

Grant Final Report

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RxSafe: Shared Medication Management and Decision Support for Rural Clinicians

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Abstract

Purpose: To improve cognitive support for clinicians by exploiting the semantics of clinical information and improving interdisciplinary collaboration.

Scope: Medication management in long term care of rural elders with chronic illness.

Methods: Naturalistic observation of clinicians and processes, and simple cognitive experiments for Aims 1 and 2. A variety of software development methods for Aims 3 and 4.

Results: We found that arrangement of information is important to clinicians and may be an important form of cognitive support. Clinicians used different categories when thinking about medications, depending on their task being performed as well as on their discipline. Organization of medication information did not improve recall (except for novices), but actual *processing* of medication lists by a clinician be more important to cognitive performance. “Medication Reconciliation” occurs as an isolated procedure to comply with regulations, but medication management was a more robust and more complex process which is distributed, dynamic, collaborative, and continuous, involving multiple professionals performing complementary tasks in different settings over time. We demonstrated the technical feasibility of a synchronization system using open source tools, but further exploration of this prototype is limited by the difficulty of interacting with proprietary closed systems produced by EMR vendors. We developed a prototype that demonstrated the feasibility of independent web based decision support services interacting in a service oriented architecture over a network, which could be used to create novel “mash-ups” to support diverse medication management tasks for providers and patients.

Key Words: medication safety; medication management; interoperability; standards; long term care; rural; elders; chronic conditions

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Final Report

Purpose

The purpose of this project was to investigate the feasibility and impact of novel approaches to clinician decision support, applied to multidisciplinary distributed ambulatory care of persons with chronic conditions. We previously developed technology (RxSafe) to share medication information across settings, including high-risk transitions of care. In this project we examined the use of medication information and technology in clinical decision making about medication management, with a goal of improving outcomes for patients and providers in the care of chronic conditions.

Specific Aims of the project were to develop and evaluate innovations in four areas:

Aim 1: Meaningful Presentation. Enhance clinician cognitive performance in medication management tasks by exploiting the underlying semantics of medication lists to improve the organization and presentation of medication list information.

Aim 2: Assisted Reconciliation. Implement medication list management tools that are integrated into clinician-specific and task-specific workflows to support medication reconciliation, at high-risk transitions as well as in ongoing ambulatory care.

Aim 3: Distributed Decision Support. Increase the effectiveness of medication management activities of clinicians in multiple roles by improving their coordination and communication through the use of shared medication management tools.

Aim 4 Web-Based Clinical Decision Support. Employ evolving standards and architectures to link external, machine actionable, evidence-based clinical information in context- appropriate and user-appropriate ways to support shared medication management by clinicians practicing in ambulatory settings

Scope

Background and Context: Following the CDS Roadmap

The promise of health information technology (HIT) to improve healthcare has been accepted by clinical, government, and industry leaders but deployment has been halting while benefits have been mixed and at times disappointing. One review of 154 studies published between 2007 and 2010 reported overall positive impacts, (Buntin, 2011) but an overview of 108 separate systematic reviews of HIT interventions published between 1997 and 2007 found that evidence was “weak and inconsistent” for claims of benefit of EHRs and related technologies such as computerized order entry and clinical decision support. (Black, 2011) In the face of this

conflicting evidence, academic, government, and industry leaders are seeking solutions to improve systems and achieve broad implementation throughout the healthcare system that would allow the expected benefits of HIT to be realized.

An essential element in achieving this vision of improved safety and quality through HIT-enabled healthcare is the role of clinical decision support (CDS). According to a white paper from the Office of the National Coordinator for Health Information Technology,

“Clinical decision support (CDS) provides clinicians, staff, patients or other individuals with knowledge and person-specific information, intelligently filtered or presented at appropriate times, to enhance health and health care.” (Osheroff, 2007; abbreviated here for space)

That white paper, “Roadmap for National Action on Clinical Decision Support” outlined key objectives and strategies for CDS, defined a critical path for achieving these objectives, and called for pilot projects with the following deliverables:

1. standard, highly practical formats for representing relevant medical knowledge, developed with CDS application in mind;
2. standard formats for general types of CDS interventions to convey this knowledge that can be readily incorporated into a variety of clinical information systems;
3. a knowledge service that collects, organizes, and makes available validated knowledge and specific interventions related to the target conditions in standard format;
4. proof of concept implementation of the above standards and services in multiple health care settings and in a variety of clinical information systems;
5. an organized collection of best practices for deploying CDS interventions reliably and successfully to improve outcomes in the targeted areas;
6. measurement and assessment of the usage of the above interventions, and an evaluation of their impact on patient care processes and outcomes, specifically on safety, efficiency, cost, and quality of care;
7. documentation of issues critical to successfully generalizing the lessons learned from these pilot initiatives to broader deployment of CDS (e.g., to support other conditions, other goals, other situations) and recommendations for successful scaling of benefits.

This project focused intensely on the first four of these deliverables, prerequisites to the latter three, in order to move the CDS Roadmap forward.

Setting: Practice Based Research and Real World Applications

Beyond the challenge of developing this foundation for CDS, there is the problem of translating results from large academic centers to community-based practice. A recent

systematic review found that while there is a large body of research concerning the benefits of HIT, a quarter of the studies originated in four exemplar institutions (Chaudry, 2006). This raises questions of generalizability and of translating the findings of research about complex technologies with extended implementation timelines that require significant local organizational integration. A recent review focusing on medication management technologies found overall improvements in prescribing and monitoring phases of medication management, but also found reports of harmful effects, notably when the HIT “system disrupts existing workflow and processes.” (McKibbin, 2011)

To address this need for HIT research that applies to community settings and practices, the RxSafe project has been based in the AHRQ-funded Oregon Rural Practice Based Research Network (ORPRN), a network of research oriented but community-based practices and clinicians which offers a real-world context for translation of clinical research about diagnostic and therapeutic interventions, but also provides a laboratory for studies of information interventions such as CDS. As Westfall, et al. put it, “Practice-based research may be the blue highway between the academic interstate of basic and clinical research and the tree-lined streets where the majority of Americans live and obtain medical care.” (Westfall, 2007)

Participants: Distributed Multidisciplinary Medication Management

For all the challenges that have been described for managing medications in acute hospital care, (such as medication errors and ADEs), and in ambulatory treatment of single conditions, (such as physician compliance with guidelines, and patient adherence to treatments), medication management is most complex in the long-term care of persons with multiple chronic conditions. For a single disorder, the goals of therapy and the means to achieve them may be clear, but long term management of multiple conditions requires priority setting among co-morbid conditions; consideration of drug-drug and drug-disease interactions; dose adjustments for therapeutic effects or because of side effects; and day-to-day operationalization according to differences in diet, activity, cognition, and other individual circumstances. In these cases, the sheer complexity of medication regimens can be daunting for even the most motivated patients and practitioners.

Management of medications in these settings is a distributed process. It is distributed *across disciplines* as the separate steps of prescribing, dispensing, administering, monitoring, and reconciliation of medications are accomplished by physicians, pharmacists, nurses, caregivers, and patients themselves. It is distributed *across settings* as these activities take place in the clinic, in the hospital, over the telephone, in long-term facilities, or in the home. It is *distributed over time*, as a series of decisions and adjustments are made by the participants according to changing requirements, resulting in continuous remodeling of the medication regimen. It is *distributed across information systems* which, whether paper based or electronic, have each been designed to perform a specific task in a specific setting, generally with little thought to interaction or exchange with others.

In most of the US, these activities take place in organizations that are independent and sometimes in competition with one another: clinics, retail pharmacies, hospitals, nursing homes, patients' homes. As a rule, the processes and the information systems and flows that support them have been fragmented and isolated, each developed and refined to support the requirements of the organization in which they take place: physician's offices, retail pharmacies, long-term care facilities, etc. Coordination has occurred only through great effort, primarily by means of telephone, fax machine, or personal interaction.

This project was highly responsive to the goals and areas of emphasis of RFA-HS-07-006: Ambulatory Safety and Quality Program: Improving Quality through Clinician Use of Health IT: it targeted medication management by a “cross disciplinary team” for a priority population (rural elders with special health care needs) in the ambulatory settings of a rural practice based research network; it investigated novel methods of clinical decision support by understanding clinical workflows; and it addressed coordination of care in the context of “movement of patients between health care providers and settings as their conditions and care needs change during the course of a chronic or acute illness.”

Inclusion of Priority Populations

This project focused on the care of chronically ill elders in rural Oregon with residing in assisted living or skilled nursing facilities because of special needs and disabilities.

Methods and Results

Aim 1: Meaningful Presentation

Enhance clinician cognitive performance in medication management tasks by exploiting the underlying semantics of medication lists to improve the organization and presentation of medication list information.

Founded in the observation of Shipman and Marshall that “a representation that is suitable for one task may not be appropriate for a similar related task,” (Shipman, 1999) as well as work by Hutchins on the use of different representations of the same information for different tasks, (Hutchins, 1995) we reasoned that a simple way to provide cognitive support to clinicians would be to reduce the cognitive demands of clinical information tasks through more helpful representation of information. We explored this hypothesis by observing medication information representations created and used by clinicians; exploring the ordering or categories used by clinicians; and testing clinician recall and mental model formation according to the arrangement of medication information presented to them.

Aim 1: Meaningful Presentation—1.1. Observation of Medication Information Representations in Clinical Use

Methods and Data Sources. We used naturalistic observation to examine arrangements of medication information in a convenience sample of health information systems.

Figure 1. Illustrative medication lists (On the left, no order seems apparent. On the right there appears to be an ASCII sort, and a '.' has been added before some items.)

LANTUS SOLN (INSULIN GLARGINE SOLN) 24 units sub every every pm	Active Medications
HUMALOG SOLN (INSULIN LISPRO (HUMAN) SOLN) 5 units sub every three times a day with meals	Scheduled
FLUOXETINE HCL 20 MG CAPS (FLUOXETINE HCL) 1 tab by mouth daily	07/04/08 .DAUNOrubicin 46 mg IV Fr
ASPIRIN 81 MG CHEW (ASPIRIN) 1 tab by mouth daily	07/11/08 .Methotrexate 15 mg intrathecal q24h interval
FLUCONAZOLE 200 MG TABS (FLUCONAZOLE) 1 tab by mouth daily until 4/29	07/04/08 .VinCRISTine 2 mg IV Push Fr
FREESTYLE TEST STRP (GLUCOSE BLOOD) Test CBG's four times daily	07/10/08 Lasix 20 mg IV q24h interval
FREESTYLE LANCETS MISC (LANCETS) Test CBG's four times daily	07/04/08 MethyIPREDNISolone Na Succ 44 mg IV q12h interval
FREESTYLE SYSTEM KIT (BLOOD GLUCOSE MONITORIN) Test CBG's four times daily	07/04/08 Ondansetron 8 mg IV q8h interval
	07/04/08 Promethazine 25 mg IV q6h interval
	07/11/08 azithromycin 250 mg IV q24h interval
	07/04/08 cefepime 2 gm IV q8h interval

Results. There was great variation in medication list arrangement in different systems and in the same systems. Some medication lists appeared to have an internal order, such as alphabetical by drug name, or by date, while for others, no order was apparent. Figure 1 shows two such lists. The list on the left has no apparent order. The list on the right appears to be sorted by ASCII code (uppercase before lowercase!) ignoring the convention of using lowercase for generic drug names (“Promethazine”) and Proper case for brand drug names (“Lasix.”) This is somewhat complicated by use of TallMan lettering (“VinCRISTine”) in that uppercase letters can change the sort order, depending on their position. Interestingly, at the top of the list are items to which a preceding dot character has been added (“.DAUNOrubicin”), forcing them to appear at the top of an ASCII sorted list. All of these with preceding dots are chemotherapeutic agents. The name of the drug has been changed in the system in order to force these to appear at the top of the list – perhaps because of their clinical importance as powerful agents with dangerous side effects. We did not examine whether changing the name in the system interfered with other functionality such drug-drug interaction checking, search functions, and the like.

In other cases, we observed that medications in a list had been rearranged and indented in groups, illustrated in Figure 2. In these cases, the order of medications in the list had been modified, with indentation suggesting groupings, and the groups suggesting common indications or categories. In Figure 2, for example, at the top are two mental health medications, followed by two used for diabetes, then two for hyperlipidemia, then four for hypertension, followed by five medications with miscellaneous indications. The list suggests, by inference, the conditions on the patient’s problem list as well as their severity (hypertension requiring four drugs). Clinicians who used the system reported it was worth the significant time and effort to produce these arrangements.

Figure 2. Ordering and indentation (The list is arranged, using indentation to create groups of items, which appear to be by common indication. See text.)

Description	Instructions	BMN?
SEROQUEL 200 MG TABS (QUETIAPINE FUMARATE)	1 by mouth once a day	
LORAZEPAM TAB 0.5MG (LORAZEPAM)	1 by mouth twice a day	
METFORMIN HCL 1000 MG TABS (METFORMIN HCL)	1 by mouth twice a day	
GLYBURIDE MICRONIZED 3 MG TABS (GLYBURIDE MICRONIZED)	2 by mouth twice a day	
SIMVASTATIN 80 MG TABS (SIMVASTATIN)	1 by mouth once a day	
GEMFIBROZIL 600 MG TABS (GEMFIBROZIL)	1 by mouth twice a day	
TOPROL XL 100 MG TB24 (METOPROLOL SUCCINATE)	1 by mouth once a day	
NORVASC 10 MG TABS (AMLODIPINE BESYLATE)	1/2 by mouth once a day - NEW D	
TRIAMTERENE-HCTZ 37.5-25 MG TABS (TRIAMTERENE-HCTZ)	1 by mouth once a day	
LISINOPRIL 20 MG TABS (LISINOPRIL)	1 by mouth once a day for high blc	
LEVOXYL 125 MCG TABS (LEVOTHYROXINE SODIUM)	1 by mouth once a day	
AZMACORT 75 MCG/ACT AERS (TRIAMCINOLONE ACETONIDE)	4 puffs twice a day	
DETROL LA 4 MG CP24 (TOLTERODINE TARTRATE)	1 by mouth once a day as needed	
LOPERAMIDE HCL 2 MG CAPS (LOPERAMIDE HCL)	1 by mouth qid as needed for diar	
ASPIRIN 81 MG TBEC (ASPIRIN)		

Conclusions. These observations supported the hypothesis that arrangement of information may be important to clinicians and might be important to providing cognitive support for medication management tasks.

Aim 1: Meaningful Presentation—1.2. Medication Information Categories: Card Sort Experiments

To make use of the observations in Aim 1.1 in clinical decision support, we next turned our attention to questions of order: What categories make sense to clinicians? Do these categories vary by discipline, by role, or by task?

Methods and Data Sources. We performed two rounds of card sort procedures (Worden, 1976) to determine the categories used by clinicians performing medication related tasks. Four actual medication lists containing 25 items were deidentified and used to create four sets of 25 index cards, each with the name of the medication in very large type and remaining prescribing information in large type, like a recipe card. Subjects were given a shuffled stack of 25 cards, asked to (1) read each card aloud; (2) sort the cards into piles in whatever way made sense to them; and (3) label each of the piles. This was repeated for four trials. Subjects in Round 1 were senior level or higher students in nursing (3), pharmacy (1), and medicine (4: 2 fourth year medical students and 2 physicians within three months of graduation). Subjects in Round 2 were rural community based clinicians including pharmacists (2), physicians (2), and home health or administrative nurses (2).

Results. In Round 1 we found that the three disciplines sorted the cards in different ways. Figure 3 illustrates a typical grouping by senior nursing students. Medical students sorted medications according to organ system or indication (gastrointestinal, cardiovascular) while

nursing students sorted medications according to timing and route (daily or monthly; oral or injectable). Pharmacy students sorted medications according to indication but with a subtle difference – pairing medications with one another based on expected side effects: a narcotic analgesic would be paired with a stool softener meant to prevent the side effect of constipation, a potent diuretic would be paired with a potassium supplement to prevent the side effect of potassium depletion.

In Round 2 we replicated these results with community based clinicians in the same three disciplines. Results were essentially the same for physicians and pharmacists, but the nurses sorted medications by organ system or indication, commenting that their roles (home health nurse and nurse manager in a long term care facility) involve education of patients and caregivers about their medications, as opposed to the medication administration roles of the senior nurses in Round 1.

Figure 3. Typical senior nursing student card sort (Medications are sorted by route and timing of administration.)

<i>Daily PO Chronic</i>	<i>Daily with Limited Duration</i>	<i>Daily Psychotrope Chronic</i>	<i>Every Other Day Constipation</i>	<i>Bedtime Dosing</i>
Risperdal	Paxil CR	Zyprexa	Milk of Magnesia	Vagifem
Potassium Chlor.	Nicotine Patch	Zoloft		
Multivitamin				
Furosemide				
Estradiol				
Digoxin				

<i>Antianxiety/Sleep Bedtime</i>	<i>BID-QID Oral Meds (not critical)</i>	<i>Monthly Injection</i>	<i>Long Acting Oral Analgesic</i>	<i>As Needed</i>
Clonazepam	Mi-Acid	Vitamin B12	Methadone HCl	Calmoseptine
	Senna			DuoNeb
	Ranitidine			Fleet Enema
	Calcium Carbonate			

Conclusion. Clinicians sorted medications according to different categories, but the categories may depend as much on the task being performed as on the discipline of the clinician.

Aim 1: Meaningful Presentation—1.3. Impact of Medication List Order on Recall and Clinician Mental Model

Using results from our card sort experiments, we turned our attention to assessing the importance of list order for medication management tasks: How is cognitive performance affected by the arrangement of information? How is task performance affected by the arrangement of information? We examined the impact of medication list order on medication list

recall and mental model formation (inferred problem list) using a simulated medication reconciliation task.

Methods and Data Sources. We modeled our procedure on the classic experiment of Chase and Simon (Chase, 1973) in which the recall of pieces on a chess board was tested in novice, intermediate, and master chess players, comparing recall with pieces in random positions to recall with pieces in meaningful patterns (drawn from classic chess games). We expected that, like Chase and Simon, recall would be greater for experts when information was presented in meaningful arrangements compared to random arrangements. We created a replica “Discharge Medication List” and populated it from actual 20 item medication lists that had been deidentified, organizing items at random or grouped by organ system (cardiovascular, diabetes, gastrointestinal, etc.) Subjects were given a manual medication reconciliation task, now familiar to most clinicians. Starting with the replica Discharge Medication List (random or ordered), subjects were informed that “the computerized medication reconciliation system is down,” and asked to copy the medications to a replica Medication Reconciliation Form for their first clinic visit. They were not asked to process the medication list in any other way. Medication lists were taken away when completed. Following a distractor task (calculating the patient’s body mass index), subjects were given lined blank paper and asked to list the patient’s medications. On completion they were given a second sheet and asked to list the patient’s problems (with no access to a problem list or other data. Each subject completed two trials, one with a random list and one with an organized list, and the order of which was presented first was randomized across subjects. These data were used to calculate the recall and formation of a mental model (problem list) of the patient by each clinician.

Subjects included 10 second year medical students (novices with first year pharmacology knowledge); 7 internal medicine residents (second or third year residents with intermediate level knowledge) and 5 general internal medicine attending physicians (experts with multiple years post residency experience).

Results. We found that recall of medication list items corresponded to experience level, with attendings recalling a median of 14 of 20 medications overall, residents a median of 10.5 of 20 items, and preclinical students a median of 8.5 items. Student recall was greater with an organized medication list, but resident and attending recall was not affected by order, in contrast to our expectation.

Table 1. Recall of medication list items for students, residents, and attendings

	students	residents	attendings
Median recall of medications, all trials (random list plus organized list), out of 20 items	8.5	10.5	14
Median gain with organized list compared to random list	2	0	0

On inspection of the medication lists, however, we noted that lists had been rearranged and annotated by the attendings, although they had been asked only to copy the list from one form to another. Attending clinicians reorganized randomly ordered lists, sorting or grouping by indication, annotated their lists with question marks and check marks, and in some cases completely omitted presumably short term medications such as antibiotics. Two attendings reflected that they found the random list easier to recall – because of the work they had to do to

reorganize it. Problem lists were longer for students than for attendings, with students listing more items separately and attendings tending to group conditions into higher level diagnoses or syndromes, consistent with the model of Evans and Gadd (Evans, 1989).

Conclusion. We anticipated that organization of medication information would improve recall, but found data to support this only for novices. However, it may be that *processing* of the list by the clinician is the more important factor. Recall by experts was high in either case, but subjectively they reported it was easier to recall the list items when they had to reorganize the lists themselves.

Aim 1 Outcomes

The outcomes of the work under Aim 1 were to inform our work under Aim 4, and presentation of findings to the biomedical informatics and human factors research communities:

- Gorman, PN. “That’s Just Semantics” Meaningful presentation and physician task performance” OHSU General Internal Medicine Research Conference, 2/10/2009
- Xiao Y, Fairbanks RJ, Gurses AP, Nemeth C, Roth E, Wears RL, Gorman PN “User Created Cognitive Artifacts: What Can They Teach Us About Design of Information Technology?” Human Factors and Ergonomics Society 53d Annual Meeting, San Antonio, TX. 10/19/2009.
- Gorman P, Richardson J, Russ A, Militello L, Xiao Y. “Supporting cognition and decision making in clinical work. Human Factors and Ergonomics Society's 54th Annual Meeting. San Francisco, CA. 9/27/2010.
- Lazzara EH, Weaver SJ, Karsh B-T, Guerlain S, Metcalf D, Marquard JL, Gorman PN. “Just What the Doctor Ordered?: The Role of Cognitive Decision Support Systems in Clinical Decision-Making & Patient Safety.” Human Factors and Ergonomics Society's 54th Annual Meeting. San Francisco, CA. 9/27/2010.
- Gorman PN, Richardson J, Russ A, Militello L, Xiao Y. “Supporting cognition and decision making in clinical work”. Human Factors and Ergonomics Society's 54th Annual Meeting. San Francisco, CA. 9/27/2010.
- Weaver SJ, DiazGranados D, Wears RL, Patterson ES, Rosen MA, Flin R, Gorman PN. “Healthcare Recovery: How the Science of Human Factors is Challenging Healthcare to Move Patient Safety Forward Human Factors and Ergonomics Society's 54th Annual Meeting. San Francisco, CA. 9/27/2010.
- Seagull FJ, Fairbanks RJ, Xiao Y, Eibling D, Gorman P. “Debate: Is There Low Hanging Fruit in Health Care Human Factors.” Human Factors and Ergonomics Society's 54th Annual Meeting. San Francisco, CA. 9/27/2010.

Aim 2: Assisted Reconciliation

Implement medication list management tools that are integrated into clinician-specific and task-specific workflows to support medication reconciliation, at high-risk transitions as well as in ongoing ambulatory care.

Aim 2 was initially viewed as a software engineering task, to create a novel software tool designed to reduce the cognitive load of medication reconciliation and thereby assist clinicians performing this task in long term care settings. To inform this design we planned naturalistic observations and field interviews with nurses, pharmacists, and physicians to understand the information requirements of the task. However, from the very first observation it became clear that in most cases "medication reconciliation" does not adequately describe what these clinicians perform and that a more robust understanding would be necessary to augment task performance. As a result, we redirected our efforts to understanding in a deeper way the cognitive properties and requirements of medication management tasks performed by nurses, pharmacists, and physicians in the care of elders with chronic conditions.

Methods and Data Sources. We used naturalistic observation with field interviews and iterative analysis, using a snowball sampling technique to find new subjects and tasks across the spectrum of out-of-hospital care for chronically ill elders. In all we completed 90 hours of fieldwork with 10 clinicians during 14 sessions of medication management activities. Subjects, settings, and tasks included 1) a Residential Care Manager (a Registered Nurse) in a skilled nursing facility who performs a monthly "recap" of all patients' orders and treatments; 2) an outside consulting pharmacist who reviews medications in periodic visits to long term care facilities; 3) pharmacy technicians in a specialized long term care pharmacy who perform a monthly comparison and update of patients' medication lists prior to packaging and distribution to long term care facilities, referred to as "doing the yellows," after the yellow copies used in this task for annotation, clarification, and batch processing; 4) hospital based nurse consultants reviewing care at unskilled nursing facilities; 5) home health nurses performing home services including reviewing medication management; and 6) a physician (MD) and a medical assistant (MA) in ambulatory practice, who together perform medication review, each focusing on different components of the task: the MA gathering information and tracking changes in medications, the MD assessing for effects and side effects and prescribing or adjusting prescriptions.

Analysis of these data began with structured "case reports" for each subject and task, describing the care setting, the subject, the goals, the specific environment for performing the task (often a separate dedicated space), the tools and cognitive resources observed in use, and the process as it was observed by the researcher, augmented by examination of artifacts and notes from after-interviews with subjects.

Results. We observed that medication management in long term care is a distributed and multidisciplinary process, where safety is an emergent phenomenon, arising not simply out of "reconciliation" that looks for *correspondence* of items in a medication list, but rather out of the pursuit of *coherence* in a model of the patient and their care that integrates many types of patient data and medical knowledge. The activity is distributed, dynamic, collaborative, and continuous, involving multiple health professionals separately performing complementary tasks in different

settings. These processes require a variety of cognitive resources, both external (medication records, diagnostic information, laboratory data) and internal (specialized expertise in pharmacology, nursing, medicine), augmented by personal familiarity with the patient himself. Hence, this overall picture of medication management is of a distributed activity system. (Hazlehurst, 2008)

Figure 4. Pharmacy workspace for “doing the yellows” (Physical arrangement and movement of cognitive artifacts and resources facilitates task performance.

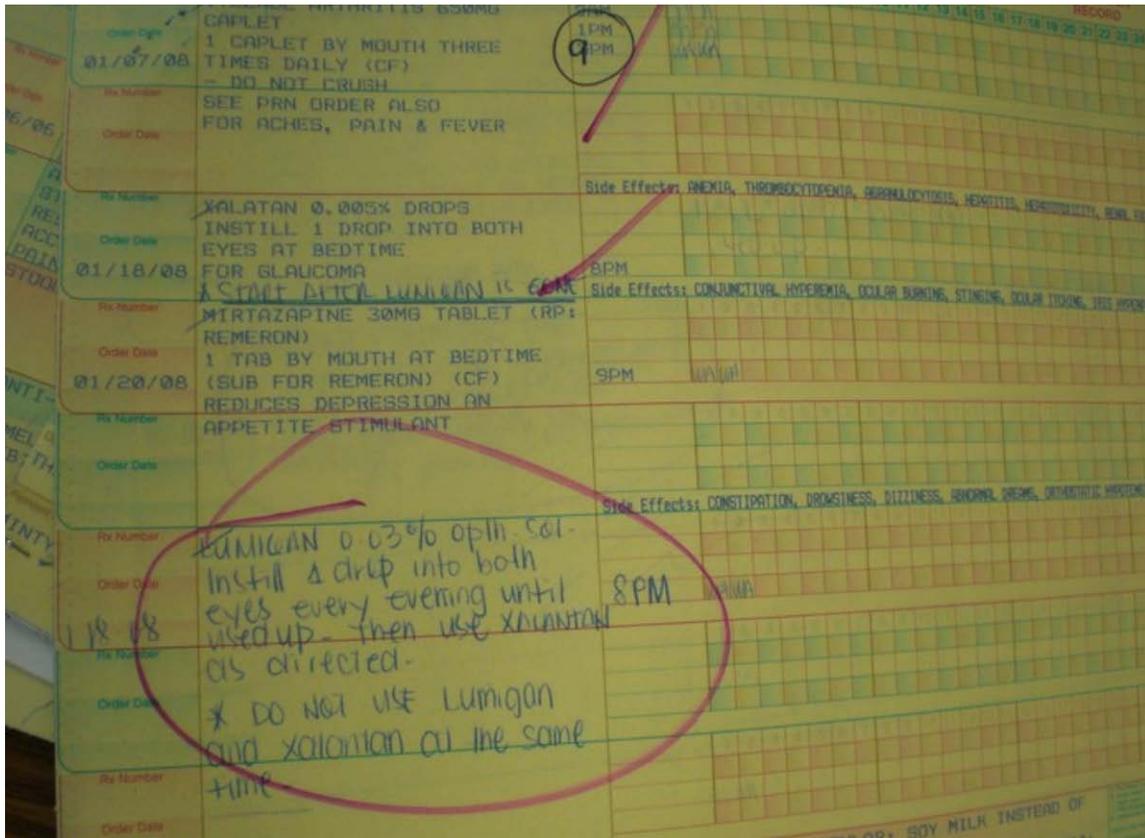


We also observed medication management tasks as sociotechnical phenomena, deeply embedded in their respective care settings. Individual tasks such as “recap” by the Residential Care Manager in a skilled nursing home, or “doing the yellows” by pharmacy technicians in the long term care pharmacy, were performed in service of and tightly integrated with multiple organizational and individual goals: physical care of the patient, documentation of care, compliance with regulations, billing and payment, supervision of other care providers. Furthermore, we observed a variety of sociotechnical strategies that were employed to support performance of these tasks. An example is the collection of practices to minimize disruption and promote concentration through the use of separate physical spaces, background music (as distinct from other workers performing other tasks in the same workplace), and informal social practices that reduce interruptions. Task performance was dependent on the affordances of the cognitive artifacts and physical spaces where these tasks were performed. Figure 4 illustrates the

arrangement of cognitive resources and the flow of cognitive artifacts for “doing the yellows” by pharmacy technicians. Document arrangement provides implicit information, including current task state. Document annotation (Figure 5) helps maintain state, indicates need for further attention. Separating document permits “batch processing” of subtasks such as contacting physician offices for clarification or traveling to records room to consult other documents.

Full details of the analysis and synthesis of these data can be found in the published doctoral dissertation describing this work. (Bhupatiraju, 2011)

Figure 5. Annotation of “yellows” (Meaningful annotations help maintain state across interruptions, indicate need for further attention, facilitate batch processing)



Conclusion. “Medication Reconciliation” may occur as an isolated procedure designed to document compliance with regulations, but medication management in long term care was a richer, more robust, and more complex process which is distributed, dynamic, collaborative, and continuous, involving multiple health professionals separately performing complementary tasks in different settings over time.

Outcomes. The principal outcomes under Aim 2 were to inform and guide work under Aim 3, as well as presentations to the biomedical informatics research community:

- Bhupatiraju RT, Gorman PN. "Doing the yellows" – Analysis of medication review processes by different clinicians in long term care” American Medical Informatics Association Annual Meeting, San Francisco, CA. 11/14/2009.
- Gorman PN. "Understanding Medication Management Activities in Long Term Geriatric Care.” OHSU Biomedical Informatics Research Conference, 9/20/2010.
- Bhupatiraju RT, Gorman PN. Correspondence and Coherence: A theoretical model of medication management activities. (manuscript in preparation)

Aim 3: Distributed Decision Support

Increase the effectiveness of medication management activities of clinicians in multiple roles by improving their coordination and communication through the use of shared medication management tools.

A “medication list” is a moving target: antihypertensives are adjusted to achieve a goal; antibiotics added for infection; analgesics adjusted, stopped, resumed to control pain. Primary care clinicians, consulting physicians, nurses, pharmacists, and patients usually track medications in separate systems tailored to their individual roles and tasks, as well as to organizational requirements. Rarely are these systems integrated so that everyone is “on the same page.” The result is multiple separate medication lists for a given patient which do not agree, jeopardizing patient safety and increasing workload as clinicians re-enter data and work to resolve discrepancies among lists.

The goal of Aim 4, consistent with the CDS Roadmap (Osheroff, 2007) was to develop a “proof of concept” prototype technology for collaborative medication management, one that would enable interaction among disparate medication information systems and improve collaboration among the clinicians using them, so that medication lists could be maintained in synchrony.

Design and Methods. Based on our previous work in the RxSafe project and on our findings under Aim 2 above, we assumed asynchronous, distributed activity by multiple users of diverse non-interoperating applications in independent organizations. We designed our prototype for such an environment, which characterizes much of the real world of out-of-hospital care.

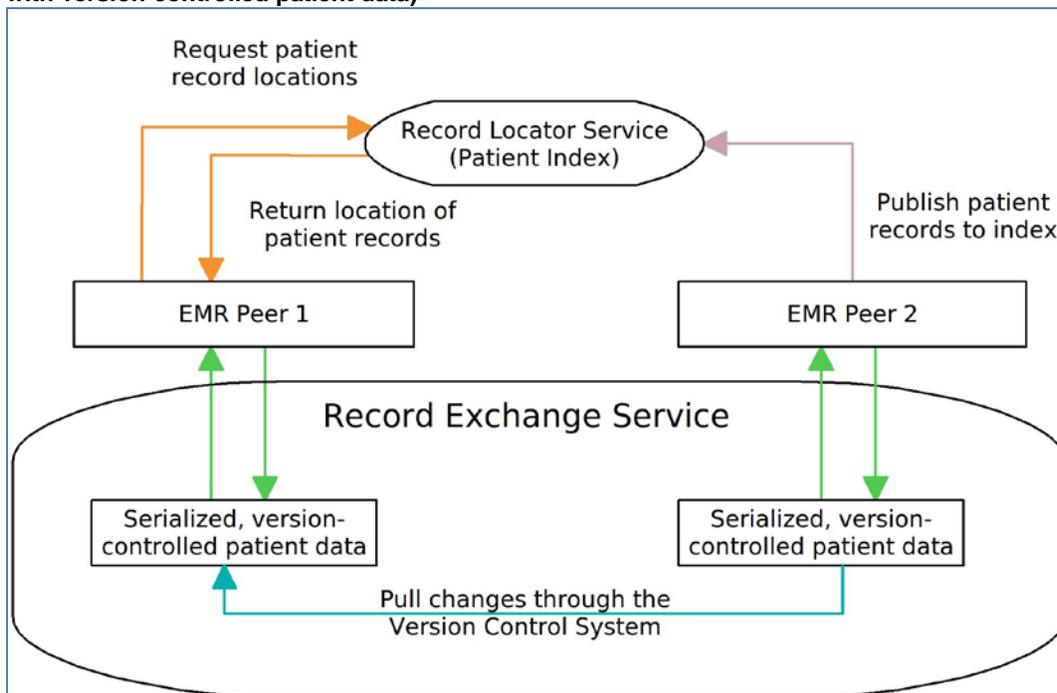
A common approach to this problem is *organization-centric*, adopting a single enterprise-wide health information system to be used for all medication management tasks within a single organization. This approach is severely limited because it is only useful within one organization, while patients typically receive care from many. A second common approach to this problem is *application-centric*, requiring multiple organizations to agree to use the same software application, implemented in the same way, to enable sharing. This approach is also severely limited because of the formidable challenges not only of achieving identical implementations in diverse organizations, but also because of its requirement for cooperation, which can be difficult

to achieve in a fragmented health care system based on competition among health systems rather than collaboration. For these reasons we chose a third approach, based on the Markle Foundation Common Framework model for health information exchange (HIE) (Markle Foundation, 2006) which incorporates distinct Record Locator Service (RLS) and Record Exchange Service (RES) to accommodate such an environment.

A second design choice concerned the underlying technology for synchronizing information across disparate data sources and users. A single database model would allow many users but requires a single shared database system, which we rejected for the reasons cited above. A synchronizing server model, such as for synchronizing personal information across multiple devices generally assumes multiple devices sharing data for a single user, also not a good fit. We instead chose to use a Version Control Model, such as is used in collaborative software development, based on asynchronous distributed use by many users, with the system keeping track of versioning, authorship, and the like. Our combination of the Markle Common Framework model for HIE with a version control model for distributed collaborative development is depicted in Figure 6.

Implementation Results. We developed a SyncRx prototype to demonstrate the feasibility of a synchronization system and to explore technical issues prior to further testing. The RLS was implemented using the Apache Jackrabbit Content Management Repository (Souer, 2008) to store and search for patient demographic information and record locations. We implemented our synchronization framework using OpenMRS, (Wolfe, 2006) an extensible open source medical record system that supported the development of custom modules including patient and provider client applications and a synchronization module to serialize data between the version controlled repository and the EMR's database.

Figure 6. SyncRx Model (A Record Locator Service (RLS) and a Record Exchange Service (RES) combined with version-controlled patient data)



Synchronization was managed by the Mercurial distributed version control system. (O’Sullivan, 2009) It provides a set of basic operations, such as push, pull, and merge, to coordinate the changes between repositories, or in our case, medication lists as well as the functionality of transferring repositories securely over HTTPS and SSH. Push, pull, and merge operations for exchanging data among independent clients were implemented and provided with corresponding buttons in the user interfaces to enable synchronization of a medication list. Actual transfer of information occurred through the Apache web server (Laurie, 2002). The model we implemented is shown graphically in Figure 7, where independent devices and applications interact and are kept in synchrony by the system. A physician e-prescribing application on a mobile device (bottom left), a patient health record on a home device (top) and a hospital or pharmacy system running within an organization are able to interact such that changes in the medications listed in one system can be automatically posted to the other devices, allowing users to view the changes, approve or modify them, and update their own system information without repetitive data entry which is currently required.

Conclusion. We were able to demonstrate the technical feasibility of a our synchronization system using open source tools, but further exploration of this prototype is limited to use of Open Source tools including OpenMRS because of the difficulty of interacting with proprietary closed systems produced by EMR vendors. The next step in this program of research is to deploy the prototype with users including patients, prescribers, pharmacists, and others to elucidate the issues arising out of user interaction with such a system.

Outcomes. The principal outcomes of the work under Aim 3 were a functional prototype demonstrating technical feasibility of a collaborative medication information management technology, and presentations to the biomedical informatics and technology development communities:

- Gorman PN, Bahr N, Bhupatiraju RT, Lam P. “Supporting Distributed Collaborative Medication Management for Chronic Conditions.” National Library of Medicine Lister Hill Center. 6/3/2010
- Bahr N, Bhupatiraju RT, Lam P, Gorman PN, “SyncRx: A prototype medication record exchange service” (poster) Agency for Healthcare Research and Quality HIT Conference, Bethesda, MD. 6/4/2010.
- Bhupatiraju RT, Gorman, PN. “CDS Pipeline: A component architecture for inter-operable decision support.” (poster) Oregon Innovation Showcase, Portland, OR. 11/2/2010.
- Bahr N, Bhupatiraju RT, Lam P, Gorman PN. Developing a Prototype Collaborative Medication Management System: Alternative Solutions and Design Considerations. (manuscript in review)

Aim 4: Web-Based Clinical Decision Support

Employ evolving standards and architectures to link external, machine actionable, evidence-based clinical information in context- appropriate and user-appropriate ways to support shared medication management by clinicians practicing in ambulatory settings.

The goal in Aim 4, consistent with CDS Roadmap objectives 1-4 (Osheroff, 2007) was to use standard formats for encoding and storing medication information, connect this information to web-based medical knowledge sources, and create a prototype that demonstrated the feasibility of web based clinical decision support using independent interacting applications and data.

Design and Methods. For maximum flexibility and applicability across disparate medication management systems and applications (the current HIT environment as described above), we used a web services model that allows interoperable interaction of independent applications in a service oriented architecture with loosely coupled services deployed over a network. We chose to implement services for parsing, identification, classification, and enhancement of information contained in medication lists. *Parsing*, because in our experience with the RxSafe system, medication information obtained from existing systems often is available only in unstructured form (e.g. the “Blue Button” option deployed by the Department of Veterans Affairs (VA) system), and even with structured databases parsing becomes necessary because of differences in implementation. *Identification*, because we found negligible use of standards (such as RxNorm) for drug identification and no consistency among systems: hence no way of computing that the string “lisinopril” in one system refers to the same thing as the string “lisinopril” in another. *Classification*, because in our work with the RxSafe system and in Aim 1 described above, clinicians process information about medications in terms of drug classes. Finally, by *enhancement*, we refer to locating and retrieving additional information (side effects, costs, indications) not present in the medication lists, that may be relevant to decisions being made by system users.

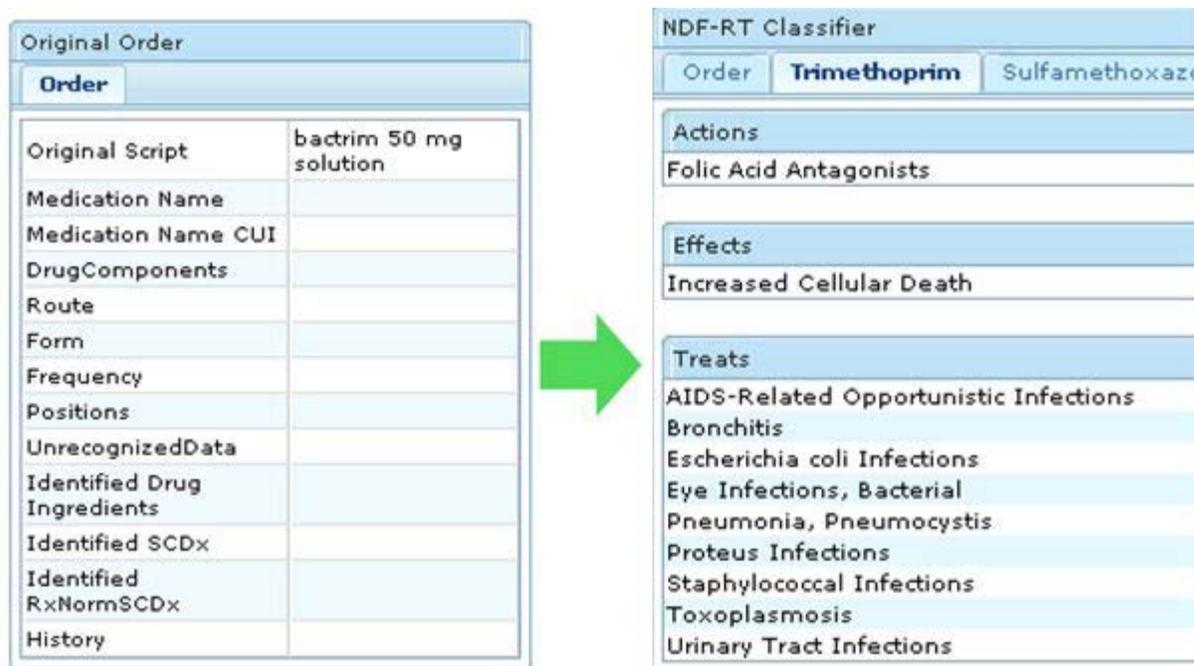
Implementation Results. Although parsing seemed to be a common problem, we found no available methods for reliably parsing medication list information, so our team developed and refined two approaches, the “fall through” parser and a parser based on grammar. Drug names available from the parser (or other sources) were then identified in terms of their respective Concept Unique Identifier s(CUI) assigned by RxNorm, using the public application programming interface (API) from the National Library of Medicine. Classification was more of a challenge, because we although found many schemas for classification (US Pharmacopeia, American Hospital Formulary System, World Health Organization ACT system) we found no standard for the classification of therapeutic agents that spans information systems currently in use. After investigating these classification systems, we chose to interact with the National Drug Formulary-Reference Terminology (NDF-RT) developed and maintained (though incompletely) by the VA. For enhancement, we investigated the use of Structured Product Labels published by the Food and Drug Administration and available through the Daily Med web site, choosing this source because we could exploit its XML format to interact with our system.

Connecting these independent services required a common format for representing the data, and for this we developed an XML format, RxOrder. Finally, to demonstrate the feasibility of our web services model for clinical decision support of medication management, we developed a

prototype web service for their interaction. As a further challenge to this implementation that would ensure real-world applicability, we developed these modules using different languages including Visual Basic, C#, Perl, and Python, and on different platforms including .Net, JVM, and MacOS.

The final prototype was implemented to accept a raw string from a medication list, convert it to RxOrder format, parse (if required) to determine the medication name, identify its RxNorm CUI, then retrieve the drugs classification from NDF-RT. Figure 7 shows an example, where the input string “bactrim 50 mg solution” has been parsed, identified as a combination containing trimethoprim and sulfamethoxazole, and then displayed with classification information including its mechanism of action, physiologic effect, and conditions for which it is indicated (using NDF-RT classes).

Figure 7. Web services model output (A raw medication list string—left panel—has been parsed, identified, classified, and enhanced with knowledge of indications—right panel)



Conclusion. We developed a prototype that demonstrated the feasibility of independent web based decision support services interacting in a service oriented architecture over a network. This prototype will allow further exploration of the technical issues we encountered, such as differences in drug terminologies used in existing systems, speed or access constraints of web-based knowledge services, inclusion of extraneous data in medication information fields of local systems, and agreement on useful common classification schema for medication information. Ideally, the expansion and implementation of this web based clinical decision support architecture can allow multiple developers, health systems, or vendors to make use of publicly available functionality (parsing, identification, classification) or publicly available medical knowledge (FDA product labels, NLM Medline Plus information) without having to “reinvent the wheel” for each of the services or separately curate local knowledge bases. It offers the

potential for creative new applications to be created as “mash-ups” of existing services and data. For example, an application could be created to allow a patient with a symptom such as dizziness to query whether any of their medications could cause that symptom as a side-effect – the ‘mash-up’ application could then combine existing functions and knowledge sources to return answers to such questions.

Outcomes. The outcomes of the work under Aim 4 were functional prototypes demonstrating technical feasibility the web services model, available for further development in subsequent projects or by others, and presentations to the informatics and development communities:

- Agrawal N, Rayner N, Bhupatiraju RT, Gorman PN, Maier D. “Evaluation of Conformity and Regularity of Structured Product Labels.” (poster) American Medical Informatics Association Annual Meeting, San Francisco, CA. 11/14/2009
- Gorman PN. “Medication Management in Long Term Care: the RxSafe Project.” Agency for Healthcare Research and Quality HIT Conference, Bethesda, MD. 6/3/2010.
- Tong T, Saito K, Binek S, Goodale M, Gorman PN. “Guideline-based automated clinical decision support - are we ready?” (student poster) American Society of Hospital Pharmacists Midyear Clinical Meeting
- Gorman PN, Maier D, Rayner N, Bhupatiraju RT, Vimegnon Y, Lam P, Rhoton D, Bahr N. “Web-Based Decision Support Services for Parsing, Identification, and Classification of Medications.” National Library of Medicine Lister Hill Center, 6/3/2010
- Gorman PN. “Medication Management in Long Term Care: the RxSafe Project.” Presentation to Office of National Coordinator site visitors. Portland, OR. 5/5/2011.

Discussion

Implications. Clinicians process medication information in terms of medication classes, and allowing task specific arrangement and rearrangement of information may provide substantial decision support by reducing the cognitive load of this processing. Medication management in long term care is more complex and more robust than current conceptions of “medication reconciliation” and further work is needed to improve the cognitive support of these activities by understanding and providing for the cognitive resource requirements as well as the sociotechnical realities of their performance in situ. Medication management in long term care is a dynamic, continuous multidisciplinary process that is distributed across time, across settings, and across systems, and while current technologies provide minimal support for this collaboration, initial prototypes suggest that synchronization technology (such as SyncRx) and web based decision support services can be developed and deployed to provide improved cognitive support and enhance collaboration in these processes. An important option to enable these technologies to be developed and deployed and refined more rapidly is a collaborative, open source software development environment for medication management.

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List of Publications and Products

Products of this work include the software prototypes described above in Aim 3 and Aim 4, manuscripts in preparation listed above and one published doctoral dissertation.

Bhupatiraju RT. "Modeling Medication Management Practices: The Coherence Theory of Medication Activities." Doctoral Dissertation. Portland, Oregon: Oregon Health & Sciences University. 2011.