 a) Validation score 0 b) Data score 1 c) Sensitivity analysis score 0 d) Prediction score 0	-not reported -baseline data: estimated from study, obtained from quality assurance records, obtained by reviewing medications ordered in a HIS over a 12 week period - days of hospitalization and costs obtained from results of 2 studies - error rates obtained from literature -sensitivity analysis was not performed before the model was used -not reported	Intervention 'a' performed the best: - total medication error rates 41.6 per 1000 at baseline - ADE rate 3.3 to 10.8 per 1000 at baseline - additional days of hospitalization 1400 to 4654 at baseline - additional hospital costs $1,652,000 to $5,490,000 at baseline	- estimated to decrease to 30.7 per 1000 orders - estimated to decrease to between 2.4 to 7.9 per 1000 - estimated to decrease to a range of 1060 to 3428 - estimated to decrease to a range of $1,251,000 to $4,044,000

Study, Method of Assessing Outcome Measure	Quality of the Study		Model Specific Results	
	Quality Score	**Comment**	**Baseline Values**	**Simulation Predictions**
Bell (2007) (Bell et al., 2007) Simulation Model Output	Total Score 1 a) Validation score 1 b) Data score 0 c) Sensitivity analysis score 0 d) Prediction score 0	 -expert panel reviewed the model -data was estimated for an average prescription -not reported -not reported	(a) formulary & benefit feature: - baseline call back rate from pharmacists to physicians 3.3 per 100 new prescriptions and 1.7 per 100 renewals (b) medication history feature (c) electronic prior authorization feature: - baseline call backs 3	 - estimated to decrease call backs to 2.2 per 100 new prescriptions and 1.1 per 100 renewals - require an average of 5% more prescriber time - estimated to reduce call backs by 0.1 to 0.2 per 100 prescriptions - result in less than 1% time savings for healthcare providers and pharmacists - estimated to reduce call backs to 1 - reduce by half the time spent by prescribers & staff in completing Prior Authorization - 4% time savings for prescribers, 35% time savings for staff per 100 new prescriptions - 2% time savings for prescribers, 38% time savings overall for staff per 100 renewals

Study, Method of Assessing Outcome Measure	Quality of the Study		Model Specific Results	
	Quality Score	**Comment**	**Baseline Values**	**Simulation Predictions**
Clancy (2006) (Clancy, 2006) Simulation Model Output	Total Score 2 a) Validation score 1 b) Data score 1 c) Sensitivity analysis score 0 d) Prediction score 0	-sample data from a different population of patients was run through the model and then the simulation output was compared to the original population of patients. Model outputs were very similar for the variables in both populations -face validity -the median number of treatments ordered by a sample of physicians was used -data from a previous time and motion study -post EHR times were estimated -not reported -not reported	CPOE with embedded guidelines: - baseline number of medications administered annually 29,100 - baseline pharmacy work time 1164 hours annually - baseline nurse work time 8374.28 hours annually - baseline physician work time 207.05 hours annually CPOE without embedded guidelines: - baseline physician work time 207.05 hours - baseline pharmacy work time 1164 hours annually - baseline nurse work time 8374.28 hours annually	- estimated to reduce number of medications administered to 15,729 - estimated to reduce pharmacy work time to 632.85 hours annually - estimated to reduce nurse work time to 5892.01 hours annually - estimated to increase physician work time to 388.747 hours annually - estimated to increase physician work time to 489.47 hours annually - no mention of changes to pharmacy work time - estimated to reduce nurse work time to 7226.802 hours annually

Study, Method of Assessing Outcome Measure	Quality of the Study		Model Specific Results	
	Quality Score	**Comment**	**Baseline Values**	**Simulation Predictions**
Dean (2001) (Dean et al., 2001) Observation, Simulation model output	Total Score 3 a) Validation score 1 b) Data score 1 c) Sensitivity analysis score 1 d) Prediction score 0	 -parts of model simulated under simpler conditions and expected output calculated by hand -face validity of model assumptions performed by 2 experienced pharmacists - reviewing records on wards -observation -survey -performed in two stages -not reported	Baseline U-MAE rate: 2.1% for surgical wards and 2.7% for medical wards	- implementing e-prescribing estimated to decrease U-MAE rate to ~1.3% for surgical wards and ~1.8% for medical wards
Wong (2003) (Wong et al., 2003) Simulation model output	Total Score 1 a) Validation score 0 b) Data Score 1 c) Sensitivity analysis score 0 d) Prediction score 0	 -not reported -detailed process data collected by observation -one month of data collected from pharmacy -not reported -not reported	CPOE system: - baseline average total turnaround time 257 minutes (observed time) - baseline % average pharmacokinetic failures 14.5% (observed value) - baseline % average 'tight' failures 57% (observed value)	- estimated to reduce the turnaround time to 122.6 minutes - estimated to be reduced to 5.7% - estimated to be reduced to 14.5%

3.2 Process Model Studies

Two process model studies (Abrams & Carr, 2005; Zamora et al., 2006) were of low quality and one (Nickerson et al., 2008) was of medium quality. Details of quality, interventions, outcomes, and results for each study are found in Table 3. While all 3 process model studies developed workflow diagrams of Canadian medication management systems, the extent to which these diagrams were actually used varied between the studies. The results of these studies are discussed according to the extent to which the workflow diagrams were used for analysis.

3.2.1 Models used to map out, analyze, and improve processes

One study (Nickerson et al., 2008) used a workflow diagram to not only map out the processes in medication management, but also to analyze and suggest improvements to the processes. Nickerson et al. (2008) used a focus group approach consisting of a physician, nurse, practical nurse, ward clerk, and a director of pharmacy to identify areas where the medication ordering process could fail. First, all the processes involved in the inpatient medication ordering process for a medical unit of a hospital were mapped out using a process model. Then, using the workflow diagram, the focus group brainstormed key areas where failures occurred. The causes and effects of those failures were then identified and potential solutions were suggested by the group. Investing in information technology, in general, was suggested to solve many of the problems identified.

3.2.2 Models used for mapping out processes only

Two studies (Abrams & Carr, 2005; Zamora et al., 2006) used process models to only map out (i.e. graphically display) the processes of medication management and did not use the diagrams further. Abrams and Carr (2005) described in their study the effects that implementing a CPOE system had on the workflow of healthcare providers at a teaching hospital in Toronto, Canada. Two workflow diagrams were developed showing workflow before and after implementing the system. They do not appear to have used these models for anything other than to show how the processes changed after implementing CPOE. Zamora et al. (2006) developed a simple representation of the medication ordering process at a hospital in Toronto, Canada, using a process model. They identified metrics and indicators that would best demonstrate the impact of implementing the CPOE system and collected data for these indicators. They found several benefits from the implementation of the electronic system. There is no indication in this study if the workflow diagram itself was used after it was developed.

Table 3. Details of Process Model Studies

Study, Method of Assessing Outcome Measure	Quality of the Study		Model Specific Results
	Quality Score	Comment	
Process Model Studies			
Nickerson (2008) (Nickerson et al., 2008) Physical measurement, focus group	Total Score 1 a)Validation Score 0 b) Flexibility Score 1	 -not reported - Workarounds built into model (i.e. in the event the pharmacy is closed)	- 78 potential failure modes were identified with scores varying from 2% to 80% in importance - analysis discovered: (a) communication issues between individuals and also departments (b) adherence to policies was not consistent (c) investing in IT hypothesized to help solve many of the problems (d) general continuous quality improvement activities suggested
Abrams (2005) (Abrams & Carr, 2005) N/A	Total Score 0 a)Validation Score 0 b) Flexibility score 0	 -not reported - workarounds not built into models	N/A
Zamora (2006) (Zamora et al., 2006) N/A	Total Score 0 a) Validation Score 0 b) Flexibility score 0	 -not reported - workarounds not built into model	N/A

4. DISCUSSION

Since there seems to be no previous review that examined the extent to which simulation modeling and process modeling have been used to improve medication management systems, including informing the design of an e-prescribing system from a Canadian perspective, we believe that the findings of this review are an important contribution to the literature. Our review found that other researchers have developed simulation models of e-prescribing/CPOE systems with medication ordering and have attempted to use these models to estimate changes to process times for healthcare providers and/or changes to patient important outcomes, such as ADEs. Some of these models predicted positive results, such as a decrease in errors, while others predicted negative results, such as an increase in process times. All simulation models included in this review, however, were judged to be of low or medium quality; there was no indication that the models actually influenced or resulted in a change to the design of an actual e-prescribing/CPOE system.

Our review also found that three studies have developed process models or workflow diagrams of Canadian medication management systems; however, we only found one of these studies for certain attempted to use a workflow diagram as a tool to analyze and improve the processes in the medication management system (Nickerson et al., 2008). This suggests that process modeling can be used to analyze Canadian medication management systems. All workflow diagrams included in this review were judged to be of low or medium quality. How these workflow diagrams actually influenced or improved the design of an actual medication management system remains

uncertain as implementation was not discussed, although there are indications that some recommendations from the Nickerson et al. study may have been implemented.

There are some limitations to this systematic review. The first level of screening by title was performed by only one screener. We chose to make the search strategy very broad due to the fact that many terms were used to refer to medication management, simulation modeling, and process modeling. This resulted in a larger number of records being found than expected and most of these were totally irrelevant. Due to limited resources, we could not perform duplicate screening at the first stage and we could not perform full duplicate screening at the other stages of screening. Instead, a second reviewer screened a small sample of abstracts and full texts in retrospect. We only searched for studies published in the English language. We were only able to judge the models and their quality based on what was reported in the studies, so we were not able to actually evaluate the models themselves if they were not included in the studies. For some of the models, it was not clear if the transmission stage, in particular, was actually simulated or modeled. In these cases, we made the assumption that this stage was included, even though, in reality, it may not have been included.

Our review has found that simulation models have been used to predict the impact of implementing new e-prescribing systems or making changes to existing systems; however, the accuracy of these models and their predictions is not known, as none of the studies reported if model predictions were validated by being compared to the actual system. We also have no information on whether the results from these simulation model studies actually influenced the development of a new e-prescribing system or influenced

modifications to an existing system. This is a significant flaw in modeling and it has been noted before. A systematic review of 31 computer simulation models of operating rooms, emergency rooms, outpatient departments, inpatient departments, intensive care, and laboratory found that few of these studies reported the outcomes of implementing the results from the simulation models, making it difficult to determine the utility of these models (van Sambeek et al., 2010). Another systematic review examining the quality of simulation model studies in healthcare found that reporting of outcomes was of such poor quality that the value of the simulation modeling could not be determined (Fone et al., 2003). We have come to a similar conclusion that even though simulation models may have been developed and used to predict the impact of e-prescribing, the utility of these models has not been established as we have no information on the accuracy of these models or their predictions. Further research is needed to prove the utility of e-prescribing simulation models.

The outputs of simulations are only as good as the data inputs and logic used to build the simulation models. We found that some studies relied on observation to collect data; some studies conducted actual studies to obtain data, while others simply estimated data values. Some of these data sources, such as estimated data, are of low quality. If low quality data are being inputted into the simulation model, one cannot expect to receive accurate output or predictions. To increase confidence in the predictions of simulation models, they need to be thoroughly tested and validated before they are used. Only 3 of the simulation model studies reported validation of the models before they were used. This is a problem that has been found for other simulation models in the health field. The

systematic review previously mentioned found that only 4 of the 31 computer simulation models had been validated prior to implementation (van Sambeek et al., 2010). Furthermore, there seems to be some selective outcome reporting bias and publication bias, as some of the simulation model studies included in our review did not discuss where the models performed badly.

As for workflow diagrams, although they may be commonly used in the healthcare setting, it may be that very few are published in the health services literature. We found that there is evidence for at least one workflow diagram being used as a tool for analysis of the medication management process in Canada; however, we found no evidence that workflow diagrams have had any positive impact on the development of e-prescribing systems in Canada.

5. CONCLUSION

Simulation modeling and process modeling have both been used as tools to analyze medication management systems, however we found no evidence that the models have benefited medication management or e-prescribing development. Validation of models appears to be a key step for them to be useful.

CHAPTER 3: DEVELOPING AND VALIDATING A WORKFLOW DIAGRAM TO INFORM THE DESIGN OF AN E-PRESCRIBING SYSTEM

ABSTRACT

Background: Our systematic review revealed that three workflow diagrams of Canadian medication management processes have been developed; however, how they have been used to inform the design of e-prescribing systems is unclear. Developing a workflow diagram may be of value in informing the design of an e-prescribing system for Canada.

Objectives: To build and establish face validity for a workflow diagram of the current medication management process in Canada to prepare for e-prescribing.

Methods: We developed a workflow diagram of the paper-based medication management system based on the expertise of members of the research team using iterative review and discussion. We then obtained feedback from 15 stakeholders regarding perceived accuracy, processes most associated with inefficiencies or patient safety problems, and processes most likely to be improved by e-prescribing.

Results: Fifteen stakeholders (5 physicians, 5 pharmacists, and 5 members of the public) participated in the study. All stakeholders at least agreed, with 9 of 15 (60.0%) strongly agreeing that the workflow diagram was a realistic representation of the current medication management process, suggesting face validity. The primary processes perceived by stakeholders as being problematic were generating the prescription by the

physician (9/15 (60.0%)) and drug checking by the physician (6/15 (40.0%)). Stakeholders also perceived these two problematic processes to be the main processes likely to be improved by information technology.

Conclusions: A workflow diagram can be used to clearly elucidate the steps in current handwritten prescribing systems, which may assist in developing e-prescribing systems. Stakeholders suggested that drug checking and generating the prescription by the physician might be improved by e-prescribing.

1. INTRODUCTION

The paper-based drug prescribing, transmission, dispensing, counseling, and monitoring process, or medication management process (Bell et al., 2004), has come under much scrutiny over the years, especially since the release of the oft cited report *To Err is Human* over a decade ago (Kohn et al., 1999). This report highlighted the incidence and impact of medication errors and adverse drug events (ADEs) occurring at different stages in the medication management process.

A systematic review examining the types of medication errors that cause preventable adverse drug events (pADEs) in ambulatory care found that 64.7% of the reported pADEs and 56.0% of the pADEs that cause hospital admission originated from errors in the prescribing phase (Thomsen et al., 2007). These errors consisted of inadequate access to complete patient records, prescribing wrong drugs or those that are contraindicated, and selecting inappropriate doses (Thomsen et al., 2007). Research on studies in medication management has found that physicians are studied substantially more than any other healthcare provider, such as pharmacists (McKibbon et al., 2011), which may be why there is a focus on preventing errors at the prescribing phase.

Because of the errors and ADEs associated with the various phases of the paper-based medication management process, electronic prescribing (e-prescribing) has been proposed as a solution to eliminate or reduce these errors (Aspden et al., 2007). An e-prescribing system would allow for the medication management process to be made electronic (Cusack, 2008).

Canada Health Infoway (CHI) is helping fund the development of an e-prescribing system for Canada (Canada Health Infoway, 2010); however, CHI has been criticized by informatics and clinical experts for failing to develop, fund or work with healthcare professionals on clinically relevant projects that might accelerate e-prescribing or a national EHR (Webster & Kondro, 2011).

One of the major barriers to e-prescribing is the lack of adoption of basic electronic medical record (EMRs) systems by physicians in Canada (Silversides, 2010). For the medication management process to be made electronic, physicians need to be comfortable with prescribing electronically. Only 16% of physicians across Canada exclusively use EMRs, while 34% use a combination of paper records and EMRs (Biro et al., 2012). This is an indication that some prescriptions are being generated electronically; however, the majority is still written by hand. Studies of successful EMR implementations have found that when physicians with e-health expertise champion a project, it often leads to successful implementation (Keshavjee et al., 2001; Ludwick & Doucette, 2009). This may also be the case for e-prescribing when users champion the system. Physicians, along with the many other stakeholders involved, including pharmacists, pharmacy corporations, nurses, other healthcare workers, patients, and vendors need to have their major requirements and concerns addressed before an e-prescribing system can be successful. Some of this work in the context of e-prescribing systems has been done by other researchers, such as Bell et al. (2007) with RAND, who used stakeholder feedback to evaluate proposed features of an outpatient e-prescribing system. This research, however, was conducted for e-prescribing systems in the United

States. Another major issue for e-prescribing is the lack of evidence of important clinical benefit. A systematic review examining the effectiveness of information technology in medication management found that the evidence suggests little to no improvement in clinical outcomes after implementing these technologies (McKibbon et al., 2011). In addition to this, current systems have produced harm in the form of several types of unintended errors, including increased mortality, and faulty design (McKibbon et al., 2011; Campbell et al., 2006). Because the unintended consequences of e-prescribing systems are almost always found after the systems are implemented (McKibbon et al., 2011), it may be of use to analyze workflow patterns before implementing an e-prescribing system (Johnson & FitzHenry, 2006).

Process modeling, or workflow modeling, is a method that is used to visually represent the operations of a system (Bandara, 2005). Process modeling allows for activities, entities, and the relationships between them to be visually represented (Bandara, 2005). Other researchers, such as Bell et al. and Johnson & FitzHenry have developed and used workflow diagrams to analyze the medication management process and evaluate (Bell et al., 2004) or potentially inform the design (Johnson & FitzHenry, 2006) of e-prescribing systems. Aside from representing and clarifying current workflows, a workflow diagram of Canadian medication management in the community could help clarify the shortcomings in the handwritten process and where technology might help.

Our systematic review of the literature (Chapter 2) identified three studies that developed workflow diagrams or process models of Canadian medication management

systems (Abrams & Carr, 2005; Zamora et al., 2006; Nickerson et al., 2008). Only one of these studies (Nickerson et al., 2008) used their diagram to analyze processes and this was in an inpatient setting. No study appears to have evaluated input from the much larger community medication management environment in Canada.

OBJECTIVES

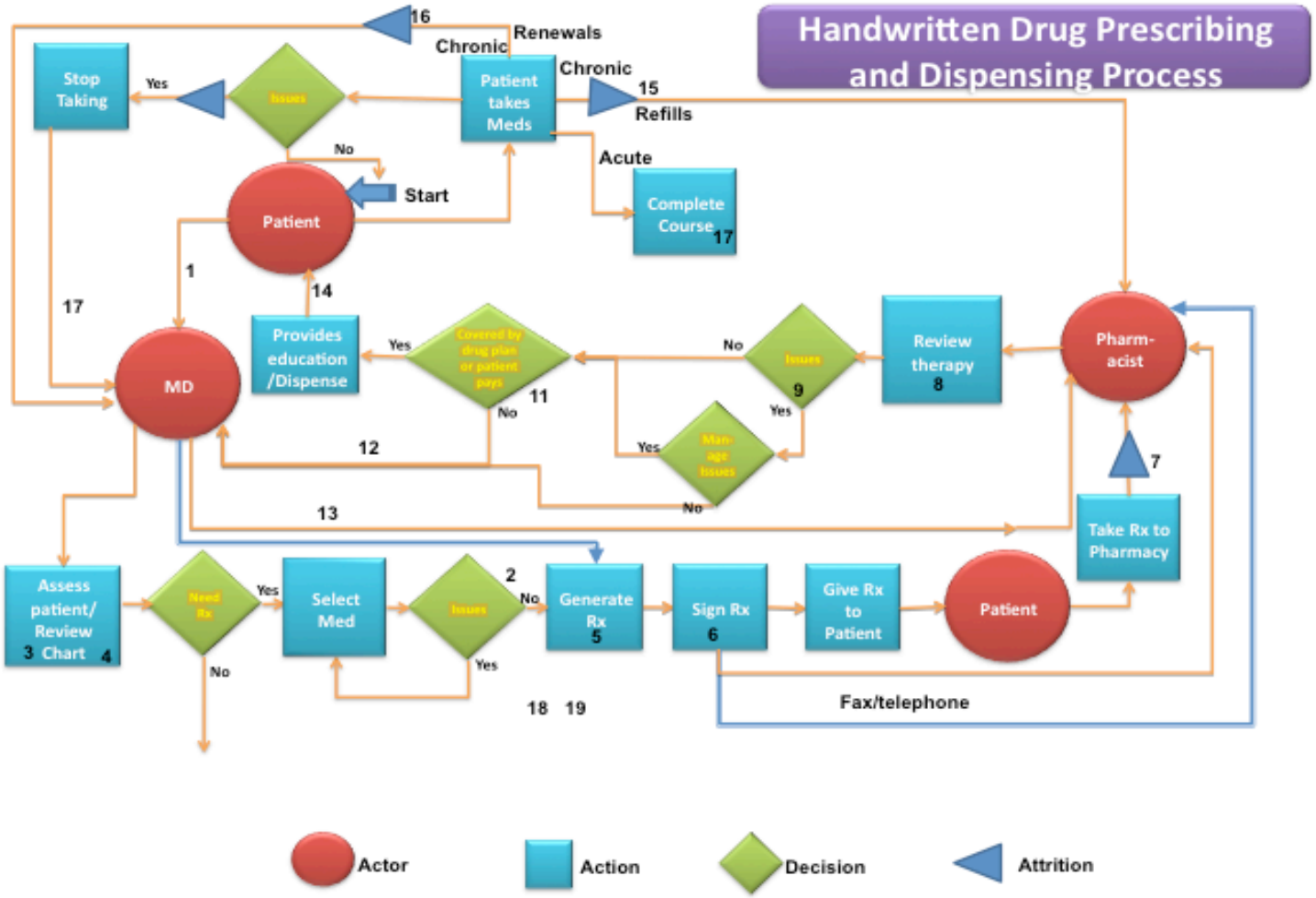
To build a workflow diagram that accurately depicts the processes involved in the handwritten medication management process for the community setting, validate this diagram, and then use it to obtain feedback from key stakeholder groups as to the shortcomings in this process and where technology might help.

2. METHODS

2.1 DEVELOPING THE WORKFLOW DIAGRAM

We aimed to develop a workflow diagram that encompassed the prescribing, transmission, dispensing, and monitoring phases of the handwritten medication management process, as this is the most common form of prescribing in Canada. Team members with expertise in e-health, clinical pharmacology, family medicine, internal medicine, health policy, and research methods, developed the initial diagram by iterative review and discussion using PowerPoint. Figure 1 displays the initial workflow diagram.

Figure 1. Initial Workflow Diagram



While PowerPoint was suitable for the initial development of the diagram, we decided it was more appropriate to use software that was designed to build models. We also wanted to use software that had simulation capabilities, as we deemed this important for future work. Two members of the research team (AG and KK) formally evaluated 10 modeling software systems using the following criteria: ease of use, capabilities and features of the software, access to resources and training, and cost. Table 1 displays the results of the evaluation. Arena (Rockwell Automation, Inc., Pittsburgh, PA) was selected as the modeling software to build our process model. Arena allowed for better model transparency and therefore useful feedback from stakeholders.

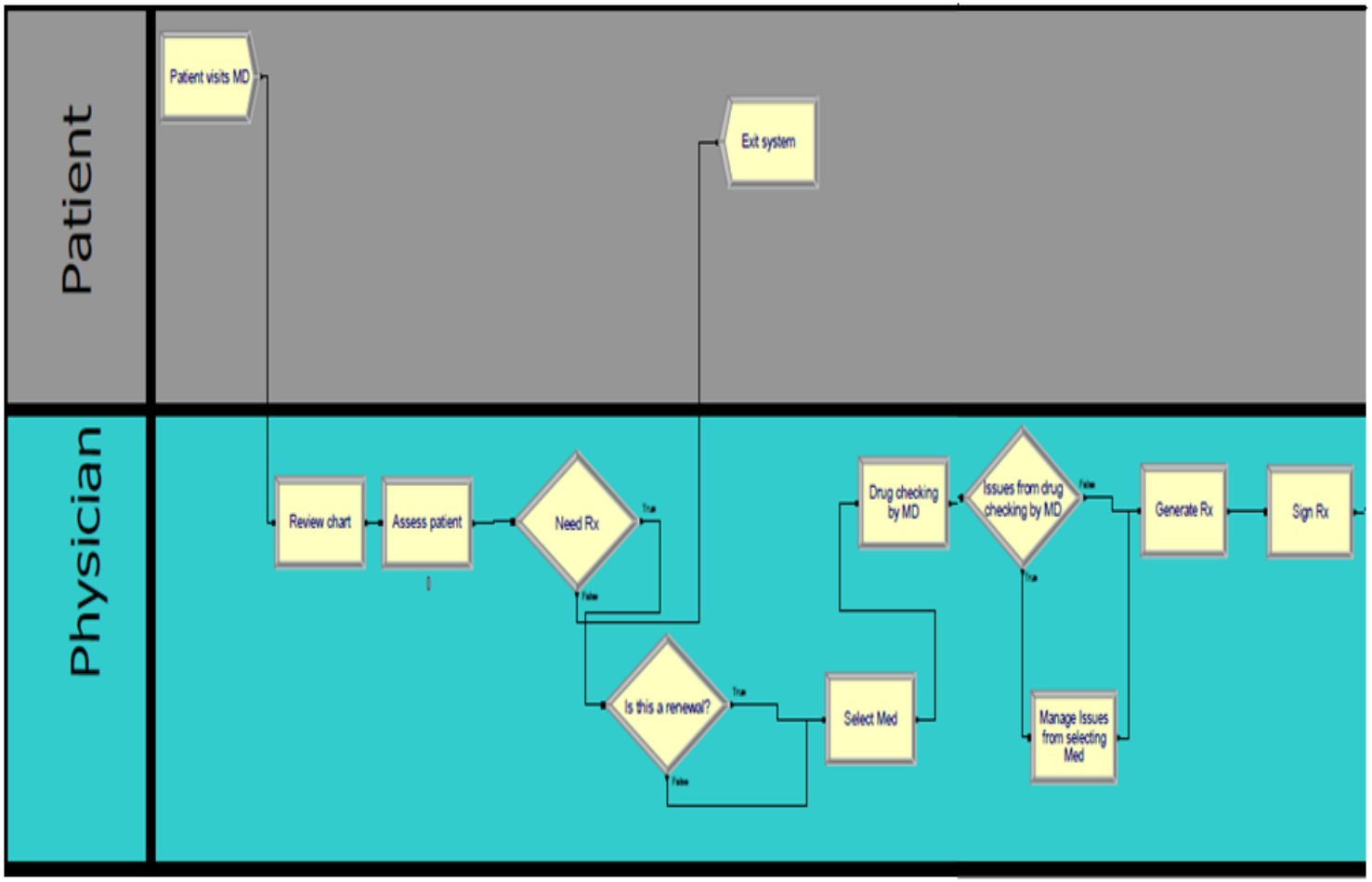
Table 1. Results of Evaluation of Modeling Software

	Process Model			ExtendSim			Arena			GoldSim		
Evaluation Criteria	**EV 1**	**EV 2**	**Consensus**	**EV 1**	**EV 2**	**Consensus**	**EV 1**	**EV 2**	**Consensus**	**EV 1**	**EV 2**	**Consensus**
Ease of Use: Navigation	3	3	3	2	3	2	3	2	3	2	2	2
Ease of Use: Entering flow diagram	1	1	1	1	1	1	1	1	1	0	0	0
Transparency	1	1	1	1	1	1	1	1	1	1	0	0
Flexibility (y/n)	0	0	0	1	1	1	1	1	1	1	1	1
Previous use in e-prescribing (y/n)	0	0	0	0	0	0	1	1	1	0	0	0
Training in Building Models	3	2	2	3	2	3	3	2	3	3	2	3
Monte Carlo Simulations	0	0	0	1	1	1	0	0	0	1	1	1
Literature Base	2	1	1	2	3	2	3	2	3	3	2	3
Access to Textbooks	0	2	1	3	2	3	3	2	3	0	0	0
Access to Other Resources	2	1	1	3	3	3	3	2	3	3	2	3
Output Report Easily Understandable	1	1	1	1	1	1	0	1	0	1	1	1
Depth of Output Report	3	1	1	3	3	3	3	3	3	3	2	3
Demo Models Provided	3	1	3	3	3	3	3	2	3	3	2	2
Animation	1	1	1	1	1	1	1	1	1	0	1	0
Quality of Graphics	3	3	3	2	2	2	2	2	2	1	2	1
Graphic Library	3	2	3	2	2	2	3	2	3	1	2	1
Output Data Analysis	2	1	1	3	3	3	2	2	2	2	2	2
Price (Commercial)			$3,964			$987, $1781 , $2475			$1,880			$3,919
Price (Academic)	$35 Stud		$590 Prof	491		$888, $1239			Free			Free, $943(research)
TOTAL	**28**	**21**	**23**	**32**	**32**	**32**	**33**	**27**	**33**	**25**	**22**	**23**

EV1 - results from the first evaluator, EV2 - results from the second evaluator, Consensus - results from the consensus between the two evaluators. Scale: 0 = feature does not exist, 1 = poor, 2 = fair, and 3 = good/excellent. For each modeling tool the price varied depending on (1) if it was going to be used for commercial or academic use, and (2) the modeling features available. All prices were converted from U.S. Dollars to Canadian Dollars using the exchange rate on February 19, 2012 and were rounded to the nearest dollar.

The workflow diagram was rebuilt from PowerPoint in Arena using a transition to a standard language for modeling business processes known as Business Process Modeling Notation (BPMN) (zur Muehlen & Recker, 2008). One of the advantages of BPMN is the use of 'swim lanes' to group processes into distinct categories for different responsibilities (zur Muehlen & Recker, 2008). These swim lanes were useful to separate the different processes according to the user performing the process. Once the diagram was built in Arena, team members, a pharmacist, and two individuals with an information technology/modeling background reviewed the model for accuracy and completeness. The workflow diagram is displayed in Figures 2-4 according to the phases of medication management. Definitions of the processes can be found in Appendix 5.

Figure 2. Workflow Diagram – Prescribing



2.2 STAKEHOLDER FEEDBACK ON THE WORKFLOW DIAGRAM

2.2.1 Stakeholder Representatives

The participants in this study were all stakeholder representatives - individuals who had some involvement in the outpatient (community-based) medication management process in Canada. They comprised three groups: physicians, pharmacists, and members of the public (or select others). A convenience sample of stakeholders was recruited from Ontario.

2.2.2 Data Collection

The study used semi-structured interviews with stakeholder representatives to obtain feedback on the medication management process. The feedback process was guided by a questionnaire (displayed in Table 2), which required stakeholders to use the workflow diagram to answer the questions and to talk out loud while providing feedback. The questionnaire was developed by members of the research team and was designed to obtain quantitative and qualitative feedback on 3 key areas: (1) the validity of the workflow model itself (i.e. at face value, those who have knowledge of the community-based medication management process believe that the workflow diagram appears to be an accurate representation of the actual process), (2) the problems in the existing handwritten process, and (3) where information technology might be helpful.

Research ethics approval was obtained from McMaster University's Research Ethics Board (Hamilton, ON) (project # 09-470-S). After signing informed consent, each participant was interviewed individually by one investigator (AG), and each interview

was audio recorded. Participants were first presented with a print version of the workflow diagram that is depicted in Figures 2,3 and 4. They were given time to review the workflow diagram and were then presented with the questionnaire to guide them through the feedback process.

Table 2. Questions for Stakeholder Feedback on the Workflow Diagram

1.a)	This flow diagram illustrates a realistic/believable representation of the actual handwritten drug prescribing and dispensing process in Canada 1 Strongly Disagree 2 Disagree 3 Undecided 4 Agree 5 Strongly Agree
b)	If your answer to (a) is less than 5, discuss what could be done to make the flow diagram a more realistic/believable representation of the actual handwritten drug prescribing and dispensing system in Canada
2.	Where are problems most common in the handwritten drug prescribing and dispensing process? Note: A "problem" is a part of the process that is inefficient or where errors occur. (Please circle the problem points with the red pen and discuss your answers out loud).
3.	Of the problem points circled in question 2, which are the ones that are most likely to cause harm to patients? (Please circle the problem points with the blue pen and discuss your answers out loud)
4.	Of the problem points circled in question 2, which are the ones that are most likely to be fixable? (Please circle the fixable problem points with the green pen and discuss your answers out loud)
5.	Where can computers/information technology help in the prescribing and dispensing process in terms of reducing harm to patients? (Please underline the process(es) with the black pen and discuss your answers out loud)
6.	Where can computers/information technology help in the prescribing and dispensing process in terms of increasing efficiency? (Please underline the process(es) with the red pen and discuss your answers out loud)
7.	Where can computers/information technology help in the prescribing and dispensing process in terms of reducing harm to patients AND increasing efficiency? (Please underline the process(es) with the green pen and discuss your answers out loud)

Figure 3. Workflow Diagram – Transmission and Dispensing

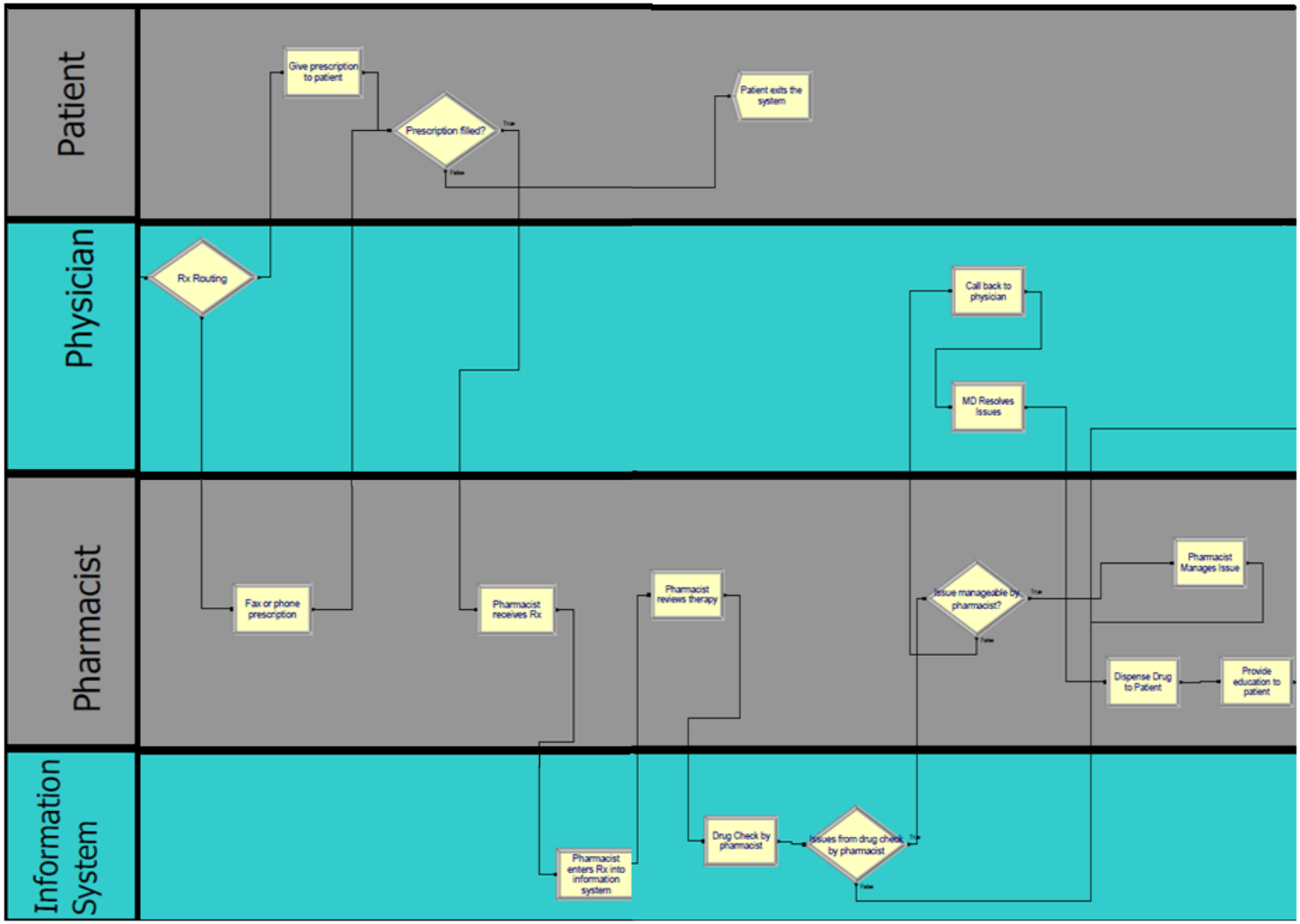
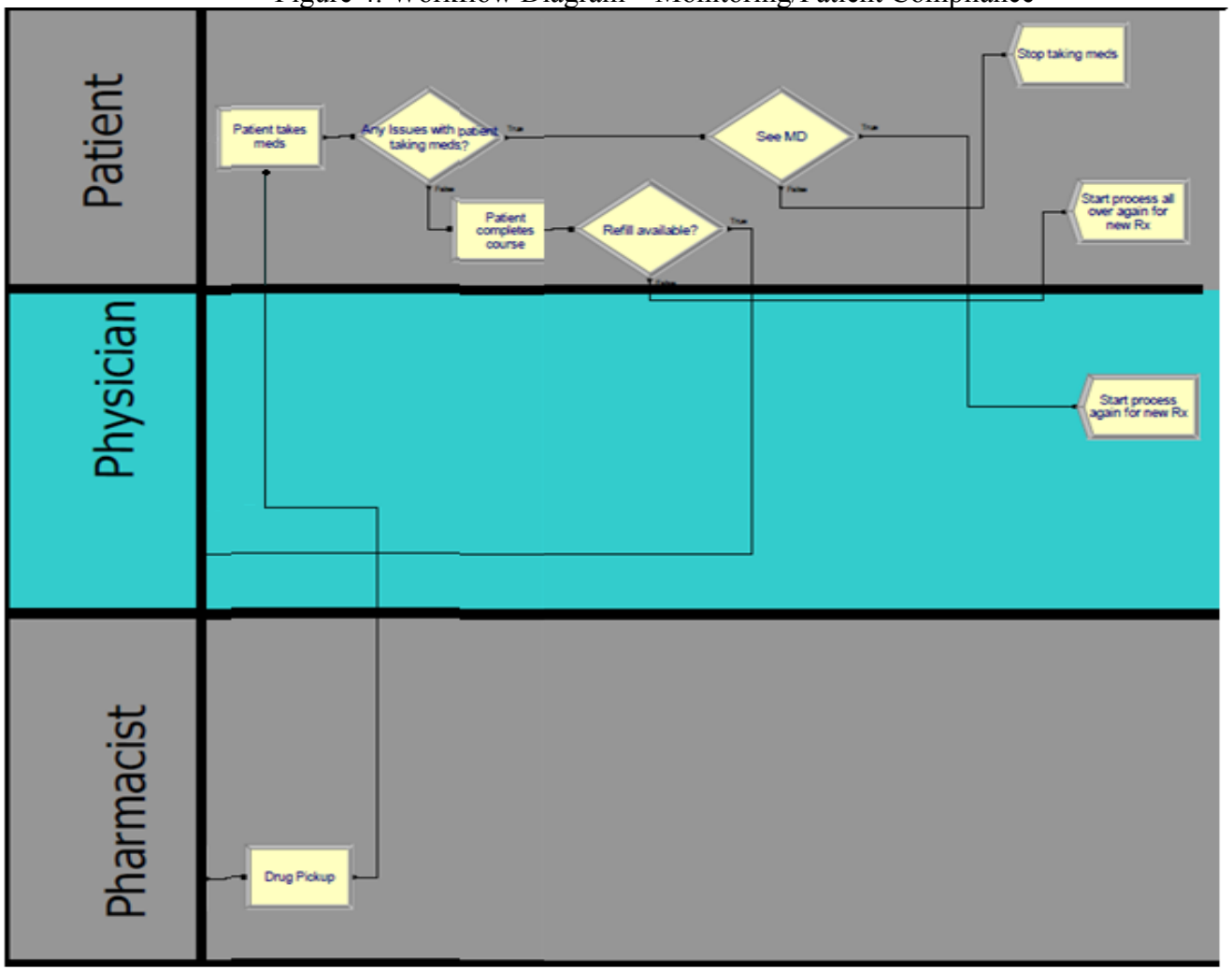


Figure 4. Workflow Diagram – Monitoring/Patient Compliance



Participants were provided with coloured markers to circle or underline (i.e. rate) processes on the workflow diagram, as these ratings were to be tabulated when analyzing stakeholder feedback. The first section of the questionnaire was a Likert scale statement that asked participants to rate their perceived accuracy of the diagram. The next section focused on identifying the problems in the paper-based medication management process, including those most likely to harm patients and those most likely to be fixable. A problem, as we defined it, was a part of the process that was inefficient or where errors occurred. The final section focused on identifying where information technology (IT) (i.e. computers or electronics) could help in the paper-based medication management process to reduce harm to patients and/or increase efficiency. Stakeholders could rate multiple processes for *each* question, but for "most likely to harm" and "most likely to be fixable", stakeholders could only rate processes if they had previously rated these processes as "problem processes".

2.2.3 Data Analysis

The ratings of the workflow diagram were categorized according to stakeholder group and tabulated. The audio recordings of interviews were analyzed for content and the verbalizations (or qualitative comments) of stakeholders were coded by AG. Qualitative comments were categorized according to stakeholder group and tabulated. Participant privacy was ensured by erasing audio recordings of interviews once they were analyzed for content, and by removing any identifiers from the content used.

3. RESULTS

3.1 STAKEHOLDERS

A total of 15 stakeholder representatives participated from June to September of 2011, including 5 physicians (2 with existing paper-based system, 3 using an EMR to prescribe; 4 family physicians, 1 specialist), 5 community pharmacists (2 using Kroll software (by Kroll Computer Systems Inc., Toronto), 2 using Nexxsys (by ProPharm Limited, Markham), and 1 using Healthwatch Next Generation (by Shoppers Drug Mart Corporation, Toronto)), and 5 others, including 3 lay public, one Chief Information Officer (CIO) for a community hospital, and a representative of a Canadian pharmacy information system vendor.

3.2 RATINGS OF WORKFLOW DIAGRAM AND QUALITATIVE COMMENTS OF STAKEHOLDERS

Ratings of the workflow diagram (i.e. processes that were circled or underlined by stakeholders) are displayed in Table 3. Process ratings are displayed according to each stakeholder group as well as the total group of stakeholders. The definitions of these processes are in Appendix 5. For the results from questions 2 through 7, we focus on those processes rated by the majority of each stakeholder group (3 or more of each group of 5) and those processes rated by 5 or more of the total group of 15 stakeholders. The qualitative comments of stakeholders were the result of open-ended questions. This resulted in much variation in the verbal feedback we received. As a result, we only included those qualitative comments where 5 (minimum 1/3 of respondents) or more of the group of 15 had stated a point. The last question posed to stakeholders as to where IT could help reduce harm to

patients AND increase efficiency caused confusion to stakeholders as some felt that they had already answered this question in the previous two questions, and so it was decided to not include stakeholder feedback for this question. The coded qualitative comments of stakeholders are displayed in Appendix 6. Those comments deemed most relevant and important are included as quotations in Appendix 7.

Table 3. Processes of the Medication Management Process That Stakeholders Rated

		PROBLEM POINTS				MOST LIKELY TO HARM				FIXABLE PROCESSES				WHERE I.T. CAN↓ HARM				WHERE I.T. CAN↑EFFICIENCY			
	Processes	MD	Pharm	Public	TOTAL	MD	Pharm	Public	TOTAL	MD	Pharm	Public	TOTAL	MD	Pharm	Public	TOTAL	MD	Pharm	Public	TOTAL
Prescribing	1. Patient visits MD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	2. Review chart (by MD)	2	1	2	**5**	1	1	0	2	2	0	0	2	1	0	3	4	2	0	1	3
	3. Assess patient	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	4. Need Rx?	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1
	5. Is this a renewal?	2	1	1	4	1	1	0	2	2	1	0	3	2	0	0	2	1	0	0	1
	6. Selecting Medication (by MD)	2	2	0	4	2	2	0	4	2	1	0	3	3	1	0	4	2	1	0	3
	7. Drug Checking by MD	2	1	3	**6**	1	1	3	**5**	2	1	3	**6**	4	1	3	**8**	3	1	3	**7**
	8. Issues from drug checking by MD	0	1	1	2	0	0	1	1	0	0	1	1	0	0	1	1	1	0	1	2
	9. MD managing issues from drug check	1	0	1	2	1	0	1	2	1	0	1	2	1	0	2	3	2	0	1	3
	10. Generate Rx	2	3	4	**9**	2	2	2	**6**	2	3	3	**8**	2	2	3	**7**	1	2	3	**6**
	11. Sign Rx	0	2	1	3	0	0	1	1	0	2	1	3	1	2	1	4	1	1	1	3
Transmission	12. Rx routing	1	0	0	1	0	0	0	0	1	0	0	1	1	0	1	2	2	0	2	4
	13. Fax of phone prescription	1	1	1	3	0	1	0	1	1	0	0	1	1	1	0	2	1	1	0	2
	14. Give prescription to patient	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	2
	15. Prescription filled?	2	0	3	**5**	1	0	1	2	1	0	2	3	2	0	0	2	1	0	0	1
Dispensing	16. Pharmacist receives Rx	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	2	1	0	1	2
	17. Pharmacist entering Rx into information system	2	1	1	4	2	1	0	3	2	1	0	3	2	2	0	4	2	1	1	4
	18. Pharmacist reviews therapy	1	1	2	4	1	0	0	1	0	1	1	2	1	2	0	3	2	2	0	4
	19. Drug Check by Pharmacist	0	1	1	2	0	1	0	1	0	1	0	1	0	3	1	4	3	2	1	**6**
	20. Issues from drug check by Pharmacist	2	1	1	4	1	1	0	2	1	1	0	2	0	0	0	0	2	0	0	2
	21. Issue manageable by Pharmacist?	2	0	0	2	0	0	0	0	2	0	0	2	1	0	0	1	1	0	0	1
	22. Call back to Physician	3	1	2	**6**	0	1	1	2	2	1	0	3	1	2	1	4	3	0	1	4
	23. MD resolves issues from call back	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	24. Pharmacist manages issues from drug check	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	25. Dispense drug to patient	0	1	1	2	0	1	1	2	0	1	1	2	0	0	1	1	0	0	1	1
	26. Provide education to patient (by Pharmacist)	1	0	2	3	0	0	2	2	0	0	2	2	1	0	1	2	2	0	1	3
Monitoring/Compliance	27. Drug pickup (by patient)	0	1	1	2	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
	28. Patient takes medication	3	1	1	**5**	1	0	1	2	1	1	0	2	2	1	2	**5**	0	0	1	1
	29. Any issues with patient taking medication?	1	0	2	3	0	0	1	1	0	0	0	0	1	0	2	3	0	0	0	0
	30. See MD (if any issues with taking medication)	0	0	1	1	0	0	1	1	0	0	0	0	0	0	1	1	0	0	1	1
	31. Patient stops taking meds (due to issues)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0
	32. Patient completes course	0	0	1	1	0	0	1	1	0	0	0	0	0	0	2	2	0	0	0	0
	33. Refill available?	0	0	1	1	0	0	1	1	0	0	0	0	0	1	1	2	1	1	1	3
	34. Start process again for new Rx	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

MD = physician, Pharm = pharmacist, Rx = prescription. The bolded numbers in the light grey boxes highlight the areas of consensus that were identified by 5 or more of all stakeholders for that particular category. 34 processes are included in this table (taken directly from the Workflow Diagram in Figures 2,3, and 4). See Appendix 5 for definitions of processes.

3.2.1 The Workflow Diagram Being Realistic

All 15 stakeholders agreed (n = 6) or strongly agreed (n = 9) that the workflow diagram illustrated a realistic representation of the actual handwritten drug prescribing and dispensing process in Canada. Those that selected agree instead of strongly agree gave the following main reasons:

(a) lack of familiarity with all the processes; e.g., a member of the public not being familiar with all pharmacy processes,

(b) minor disagreement with how we modeled one or more processes; e.g., a pharmacist stated that patients usually see the pharmacist first, not the physician, if they have issues with taking their medications; and

(c) diagram viewed as a template that could differ on a case by case basis; e.g., a member of the public stated that adding more disease states could change the processes.

3.2.2 Problematic Processes

In terms of processes that cause inefficiencies or errors, the processes rated by a majority (i.e. 3 or more) of each stakeholder group were as follows: physicians perceived (a) call back to physicians by the pharmacists, and (b) patients taking their medications as problematic processes; pharmacists perceived only generating the prescription (by the physician) as a problematic process; and public members perceived (a) drug checking by the physician, (b) generating the prescription (by the physician), and (c) whether or not the prescription was filled by the patient as being problematic processes.

The processes rated by 5 or more of all stakeholders are highlighted in Table 3. The top rated problematic processes were (a) generating the prescription (by the physician) (9/15 (60.0%)), (b) drug checking by the physician (6/15 (40.0%)), and (c) call back to physician (by the pharmacist) (6/15 (40.0%)).

From the qualitative comments of stakeholders we find that when stakeholders rated generating the prescription (by the physician) as a problematic process, stakeholders meant that prescriptions were illegible. We also find that by rating drug checking by the physician as a problematic process, stakeholders meant that physicians do not have a full list of medications the patient is taking.

3.2.3 Problematic Processes Most Likely To Cause Harm To Patients

There were no processes that the majority of physicians or pharmacists rated as most likely to harm patients. A majority of members of the public perceived that problems with drug checking by the physician were most likely to harm patients. The top problematic processes most likely to cause harm to patients that were rated by 5 or more of all stakeholders were (a) generating the prescription (by the physician) (6/15 (40.0%)), and (b) drug checking by the physician (5/15 (33.3%)).

Although processes such as the physician assessing the patient, the doctor giving the prescription to the patient, and the pharmacist receiving the prescription were initially selected by one or more stakeholders as being problematic processes, none of the stakeholders rated these as most likely to cause harm to patients (i.e. no stakeholder perceived these problematic processes as causing harm to patients).

From the qualitative comments of stakeholders we find that when stakeholders rated generating the prescription (by the physician), stakeholders meant that illegible prescriptions were a problem that was most likely to harm patients. An additional problematic process most likely to cause harm to patients was found from the qualitative comments of stakeholders: the physician selecting the drug or the dose for the prescription.

3.2.4 Problematic Processes Most Likely To Be Amenable To Improvement

In terms of problematic processes most likely to be fixable, the processes rated by the majority of each stakeholder group were as follows: physicians did not agree on any process; pharmacists perceived generating the prescription (by the physician) as being amenable to improvement; and members of the public perceived (a) drug checking by the physician, and (b) generating the prescription (by the physician) as being amenable to improvement. The top problematic processes rated by 5 or more of all stakeholders as being fixable were (a) generating the prescription (by the physician) (8/15 (53.3%)), and (b) drug checking by the physician (6/15 (40.0%)).

Although one or more stakeholders rated processes such as the pharmacist receiving the prescription, whether or not there are any issues with patients taking their medications, and the patient completing the course of medication as being problematic processes in the handwritten system, no stakeholder rated these as being most likely to be fixable (i.e. no stakeholder perceived these problematic processes as being amenable to improvement).

From the qualitative comments of stakeholders an additional problematic process most likely to be fixable was identified: call backs/fax to physician.

3.2.5 Information Technology (IT) Potentially Helpful In Reducing Harm

The parts of the medication management process where IT could help in reducing harm to patients rated by the majority of each stakeholder group were as follows: physicians perceived (a) drug checking by the physician, and (b) selecting medication (by the physician) as amenable to improvement by IT to help in reducing harm to patients; pharmacists only perceived drug check by pharmacist as being amenable to improvement by IT to help in reducing harm to patients; and members of the public perceived (a) review patient chart (by the physician), (b) drug checking by the physician, and (c) generating the prescription (by the physician) as being amenable to improvement by IT to help in reducing harm to patients. The processes rated by 5 or more of all stakeholders are highlighted in Table 3. The top rated processes amenable to improvement by IT to help in reducing harm to patients were (a) drug checking by the physician (8/15 (53.3%)), and (b) generating the prescription (by the physician) (7/15 (46.7%)).

Some processes, such as the physician assessing the patient, issues from drug checking by pharmacist, and the physician resolving the issues from call backs by pharmacists were not perceived by any stakeholders as amenable to improvement by IT to help in reducing harm to patients.

From the qualitative comments of stakeholders, we find that when stakeholders rated drug checking by the physician as being amenable to improvement by IT to help in reducing harm to patients, stakeholders meant that physicians would be provided with a complete list of medications the patient is taking and complete patient history.

3.2.6 Information Technology (IT) Potentially Helpful In Increasing Efficiency

The processes where IT could help to increase efficiency as rated by the majority of each stakeholder group were as follows: physicians perceived (a) drug checking by the physician, (b) drug checking by the pharmacist, and (c) call back to the physician (by the pharmacist) as amenable to improvement in efficiency through the use of IT; pharmacists did not agree on any process; and members of the public perceived (a) drug checking by the physician, and (b) generating the prescription (by the physician) as amenable to improvement in efficiency through the use of IT. The top rated processes by 5 or more of all stakeholders as being amenable to improvement in efficiency through the use of IT were (a) drug checking by the physician (7/15 (46.7%)), (b) generating the prescription (by the physician) (6/15 (40.0%)), and (c) drug check by pharmacist (6/15 (40.0%)).

Some processes such as the physician resolving issues from call backs by pharmacists, whether or not there were any issues with a patient taking their medication, and the patient stopping medication due to issues, were not perceived by any stakeholders as amenable to improvement in efficiency through the use of IT.

From the qualitative comments of stakeholders, an additional process was identified as being amenable to improvement in efficiency through the use of IT: eliminating the manual entry of prescriptions into the pharmacy information system.

4. DISCUSSION

Given the lack of workflow diagram development and validation for community-based medication management in Canada, we believe that our study is an important addition to the literature. Our 34-step workflow diagram, which mapped out 11 prescribing, 4 transmission, 11 dispensing, and 8 monitoring processes was found to be transparent and accurate by stakeholders and they were able to use it as a reference to discuss current problems with paper-based medication management and where e-prescribing might help. Validation of a diagram is an important step as assurance that the diagram accurately reflects the actual system. All stakeholders at least agreed that the workflow diagram illustrated a realistic representation of the actual handwritten drug prescribing and dispensing process in Canada, with the majority (9 of 15) strongly agreeing with this. This suggests face validity. Other workflow diagrams of Canadian medication management processes that have been developed (Abrams & Carr, 2005; Zamora et al., 2006; Nickerson et al., 2008) range from very basic (e.g., only mapping out a few processes) to detailed. The most detailed of these diagrams (Nickerson et al., 2008) was of a hospital inpatient setting that modeled only 16 processes compared to our 34, missed the entire monitoring/patient compliance phase, and did not report any validation.

Stakeholders were able to use our workflow diagram to rate processes throughout the medication management process. In terms of problematic processes, stakeholders were able to identify specific processes where they perceived errors or inefficiencies are occurring. Stakeholders were also able to identify specific problematic processes that they perceived as being most likely to cause harm to patients. The top problematic processes and

those most likely to cause harm identified by stakeholders were drug checking and generating the prescription by the physician. The perceived problems and perceived harms identified by stakeholders can be summarized into three themes: poor quality or lack of information (e.g., incomplete patient records), poor method of documentation (e.g., illegible prescriptions), and non-adherence by patients (e.g., patients not taking their medications). The perceptions of our stakeholders in terms of problems and harms were similar to what has been found in other studies (Thomsen et al., 2007; Bates et al., 1995). Besides using the workflow diagram to identify perceived problems and perceived harm, stakeholders were also able to use the diagram to identify specific problematic processes that they felt could be fixed. Finally, stakeholders were able to use the diagram to identify specific processes where they perceived IT as being helpful in either reducing harm to patients or increasing efficiency. The processes that were identified by stakeholders as being most amenable to improvement by IT to help in reducing harm to patients or increasing efficiency were drug checking and generating the prescription by the physician. The perceptions of our stakeholders as to where IT has potential value can be summarized into three themes: improving the method of documentation (i.e., when generating the prescription), providing more complete and better quality of information (e.g., complete patient records), and improving patient adherence.

There are some limitations to our study. The 15 stakeholders were all from Ontario and were under the same Provincial legislation governing medication management. As there are limited differences between the Provinces and Territories in terms of medication management, this may limit for some aspects the ability to generalize our findings across

Canada. Another limitation is that we did not include all prescribers as stakeholders. Non-physicians may have provided valuable feedback as prescribing is done by certain groups of non-physicians in Ontario. Question design may have hindered stakeholder ability to identify process areas likely to cause harm to patients and likely to be fixable, as these questions were contingent on the previous question of identifying problematic processes. Simpler terms could have been used to identify processes on the workflow diagram, as this would avoid any ambiguity. Finally, this study relied on the opinions and feedback of a small group of stakeholders, which are perceptions and may not necessarily be true.

Several implications come from our study in terms of e-prescribing development. Firstly, we have demonstrated that it is possible to use a workflow diagram as an illustrative tool to engage stakeholders from various backgrounds and bring them to a common platform for discussing e-prescribing. Stakeholders were able to provide their perceptions not only about processes that they performed, but were also able to provide feedback on processes performed by other stakeholder groups with relative ease. Secondly, we were able to map out the handwritten prescribing and dispensing system into detailed steps, which allowed stakeholders to identify actual processes rather than speak of general problems and solutions. Identifying specific processes is important when developing an e-prescribing system as it allows system developers to focus on specific areas of improvement and is more likely to address the specific concerns of each stakeholder group. Finally, this study provides preliminary identification of perceptions of stakeholders in terms of problematic processes in the current medication management process and where IT may be of benefit. Although the number of stakeholders that participated in this study was small and there was generally a

lack of consensus amongst stakeholders, two processes were consistently rated by stakeholders as the top processes for each question asked: (1) drug checking by the physician and (2) generating the prescription by the physician. Due to the small number of stakeholders involved, system developers can consider and focus attention to these two processes when it comes to examining the pathways that need to be developed for e-prescribing; however, ongoing user stakeholder involvement is required to obtain a more accurate understanding of the perceptions of stakeholders and to ensure that e-prescribing systems are useable and meet their high safety and reliability goals. Now that this diagram has been developed and validated, it can be used by system developers to better understand what changes need to be made to the current paper-based medication management system based on the feedback of larger groups of stakeholders. Focus groups with stakeholders from different groups participating in the feedback process simultaneously, including non-physician prescribers, may be of value as the different groups can understand each other's perspectives as part of the discussion and not simply resort to blaming each other for the problems found in the current system.

5. CONCLUSION

A workflow diagram can be used to better understand current processes, the steps required for a proposed system, and can be used to seek opinions of stakeholders when developing e-health initiatives. Stakeholders perceived drug checking and generating the prescription by the physician to be the top problematic processes and suggested that these could be improved by e-prescribing; however, ongoing stakeholder involvement with

larger groups of stakeholders is required to obtain a more accurate estimate of the perceptions of those involved in community-based medication management in Canada.

CHAPTER 4: DISCUSSION AND CONCLUSION

At the time of conducting the systematic review of the literature (Chapter 2), it was not known the extent to which computer simulation modeling and process modeling have improved medication management systems, including informing the design of an e-prescribing system for Canada. The systematic review revealed that simulation modeling has been used to make predictions as to how electronic prescribing systems, either existing or planned, might perform. These models were used to predict changes to task times, the number of errors, costs, and other variables. Since this review revealed that researchers are using simulation models to predict the performance of e-prescribing systems, it might seem like a viable option to test an e-prescribing system before actually developing the system. However, a major flaw found in all of these studies was that none reported whether the model predictions were validated by the actual e-prescribing systems, which makes it very difficult to assess the usefulness of these models. Furthermore, there is no information in the publications that any of these models improved or informed the design of actual e-prescribing systems. Further research examining the accuracy of these models is definitely needed to prove the utility of simulation models for e-prescribing systems.

The systematic review also revealed that process or workflow modeling is a tool that has not been widely published or potentially adequately explored for analyzing Canadian medication management processes. Only one study (Nickerson et al., 2008) actually used a workflow diagram as a tool to analyze a medication management process

in Canada. Although there is no evidence of workflow diagrams having any impact on e-prescribing development in Canada, there is evidence that workflow diagrams can be used to analyze Canadian medication management processes.

The workflow diagram that was built and then validated by stakeholders (Chapter 3) made it easy to obtain feedback from stakeholders. Stakeholders were able to pinpoint actual processes that they perceived as problematic or where e-prescribing could be of benefit. Due to the limited number of stakeholders in this study and the limited consensus concerning processes, it cannot be stated for certain that the perceptions of stakeholders in this study are representative of the broader population of stakeholders in Canada. It can be stated that it is possible to use a workflow diagram to engage stakeholders from various backgrounds and bring them to a common platform to discuss e-prescribing.

As for future research, it may be of benefit to use this workflow diagram to obtain the feedback of larger groups of stakeholders. Larger groups of stakeholders may provide a more accurate representation of the perceptions of stakeholders in the broader outpatient Canadian medication management community. These perceptions, or stakeholder requirements, could then be taken into consideration by system developers when developing an e-prescribing system for Canada. Another potential option that could help with informing the design of an e-prescribing system would be to develop a simulation model of the paper-based medication management process and use this model to determine the shortcomings of the paper-based system from a different angle by examining specific variables, such as process times. This could help system developers determine which processes need to be improved or changed when developing an e-

prescribing system. Developing this simulation model is realistic as paper-based medication management systems are in place in Canada from which data can be obtained to populate the model. Furthermore, the predictions of this model can be validated by comparing the model predictions to the performance of the actual paper-based system.

Aside from using workflow diagrams and simulation modeling to inform the design of an e-prescribing system, other factors need to be considered before there will be a functioning e-prescribing system in Canada. Users of the system, including physicians, non-physician prescribers, pharmacists, and to a certain extent patients, need to be comfortable with using IT. As pharmacies already employ information systems, the transition to e-prescribing may not have a large impact on pharmacists. The majority of prescriptions are still written by hand in Canada, which is evident by the lack of adoption of EMRs by physicians (Biro et al., 2012). Because of this, the prescribing and transmission processes will need to undergo considerable changes to be made electronic. Early adoption of EMRs by physicians could ease the transition to e-prescribing, as most of the electronic processes for prescribing would be the same. Thus, it may be of benefit to make the adoption of EMRs mandatory to pave the way for an e-prescribing system. Measures also need to be put in place to prevent unauthorized access to electronic records and there will need to be a secure method for transmission of prescriptions electronically. A thorough analysis of these methods needs to be performed to determine which ones are most suitable for health information. Another factor to consider is the development of a comprehensive drug information system (DIS), which is a central component of e-prescribing. Physicians, pharmacists, payers, and possibly others will need to be

connected to the DIS and have real-time access to information such as medication history and the latest drug interaction information. It also needs to be decided whether the DIS will be managed provincially (i.e. one DIS per Province or Territory) or municipally (i.e. multiple DISs per Province or Territory). One final factor that is an essential aspect to implementing an e-prescribing system is end-user satisfaction. Process modeling, if employed properly, could help to achieve stakeholder buy-in as stakeholder requirements could be assessed and addressed prior to implementing the system.

REFERENCES

Abrams, H., & Carr, D. (2005). The human factor: Unexpected benefits of a CPOE and electronic medication management implementation at the University Health Network. *Healthcare Quality*, 8(special issue), 94-98.

Ammenwerth, E., Schnell-Inderst, P., Machan, C., and Siebert, U. (2008). The effect of electronic prescribing on medication errors and adverse drug events: a systematic review. *Journal of the American Medical Informatics Association*, 15(5), 585-600.

Anderson, J.G. (2002). Evaluation in health informatics: computer simulation. *Computers in Biology and Medicine*, 32, 151-164.

Anderson, J., Jay, S., Anderson, M., and Hunt, T. (2002). Evaluating the capability of information technology to prevent adverse drug events: a computer simulation approach. *Journal of the American Medical Informatics Association*, 9(5), 479-490.

Aspden, P., Wolcott, J.A., Bootman, J.L., and Cronenwett, L.R. (Ed.) (Institute of Medicine). (2007). *Preventing medication errors: Quality chasm series*. Washington: National Academy of Sciences.

Bandara, W., Gable, G., and Rosemann, M. (2005). Factors and measures of business process modeling: model building through a multiple case study. *European Journal of Information Systems*, 14, 347-360.

Banks, J. (1999). Introduction to simulation. *Proceedings of the 1999 Winter Simulation Conference*, 7-13.

Bates, D., Cullen, D., Laird, N., Peterson, L., Small, S., Servi, D., Laffel, G., Sweitzer, B., Shea, B., Hallisey, R., et al. (1995). Incidence of adverse drug events and potential adverse drug events. *JAMA*, 274(1), 29-34.

Bell, D., Cretin, S., Marken, R., and Landman, A. (2004). A conceptual framework for evaluating outpatient electronic prescribing systems based on their functional capabilities. *Journal of the American Medical Informatics Association*, 11, 60-70.

Bell, D., Schueth, A., Crosson, J., Guinan, J., Wu, S., Pevnick, J., Wang, C.J., Neuman, S., Patel, M., Park, H., Tysinger, B., Malakar, C.L., Schoeff, D., Bradley, M., and Newberry, S. (2007). Pilot testing of electronic prescribing standards. (Report). Funded by the *Agency for Healthcare Research and Quality.*

Biro, S., Barber, D., and Kotecha, J. (2012). Trends in the use of electronic medical records. *Canadian Family Physician*, 58(1), e21.

Buckley, M. (2002). Improving drug prescribing practices in the outpatient setting: A market analysis. *California HealthCare Foundation*, 1-35.

Campbell, E., Sittig, D., Ash, J., Guappone, K., & Dykstra, R. (2006). Types of unintended consequences related to computerized provider order entry. *Journal of the American Medical Informatics Association*, 13(5), 547-556.

Canada Health Infoway. (2009). Economic news: Trends & analysis: Healthcare facility. *Canada boosts electronic health record system spending by $500 million*. Retrieved June 20, 2012 from Canada Newswire Web site http://www.newswire.ca/en/story/476623/canada-boosts-electronic-health-record-system-spending-by-500-million

Canada Health Infoway. (2010). National impacts of generation 2 drug information systems. Technical Report. Deloitte. Retrieved March 19, 2012 from Canada Health Infoway Web site https://www.infoway-inforoute.ca/index.php/resources/reports?start=5

Clancy, T.R. (2006). Predicting the impact of an electronic health record on practice patterns using computational modeling and simulation. *ProQuest Dissertations and Thesis*, 64-90.

Cusack, C. M. (2008). Electronic health records and electronic prescribing: promise and pitfalls. *Obstetrics and Gynecology Clinics of North America*, 35(1), 63-79.

Dean, B., Barber, N., van Ackere, A., and Gallivan, S. (2001). Can simulation be used to reduce errors in health care delivery? The hospital drug distribution system. *Journal of Health Services Research & Policy*, 6(1), 32-37.

Eslami, S., Abu-Hanna, A., and de Keizer, N. (2007). Evaluation of outpatient computerized physician medication order entry systems: a systematic review. *Journal of the American Medical Informatics Association*, 14(4), 400-406.

Eslami, S., de Keizer, N., and Abu-Hanna, A. (2008). The impact of computerized physician medication order entry in hospitalized patients – a systematic review. *International Journal of Medical Informatics*, 77, 365-376.

Fone, D., Hollinghurst, S., Temple, M., Round, A., Lester, N., Weightman, A., Roberts, K., Coyle, E., Bevan, G., and Palmer, S. (2003). Systematic review on the use and value of computer simulation modelling in population health and health care delivery. *Journal of Public Health Medicine*, 25(4), 325-335.

GraphPad Software, Inc. (2012). QuickCalcs – Quantify agreement with kappa. Accessed June 14, 2012 from GraphPad Software Inc. Web site graphpad.com/quickcalcs/Kappa2.cfm

Havey, M. (2005). *Essential business process modeling*. United States of America: O'Reilly Media Inc.

Hook, G. (2011). Business process modeling and simulation. *Proceedings of the 2011 Winter Simulation Conference*, 773-778.

Jha, A., Doolan, D., Grandt, D., Scott, T., and Bates, D. (2008). The use of health information technology in seven nations. *International Journal of Medical Informatics*, 77, 848-854.

Johnson, K. & FitzHenry, F. (2006). Case Report: Activity diagrams for integrating electronic prescribing tools into clinical workflow. *Journal of the American Medical Informatics Association*, 13(4), 391-395.

Kaushal, R., Bates, D., Landrigan, C., McKenna, K., Clapp, M., Federico, F., and Goldmann, D. (2001). Medication errors and adverse drug events in pediatric inpatients. *JAMA*, 285(16), 2114-2120.

Kelton, W.D., Sadowski, R.P., and Swets, N.B. (2010). *Simulation with Arena*. (5th ed.). Singapore: McGraw-Hill.

Keshavjee, K., Troyan, S., Langton, K.B., Holbrook, A.M., Naghi, A., Topps, D., Nazaerali, N., and VanderMolen, D. (2001). Successful computerization in small primary care practices: A report on three years of implementation experience. *Proceedings of eHealth 2001Conference*, 64-72.

Kohn, L., Corrigan, J., and Donaldson, M. (Ed.) (Institute of Medicine). (1999). *To err is human: Building a safer health system*. Washington: National Academy of Sciences.

Kondro, W. (2010). News: Pharmaceutical sales increased during recession. *CMAJ*, 182(8), E341-E342.

Koppel, R., Metlay, J. P., Cohen, A., Abaluck, B., Localio, A. R., Kimmel, S. E., and Strom, B.L. (2005). Role of computerized physician order entry systems in facilitating medication errors. *JAMA*, 293(10), 1197-1203.

Kuperman, G., & Gibson, R. (2003). Computer physician order entry: benefits, costs, and issues. *Annals of Internal Medicine*, 139, 31-39.

Lepley, C.J. (2001). Simulation software: engineer processes before reengineering. *Journal of Nursing Administration*, 31(7/8), 377-385.

Lim, M., Nye, T., Bowen, J., Hurley, J., Goeree, R., and Tarride, J.R. (2012). Mathematical modeling: the case of emergency department waiting times. *International Journal of Technology Assessment in Health Care*, 28(2), 93-109.

Ludwick, D.A. & Doucette, J. (2009). Adopting electronic medical records in primary care: Lessons learned from health information systems implementation experience in seven countries. *International Journal of Medical Informatics*, 78, 22-31.

McKibbon, K.A., Lokker, C., Handler, S.M., Dolovich, L.R., Holbrook, A.M., O'Reilly, D., Tamblyn, R., Hemens, B.J., Basu, R., Troyan, S., Roshanov, P.S., Archer, N.P., Raina, P. (2011). Enabling medication management through health information technology. Evidence Report/Technology Assessment No. 201. (Prepared by the McMaster University Evidence-based Practice Center under Contract HHSA 290-2007-10060-I). AHRQ Publication No. 11-E008-EF. Rockville MD: Agency for Healthcare Research and Quality.

Mo, J.P.T. & Mahmoudi, M. (2008). Optimisation and simulation of high speed production system. *Journal of Achievements in Materials and Manufacturing Engineering*, 31(2), 794-802.

Nickerson, T., Jenkins, M., and Greenall, J. (2008). Using ISMP Canada's framework for failure mode and effects analysis: a tale of two FMEAs. *Healthcare Quarterly*, 11(special issue), 40-46.

Reckmann, M., Westbrook, J., Koh, Y., Lo, C., and Day, R. (2009). Does computerized provider order entry reduce prescribing errors for hospital inpatients? A systematic review. *Journal of the American Medical Informatics Association*, 16(5), 613-623.

Robinson, S. (1997). Simulation model verification and validation: Increasing the user's confidence. *Proceedings of the 1997 Winter Simulation Conference*, 53-59.

Sargent, R.G. (2005). Verification and validation of simulation models. *Proceedings of the 2005 Winter Simulation Conference*, 130-143.

Silversides, A. (2010). News: Canadian physicians playing "catch-up" in adopting electronic medical records. *CMAJ*, 182(2), E103-E104.

Sweetster, A. (1999). A comparison of system dynamics and discrete event simulation. *Proceedings of 17th International Conference of the System Dynamics Society and 5th Australian & New Zealand Systems Conference*.

Thomsen, L.A., Winterstein, A.G., Søndergaard, B., Haugbølle, L.T., and Melander, A. (2007). Systematic review of the incidence and characteristics of preventable adverse drug events in ambulatory care. *Annals of Pharmacotherapy*, 41(9), 1411-1426.

van Sambeek, J.R.C., Cornelissen, F.A., Bakker, P.J.M., and Krabbendam, J.J. (2010). Models as instruments for optimizing hospital processes: a systematic review. *International Journal of Health Care Quality Assurance*, 23(4), 356-377.

Webster, P.C. & Kondro, W. (2011). News: Audit concludes Infoway missed program targets. *CMAJ*, 183(8), 893-894.

White, S. (2004). Introduction to BPMN. *BPTrends*, July.

Wolfstadt, J., Gurwitz, J., Field, T., Lee, M., Kalkar, S., Wu, W., and Rochon, P. (2008). 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*, 23(4), 451-458.

Wong, C., Geiger, G., Derman, Y., Busby, C., and Carter, M. (2003). Redesigning the medication ordering, dispensing, and administration process in an acute care academic health sciences centre. *Proceedings of the 2003 Winter Simulation Conference*, 1894-1902.

Zamora, N., Carter, M., Saull-McCaig, S., and Nguyen, J. (2006). The benefits of the MOE/MAR implementation: a quantitative approach. *Healthcare Quarterly*, 10(special issue), 77-83.

zur Muehlen, M. & Recker, J.C. (2008). How much language is enough? Theoretical and practical use of the business process modeling notation. *Proceedings 20th International Conference on Advanced Information Systems Engineering*, *Montpellier, France.*

APPENDICES

Appendix 1: Search Strategies for Electronic Databases

MEDLINE (using Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to Present) – Searched January 26th, 2012

1	Computer Simulation/	
2	Systems Theory/	
3	exp Systems Analysis/	
4	((accident or comput* or process or queuing or systems or theoretical or workflow? Or work-flow?) adj2 (model* or simulat* or microsimulat*)).ti,ab.	
5	(model* adj2 simulat*).ti,ab.	
6	((systems or queuing) adj2 theor*).ti,ab.	
7	or/1-6	
8	Quality of Health Care/	
9	Outcome and Process Assessment (Health Care)/	
10	Process Assessment (Health Care)/	
11	exp Program Evaluation/	
12	Quality Assurance, Health Care/	
13	Quality Improvement/	
14	Guideline Adherence/	
15	Efficiency, Organizational/	
16	Technology Assessment, Biomedical/	
17	Cost-Benefit Analysis/	
18	((accident or process or systems or theoretical or workflow? Or work-flow?) adj2 (model*)).ti,ab.	
19	(systems adj2 analys#s).ti,ab.	
20	or/2,3,8-19	
21	Drug Therapy, Computer-Assisted/	
22	Electronic Prescribing/	
23	Clinical Pharmacy Information Systems/	
24	exp Medication Systems/	
25	(electronic* adj (deliver* or dispens* or medication? or prescribing or prescription?)).ti,ab.	
26	(e-dispensing or e-prescription? or e-prescribing or e-ps).ti,ab.	
27	exp Hospital Information Systems/	
28	((medication* or pharmaceut* or prescription? or drug*) adj2 (deliver* or dispens* or order* or prescribing)).mp.	
29	((medication* or pharmaceut* or prescription? or drug*) adj2 system?).mp	
30	Decision Support Systems, Clinical/	
31	exp Medical Records Systems, Computerized/	

32	((decision support or hospital information or medical record?) adj system?).ti,ab.	
33	or/21-32	
34	exp Drug Prescriptions/	
35	((drug* or handwritten) adj2 (prescri*)).ti,ab.	
36	or/33-35	
37	(Canad$ or British Columbia$ or Alberta$ or Saskatchewan$ or Manitob$ or Quebe$ or Ontari$ or Nova Scotia$ or Newfoundland$ or Labrador$ or Prince Edward Island$ or New Brunswick$ or Northwest Territor$ or Yukon$ or Nunavut$).in,mp.	
38	7 and 33	
39	20 and 36 and 37	
40	or/38-39	

EMBASE 1974 to 2012 week 03 (using OVID) – Searched January 26th, 2012

1	exp Computer Simulation/	
2	Systems Theory/	
3	exp System Analysis/	
4	((accident or comput* or process or queuing or systems or theoretical or workflow? Or work-flow?) adj2 (model* or simulat* or microsimulat*)).ti,ab.	
5	(model* adj2 simulat*).ti,ab.	
6	((systems or queuing) adj2 theor*).ti,ab.	
7	or/1-6	
8	Health care quality/	
9	Total quality management/	
10	Practice guideline/	
11	Organization and management/	
12	Biomedical technology assessment/	
13	Cost benefit analysis/	
14	Qualitative analysis/	
15	((accident or process or systems or theoretical or workflow? Or work-flow?) adj2 (model*)).ti,ab.	
16	(systems adj2 analys#s).ti,ab.	
17	or/2,3,8-16	
18	Computer assisted drug therapy/	
19	exp Computerized provider order entry/	
20	Medical information system/	
21	Hospital organization /	
22	Multihospital system/	
23	exp Hospital information system/	
24	(electronic* adj (deliver* or dispens* or medication? or prescribing or prescription?)).ti,ab.	
25	(e-dispensing or e-prescription? or e-prescribing or e-ps).ti,ab.	

26	((medication* or pharmaceut* or prescription? or drug*) adj2 (deliver* or dispens* or order* or prescribing)).mp.	
27	((medication* or pharmaceut* or prescription? or drug*) adj2 system?).mp	
28	Decision support system/	
29	Medical record/	
30	((decision support or hospital information or medical record?) adj system?).ti,ab.	
31	or/18-30	
32	Prescription/	
33	((drug* or handwritten) adj2 (prescri*)).ti,ab.	
34	or/31-33	
35	(Canad$ or British Columbia$ or Alberta$ or Saskatchewan$ or Manitob$ or Quebe$ or Ontari$ or Nova Scotia$ or Newfoundland$ or Labrador$ or Prince Edward Island$ or New Brunswick$ or Northwest Territor$ or Yukon$ or Nunavut$).in,mp.	
36	7 and 31	
37	17 and 34 and 35	
38	or/36-37	

CINAHL 1975 to December 2011 (using EBSCO) – Searched January 26th, 2012

1	Computer Simulation/	
2	Systems Theory/	
3	exp Systems Analysis/	
4	TX accident N2 model* (Exclude MEDLINE records)	
5	TX Accident N2 simulat*(Exclude MEDLINE records)	
6	TX Accident N2 microsimulat*(Exclude MEDLINE records)	
7	TX Comput* N2 model*(Exclude MEDLINE records)	
8	TX Comput*N2 simulat*(Exclude MEDLINE records)	
9	TX Comput*N2 microsimulat*(Exclude MEDLINE records)	
10	TX process N2 model*(Exclude MEDLINE records)	
11	TX process N2 simulat*(Exclude MEDLINE records)	
12	TX process N2 microsimulat*(Exclude MEDLINE records)	
13	TX queuing N2 model*(Exclude MEDLINE records)	
14	TX queuing N2 simulat*(Exclude MEDLINE records)	
15	TX queuing N2 microsimulat*(Exclude MEDLINE records)	
16	TX Systems N2 model*(Exclude MEDLINE records)	
17	TX Systems N2 simulat*(Exclude MEDLINE records)	
18	TX systems N2 microsimulat*(Exclude MEDLINE records)	
19	TX Theoretical N2 model*(Exclude MEDLINE records)	
20	TX theoretical N2 simulat*(Exclude MEDLINE records)	
21	TX theoretical N2 microsimulat*(Exclude MEDLINE records)	
22	TX Workflow? N2 model*(Exclude MEDLINE records)	
23	TX Workflow? N2 simulat*(Exclude MEDLINE records)	
24	TX Workflow? N2 microsimulat*(Exclude MEDLINE records)	
25	TX Work-flow? N2 model*(Exclude MEDLINE records)	

26	TX Work-flow? N2 simulat*(Exclude MEDLINE records)	
27	TX Work-flow? N2 microsimulat*(Exclude MEDLINE records)	
28	TX model* N2 simulat* (Exclude MEDLINE records)	
29	TX queuing N2 theor* (Exclude MEDLINE records)	
30	TX systems N2 theor* (Exclude MEDLINE records)	
31	or/1-30	
32	Quality of Health Care/	
33	Quality Assessment/	
34	Process Assessment (Health Care)/	
35	Program Evaluation/	
36	Quality Assurance /	
37	Quality Improvement/	
38	Guideline Adherence/	
39	exp Organizational efficiency/	
40	Cost Benefit Analysis/	
41	TX accident N2 model* (Exclude MEDLINE records)	
42	TX process N2 model*(Exclude MEDLINE records)	
43	TX Systems N2 model*(Exclude MEDLINE records)	
44	TX Theoretical N2 model*(Exclude MEDLINE records)	
45	TX Workflow? N2 model*(Exclude MEDLINE records)	
46	TX Work-flow? N2 model*(Exclude MEDLINE records)	
47	TX systems N2 analys?s (Exclude MEDLINE records)	
48	or/2,3,32-47	
49	Drug Therapy, Computer-Assisted/	
50	Electronic Order Entry/	
51	Clinical Pharmacy Information Systems/	
52	Medication Systems/	
53	TX electronic* N1 deliver*(Exclude MEDLINE records)	
54	TX electronic* N1 dispens*(Exclude MEDLINE records)	
55	TX electronic* N1 medication? (Exclude MEDLINE records)	
56	TX electronic* N1 prescribing (Exclude MEDLINE records)	
57	TX electronic* N1 prescription? (Exclude MEDLINE records)	
58	TX (e-dispensing or e-prescription? or e-prescribing or e-ps) (Exclude MEDLINE records)	
59	Hospital Information Systems/	
60	Clinical Information Systems/	
61	TX medication* N2 deliver*(Exclude MEDLINE records)	
62	TX medication* N2 dispens*(Exclude MEDLINE records)	
63	TX medication* N2 order*(Exclude MEDLINE records)	
64	TX medication* N2 prescribing (Exclude MEDLINE records)	
65	TX pharmaceut* N2 deliver*(Exclude MEDLINE records)	
66	TX pharmaceut* N2 dispens*(Exclude MEDLINE records)	
67	TX pharmaceut* N2 order*(Exclude MEDLINE records)	
68	TX pharmaceut* N2 prescribing (Exclude MEDLINE records)	
69	TX prescription? N2 deliver*(Exclude MEDLINE records)	
70	TX prescription? N2 dispens*(Exclude MEDLINE records)	

71	TX prescription? N2 order*(Exclude MEDLINE records)	
72	TX prescription? N2 prescribing (Exclude MEDLINE records)	
73	TX drug* N2 deliver* (Exclude MEDLINE records)	
74	TX drug* N2 dispens*(Exclude MEDLINE records)	
75	TX drug* N2 order*(Exclude MEDLINE records)	
76	TX drug* N2 prescribing (Exclude MEDLINE records)	
77	TX medication* N2 system? (Exclude MEDLINE records)	
78	TX pharmaceut* N2 system? (Exclude MEDLINE records)	
79	TX prescription? N2 system? (Exclude MEDLINE records)	
80	TX drug* N2 system? (Exclude MEDLINE records)	
81	Decision Support Systems, Clinical/	
82	exp Patient Record Systems/	
83	TX decision support N1 system? (Exclude MEDLINE records)	
84	TX hospital information N1 system? (Exclude MEDLINE records)	
85	TX medical record? N1 system? (Exclude MEDLINE records)	
86	or/49-85	
87	Prescriptions, Drug/	
88	TX drug* N2 prescri*(Exclude MEDLINE records)	
89	TX handwritten N2 prescri* (Exclude MEDLINE records)	
90	or/86-89	
91	TX (Canad* or British Columbia* or Alberta* or Saskatchewan* or Manitob* or Quebe* or Ontari* or Nova Scotia* or Newfoundland* or Labrador* or Prince Edward Island* or New Brunswick* or Northwest Territor* or Yukon* or Nunavut*) (Exclude MEDLINE records)	
92	31 and 86	
93	48 and 90 and 91	
94	or/92-93	

Appendix 2: Search Strategies for Grey Literature Sources

The following sources were searched for grey literature:

- AHRQ Knowledge Library (for conference proceedings, white papers, and other papers from proceedings)
    - Searched AHRQ Knowledge Library December 27, 2011 for the terms:
        - "Simulation Model".
        - "workflow model Canada".
        - "process model Canada".
- CIHI (Canadian Institute for Health Information)
    - Searched CIHI on January 11, 2012 for:
        - "electronic prescribing simulation model"
        - "workflow model", exact phrase
        - "process model", exact phrase
- Canada Health Infoway
    - Searched CHI on January 11, 2012 for:
        - "electronic prescribing simulation model"
        - "drug prescribing model"
- PapersFirst, ProceedingsFirst, and WorldCat.org (for conference proceedings, congresses, and symposia)
    - Searched PapersFirst on January 10, 2012 for the keywords:
        - (kw: electronic and kw: prescribing) and kw: model
        - (kw: drug and kw: prescribing) and kw: model
    - Searched ProceedingsFirst on January 10, 2012 for the keywords:
        - (kw: electronic and kw: prescribing) and ((kw: simulation and kw: model))
        - (((kw: drug and kw: prescribing)) and kw: model) and kw: canada and ln= "english"
    - Searched WorldCat.org on January 10, 2012 for:
        - (kw: electronic and kw: prescribing) and ((kw: simulation and kw: model)) and la= "eng"
        - (((kw: drug and kw: prescribing)) and kw: model) and kw: canada.
- Google
    - Searched Google on December 27, 2011 for "electronic prescribing simulation model".
    - Searched Google on December 31, 2011 for "drug prescribing process model Canada".

- Winter Simulation Conference
    - Searched Winter Simulation Conference archive on January 11, 2012
        - Searched the "health care" section from the year 1996 to 2010
- Websites for vendors of simulation software
    - Searched the website for the software vendor Arena on January 11, 2012
        - Searched the section "health care simulation"
    - Searched the website for the software vendor Stella on January 11, 2012
        - Searched for "electronic prescribing"

Appendix 3: Inclusion and Exclusion Criteria for Systematic Review

IF THE STUDY IS ABOUT A SIMULATION MODEL:

1. Was the study published after 1975? Yes No
2. If yes, is the study about a simulation model? Yes No
3. If yes, is the study about an electronic prescribing system or a CPOE system? Yes No
4. If yes, is the study discussing the entire drug prescribing and dispensing process? Yes No
5. If yes, does the study discuss the outcome of using the simulation model? Yes No

If **All 5** answers above are **"yes"**, then **include**. If **any** of the above answers is **"no"**, then **exclude**. Please provide the reason(s) for exclusion.

IF THE STUDY IS ABOUT A PROCESS MODEL:

1. Was the study published after 1975? Yes No
2. If yes, is the study about a Canadian drug prescribing and dispensing process? Yes No
3. If yes, is the study discussing the entire drug prescribing and dispensing process? Yes No
4. If yes, was an actual process model described/developed? Yes No

If **All 4** answers above are **"yes"**, then **include**. If **any** of the above answers is **"no"**, then **exclude**. Please provide the reason(s) for exclusion.

Appendix 4: Data Extraction Form

Data extraction form (one per study evaluated)

PART 1: COVER SHEET

Study ID #:	
First author:	Data extracted by:
Journal:	Date of completion:
Year:	Final status:
Category of Study: ❑ Simulation model of electronic prescribing system ❑ The use of process modeling to describe the prescribing and dispensing process in Canada (whether electronic or handwritten)	Type of publication: ❑ full paper ❑ abstract ❑ conference proceeding ❑ unpublished report ❑ dissertation other: _____
Author contacted? ❑ Yes ❑ No	Author responded? ❑ Yes ❑ No ❑ Not applicable

PART 2: BASELINE DATA & POPULATION

(please circle the correct option and write in where necessary)

Year of study (if more than one year, report start and stop years)	NR	If reported:			
Where did the study take place? (specify Country)	NR	If reported:			
Study design	NR	Qualitative (i.e. data in the study is non-numerical) Specify:	Quantitative (i.e. data in the study is numerical) Specify:		
	Other:				
Type of setting in the study:	NR	Inpatient	Out-patient	Both	Other:
Type of system in the study:	NR	Hand-written prescribing system	E-prescribing system/ CPOE	Both	Other:
Did the study discuss the complete prescribing & dispensing system (whether handwritten or electronic)	NR	Yes		No	

Study Population

What is the primary unit of study?	eRx /CPOE system	Prescribing /dispensing process	Patients	Health care providers	Other (specify)
If patients are the primary unit of study, what was the target group of patients?					
If applicable, how many groups were being studied?					

Other relevant information on study setting and population:

PART 3: INTERVENTION

(please circle the correct option and write in where we ask "Other")

Type of intervention (for simulation model of eRx system ONLY)	NR	Process Simulation model		Other type of computer simulation model (Specify)				
Method of analysis (for process model of Rx/eRx process ONLY)	NR	Process Model	Process analysis	Systems analysis	Workflow analysis	Quality assurance	Evaluation	Other (Spec-ify)
Control	NR	If reported, what was the intervention being compared to?:						
Duration of Intervention	NR	If reported						
Fidelity/ Integrity (was the intervention delivered as intended?)	NR	Yes		No		Other (specify)		

Other relevant information on intervention: Describe the model here in detail – 1. What is the primary unit of study in the model? (for simulation model of eRx system ONLY) ☐ # of prescriptions going through the model. Specify number _____ ☐ # of patients going through the model. Specify number _____ ☐ # of medication errors or adverse drug events. Specify number _____ ☐ Efficiency. Specify _____ ☐ Other. Specify _____	NR
2. How long did the simulation model run for? (for simulation model of eRx system ONLY) Specify duration and unit of measure _____ How many replications of the simulation were done? _____	NR NR

3. Please check all phases of the drug prescribing and dispensing process that were modeled: ☐ Prescribing ☐ Dispensing ☐ Transmission of prescription ☐ Patient compliance	NR
4. Explain the method that was used to determine the processes in the model (simulation model or process model)	NR
5. Explain how data was obtained to populate the simulation model (for simulation of eRx system ONLY)	NR
6. a) Was the model (simulation model or process model) validated before it was used? ☐ Yes ☐ No ☐ NR b) If yes, explain what validation method was used.	
7. What software was used to develop the model?	NR
8. Were the primary users of the system/process involved in developing the model? If yes, specify their level of involvement.	NR
9. Were test scenarios run and the simulation model debugged before it was used in the study? (for simulation model of eRx system ONLY) ☐ Yes ☐ No ☐ NR	
10. Any other important details about the intervention:	

PART 4: OUTCOMES

(please circle the correct option and write in where we ask "Other")

What was the primary outcome measure? (as defined by the authors)				
If applicable, what was the secondary outcome measure? (as defined by the authors)	NR			
Method(s) of assessing outcome measures (select all that apply):	Survey	Questionnaire	Interview	Focus Group
	Physical measure-ment	Observation		
	Other (specify)			
Were incomplete outcome data adequately addressed?	NR	Yes	No	Unclear
Are reports of the study free of suggestion of selective outcome reporting?	NR	Yes	No	Unclear
Were outcome measurement tools validated?	NR	Yes	No	Unclear
Were outcome assessors blinded to the intervention?	NR	Yes	No	Unclear

PART 5: RESULTS

(please circle the correct option and write in where we ask "Other")

For Simulation Model of eRx system ONLY	NR	Simulation modeling influenced or resulted in a change in the design of an eRx system (this includes existing eRx systems and systems still being designed) State results of study:	Simulation modeling did not influence or result in a change in the design of an eRx system (this includes existing eRx systems and systems still being designed) State results of study:

For Process Model of Rx/eRx process ONLY	NR	The model influenced or resulted in a change in the design of a handwritten or electronic prescribing process (this includes existing processes/ systems as well as processes/ systems still being designed) State results of study:	The model did not influence or result in a change in the design of a handwritten or electronic prescribing process (this includes existing processes/ systems as well as processes/ systems still being designed) State results of study:
Was the process model used to actually measure workflow? (for process model of Rx/eRx process ONLY)	NR	Yes (specify)	No

Appendix 5: Definitions of Processes on the Workflow Diagram

	Processes	Definition
Prescribing	1. Patient visits MD	The patient starts the process by visiting the physician
	2. Review chart (by MD)	The physician reviews the patient's paper chart
	3. Assess patient	The physician assesses the patient
	4. Need Rx?	The physician decides whether the patient requires a prescription
	5. Is this a renewal?	The physician determines whether the prescription is a renewal
	6. Selecting Medication (by MD)	The physician mentally selects the medication to prescribe
	7. Drug Checking by MD	The physician checks for any drug-drug, drug-allergy interactions
	8. Issues from drug checking by MD	Whether any issues (i.e. an interaction) arose from drug check
	9. MD managing issues from drug check	If there were issues, the physician resolves these issues (i.e. Selects a different medication)
	10. Generate Rx	The physician writes out the prescription
	11. Sign Rx	They physician signs the prescription
Transmission	12. Rx routing	The different paths a prescription can take to the pharmacy
	13. Fax of phone prescription	The prescription is faxed or verbally communicated by telephone to the pharmacy
	14. Give prescription to patient	The physician gives the paper prescription to the patient
	15. Prescription filled?	Whether the patient actually fills the prescription
Dispensing	16. Pharmacist receives Rx	The pharmacist receiving the paper prescription (or verbal, if telephoned by physician)
	17. Pharmacist entering Rx into information system	Pharmacist copies the paper prescription into the pharmacy information system
	18. Pharmacist reviews therapy	Pharmacist reviews and looks over the prescription
	19. Drug Check by Pharmacist	Pharmacist checks for any drug-drug, drug-allergy interactions
	20. Issues from drug check by Pharmacist	Whether any issues (i.e. an interaction) arose from drug check
	21. Issue manageable by Pharmacist?	Whether the pharmacist can manage/resolve these issues on his/her own
	22. Call back to Physician	The pharmacist calling back the physician to resolve the issues
	23. MD resolves issues from call back	The physician resolves the issues from the call back by the pharmacist
	24. Pharmacist manages issues from drug check	Pharmacist resolves the issues that arose from performing drug check
	25. Dispense drug to patient	Pharmacist dispenses the drug to the patient
	26. Provide education to patient (by Pharmacist)	Pharmacist educates the patient on how to properly take the medication
Monitoring/Compliance	27. Drug pickup (by patient)	The patient picks up the medication from the pharmacy
	28. Patient takes medication	The patient starts to take the medication
	29. Any issues with patient taking medication?	Whether the patient has any issues (i.e. Side effects) with taking the medication
	30. See MD (if any issues with taking medication)	Whether the patient visits their physician because of the issues they experienced
	31. Patient stops taking meds (due to issues)	The patient decides to stop taking the medication because of the issues they experienced
	32. Patient completes course	The patient completes the course of the medication
	33. Refill available?	Whether a refill is available for the medication the patient is taking
	34. Start process again for new Rx	The patient starts the process again for a new prescription

Appendix 6: Summary of Comments Made by Stakeholders

CODED VERBALIZATIONS	PHYSICIANS	PHARMACISTS	PUBLIC	FINAL TOTAL
Problem Points				
Drug Checking by MD	1	2	4	7
MD does not have full list of meds patient is taking	1	2	2	5
Chart Review (by MD)	2	1	2	5
Illegible Prescription	4	3	5	12
Callbacks/fax to physician	4	3	2	9
Patient compliance with taking medications	4	1	2	7
Problem Points Most Likely to Harm Patients				
Drug checking by MD	3	1	3	7
Selecting Drug/dose (by MD)	3	2	0	5
Illegible Prescription	4	1	1	6
Problem Points Most Likely to be Fixable				
Drug checking by MD	2	1	3	6
Callbacks/fax to physician	3	2	0	5
Where I.T. Can Help Reduce Harm to Patients				
Chart Review (by MD)	2	0	3	5
Providing MD with complete list of meds patient is taking	2	1	3	6
Providing MD with complete patient history	1	1	4	6
Assisting with drug interaction/allergy checking (by MD)	3	2	4	9
Generate Rx	2	3	1	6
Patient compliance with taking medications	1	2	2	5
Where I.T. Can Help Increase Efficiency				
Assisting with drug interaction checking (by MD)	3	1	2	6
Clearly generated prescription	0	2	3	5
Eliminating manual entry of Rx into pharmacy information system	1	3	1	5
Assist pharmacist in reviewing therapy	3	2	1	6
Prevent callbacks/faxes to MD	1	3	3	7

This table highlights the coded qualitative comments that were made by stakeholders during interviews. Comments that were made by at least 5 out of 15 stakeholders are included in the table. MD = physician.

Appendix 7: Sample Quotations from Stakeholder Representatives

Problematic Processes	*"Even once it's filled, there's no verification if the patient actually did take it or not. And there's no verification that if the doctor prescribes a medication that the patient is actually got it filled because of doctors and pharmacies are not connected, so that doctor will never even know that medication has even been filled"* Pharmacist *"If it's a paper chart, then it's difficult reading the chart because sometimes (in) the paper chart it's hard to see all the information that you need".* Physician *"Generating the Rx is a huge huge huge one (i.e. problem), because it's handwriting, and at best that in and of itself allows for, not only difficulty reading, but also being manipulated. There is a number of people out there that can have the ability to change numbers, drugs, strengths for their own purposes."* Public member
Problematic Processes Most Likely to Cause Harm to Patients	*"This one is a huge issue… if we're talking specifically with handwriting prescriptions where a pharmacist misreads the prescription, and it happens time and again, and it's not that they're guessing that "oh yeah, I think it's that". That happens a lot, where "is it this, or is it that?". That's not what I'm talking about, it's where you look at a prescription and you think it's one thing but it's actually another".* Pharmacist *"If the prescription is not legible there is a significant chance of problems, or if it's hand entered incorrectly, I suppose that could also be a problem."* Physician
Problematic Processes Most Likely to be Amenable to Improvement	*"Whether or not the actual prescription is ever filled or not, that's a patient choice, although to the extent that in an electronic system you can be aware of prescriptions that were never filled, it allows you follow-up, so I would say that's also again you can improve it. Again the fact that you follow-up with the patient, it doesn't actually necessarily change their behavior."* Physician *"If they (i.e. the physician) can get something where they have up to date information as opposed to going to these preprinted books that could be outdated, they would have more accurate information and be able to decide whether that would work for the patient or not."* Public member

Information Technology Potentially Helpful in Reducing Harm	*"If there's a central database, which only computers could possibly hold, then that would provide a complete list of the medications, so therefore doctor would have a full history, pharmacist would have a full history, and it would be a way a secure form of prescribing. Also, the doctor … through the computer use would know exactly if the patient got the medication filled, the only part of the problem I guess would still be the patient's honesty, the patient can get it filled but him actually taking it at home is the only part I can see is the downside."* Pharmacist *"Drug interactions and drug allergy (i.e. Drug checking). This could be on the patient's profile, we can highlight which drugs the patient is allergic to and then there is software now that can tell you whether the drug you're prescribing will interact with this drug. So I think that can be solved with the computer very quickly."* Physician *"Streamlining the communication between the physician and to the pharmacy, taking the patient out of the loop."* Public member
Information Technology Potentially Helpful in Increasing Efficiency	*"So if he's (the physician) got a prescription for a pharmacist … he can enter all of his information in there, the same information is accessed in the pharmacy, and the pharmacist can just sort of print that prescription immediately in the pharmacy. There's none of this where you give it to the patient and the patient takes it there, they fax it or, instead of faxing there is like an electronic way of transferring the prescription electronically"* Pharmacist *"…If interactions pop up in there than that saves the pharmacist from actually putting down and having to phone the doctor. So let's say there's two very classical drug interactions going on in a prescription. The way the system is right now, unless the physician is aware of it, he'll send it to the pharmacist, the pharmacist will maybe discover the drug interaction, call the doctor, try to change it, but if there was a system that would flag him (i.e. the physician) right away that there is a drug interaction here, then that would save a lot of time of both parties"* Pharmacist *"It takes extremely mature electronic systems to beat the speed of writing the prescription, but you can write a very harmful prescription fast, so I'm quite confident you can … improve efficiency in some circumstances, specifically the refill process where you got the patient on multiple medications who comes in and says 'I need all my medications refilled', you can certainly be more efficient about that …"* Physician