Just in Time Radiology Decision Support Using Real-time Data Feeds

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Abstract

Ready access to relevant real-time information in medical imaging offers several potential benefits. Knowing both when important information will be available and that important information is available can facilitate optimization of workflow and management of time. Unexpected findings, as well as deficiencies in reporting and documentation, can be immediately managed. Herein, we present our experience developing and implementing a real-time web-centric dashboard system for radiologists, clinicians, and support staff. The dashboards are driven by multi-sourced HL7 message streams that are monitored, analyzed, aggregated, and transformed into multiple real-time displays to improve operations within our department. We call this framework *Pipeline*. Ruby on Rails, JavaScript, HTML, and SQL serve as the foundations of the Pipeline application. HL7 messages are processed in real-time by a Mirth interface engine which posts exam data into SQL. Users utilize web browsers to visit the Ruby on Rails-based dashboards on any device connected to our hospital network. The dashboards will automatically refresh every 30 seconds using JavaScript. The Pipeline application has been well received by clinicians and radiologists.

Keywords Radiology dashboard · Real-time productivity · Pipeline · Decision support · HL7

Background

A review of communications from clinicians in our department, particularly with respect to stat radiology examinations, indicated that: (1) the majority of the time spent by our emergency clinicians in verbal communication with the radiology department involves tracking the progress of pending radiology examinations and reports. For example, inquiries such as “where is the patient in the radiologist queue” are frequently directed to the radiologist reading room to be resolved. (2) Radiology staff spend significant time fielding administrative requests via phone or instant messaging systems. Frequently, the same request is repeated from multiple people. These recurring low-value interactions can waste time and distract from patient care. In August 2015, our health system level 1 trauma center emergency department (ED) providers were surveyed regarding their utilization of radiology resources.

Approximately one quarter of the clinicians responded. On average, providers estimated that they utilized 20 minutes per 8-hour shift tracking radiology exams. This ED serves 10 provider shifts per day; we see a maximum potential of 1200 hours per annum to be returned to the ED clinicians. The survey further indicated a frustration with the various decentralized systems and dissatisfaction regarding inability to gauge “reasonable” turn-around-times for radiology exams. Our electronic medical record (EMR) stands separate from the picture archive and communication system (PACS) or radiology information system (RIS). Pipeline has an opportunity to centralize access to these systems and reduce the clinical barrier to entry.

Access to real-time workflow information provides a great opportunity to deliver improvements in patient safety. In our current process, radiology examinations can be electronically “misplaced” and/or stalled in workflow secondary to idiosyncratic events that can occur in the information systems used in our medical imaging and reporting chain. While rare, when this happens, an exam can be unreported for extended periods of time, potentially delaying diagnosis and care for a critically ill patient. A prototype Pipeline system revealed that every day, 5 to 10 ED radiology exams, of the several hundred performed, become delayed or lost in workflow. Without intervention, there is downstream delay in availability of a final report, often for several hours. The entire gamut of causes is

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beyond the scope of this review, but they include both human errors (e.g., exam accidentally marked as dictated in the PACS but not actually reported) and technology errors (e.g., exam reverts from “complete” to an incomplete status on the PACS whenever a modality sends additional data). In both cases, the unreported exam falls off the “unread” list of exams on the PACS and becomes invisible to radiologists.

Finding and rectifying such examinations manually is an inefficient, time-consuming, and inexact process, requiring the ED and radiology clinicians and staff to interrupt other clinical activities to periodically survey multiple reporting systems and initiate phone calls to nurses, technologists, and other staff. Our real-time dashboard provides up-to-the-moment display of all ED exams awaiting interpretation, sorted by waiting time, color-coded for quick recognition of outliers, providing immediate and comprehensive visibility for ED and radiology users, as well as providing hyperlinks into the PACS to quickly vet and mitigate a problem, all with minimal interruptions to ongoing clinical care. From a broader perspective, this system can be used to identify new areas for improvement in overall workflow and communication. Issues which today cannot be quantified by available methods and cannot be addressed in the absence of a dynamic monitoring system to identify and quantify these very issues.

Additionally, Pipeline is uniquely positioned to provide automated real-time analysis of radiology reports with dashboard displays of actionable issues. For example, a report that is missing information required for billing could trigger immediate notification of the reporting radiologist. Examinations appropriate for quality-improvement initiatives could be detected and shuttled into data streams for specific projects.

Pipeline solves radiology-centric ED workflow, time-management, quality-of-service, and patient-safety problems by making *crucial, actionable, current information available in real-time* and presenting it in unprecedented meaningful ways for the stakeholders (ED clinicians and staff), expediting their patient-care decisions and enabling early discovery of radiology workflow problems. The end result is that it helps our ED take better care of patients.

Consideration was given to commercially available systems. However, a system that integrated all relevant HL7 streams—multiple RIS, PACS, and VR spanning several institutions—and subsequently generated dashboards desired for our needs was not readily available. The challenge for vendors is that there is heterogeneity across facilities in systems, interfaces, and workflow. Needs and gaps are rarely identical from site to site. This tends to apply even to sites with the same EMR, RIS, PACS, and speech recognition systems. Therefore, every customer’s solution represents a highly customized product with costs unfeasible to vendors. To the contrary, these circumstances are well suited for an internal project that leverages current infrastructure as well as familiarity with existing systems, interfaces, and successful

prototypes. When this project was initially proposed in 2015, published articles supporting our implementation did not exist. PubMed searches for “HL7 Radiology Dashboard” and “Decision Support Radiology” return no results. Expanding the scope to include non-radiology instances, we were able to find resources describing the use of HL7 standards for CDSS outside of radiology. An initial PubMed search in August 2015 for “decision support HL7” in the previous 10 years returned 56 results. Based on the abstracts, we eliminated results for articles directed at patient or student education, standards development, FHIR, and for readability issues. Remaining articles gave insight into the usage of HL7 Reference Information Model (RIM), HL7 version 2 (HL7v2), HL7 Clinical Document Architecture (CDA), and Continuity of Care Document (CCD).

“A Guideline-Derived Model to Facilitate the Implementation of Test-Ordering Rules Within a Hospital Information System” utilizes the HL7 Reference Information Model (RIM) to optimize patient care and costs with respect to clinical laboratory requests utilizing CDSS. The paper outlines RIM’s relevant sections such as clinical conditions, family history and demographic information, medical treatment, habits—dietary/alcohol/substance, laboratory and imaging orders, and results. The article conclusion speaks to the relation of this work to Pipeline, “Retrieving clinical information for every biological investigation and for the right health care professional will improve the quality of laboratory medicine. Using the proposed model for the implementation of laboratory medicine guidelines may facilitate decision support tasks by defining what is required in the EHR structure and the elements of information to be coded. It is possible to link guideline-derived conditions for ordering tests to HL7 RIM” [1].

Konrad, Tulu, and Lawley review HL7v2 in their article “Monitoring Adherence to Evidence-based Practices: a Method to Utilize HL7 Messages from Hospital Information Systems.” Their CDSS tool was designed to identify both patients whose length of stay was shorter and longer than expected, enabling research into new pathways that could improve over current pathways while ensuring that appropriate steps were taken to retrospectively correct pathways that were not being appropriately followed. They performed this task through interpretation of real-time HL7v2 data feeds, but their output was not in real time. The authors suggest that real-time review of HL7v2 messages and generation of instant feedback would be valuable to adherence to clinical pathways [2].

We found that CDA/CCD documents were not appropriate for our implementation. These HL7 implementations are inherently not real-time data. Instead, documents are generated at the time of request. We were unable to acquire any HL7 version 3 or HL7 RIM data feeds within our institution. HL7v2 data feeds were abundant at our institution.

Methods

Pipeline's infrastructure can be viewed as a multi-tiered data flow system (Fig. 1). The first tier of this system is composed of three types of real-time outbound HL7v2 [3] data streams emitted by our supported enterprises. These streams consist of RIS, PACS, and voice recognition (VR) reporting systems. These streams contain exam-centric messages that convey order and status information as well as radiology reports as exams transition in workflow. The streams are received, parsed, and filtered by a Mirth interface engine [4], which then writes the resulting data to Pipeline's second tier, a Microsoft 2012R2 SQL Server [5]. A Red Hat Enterprise Linux [6] web server is the final tier. This runs a Ruby on Rails [7] application to query recent exam records in the SQL Server, analyze and/or aggregate the retrieved data, format it, and pass the results to the user's web browser. Ancillary resources used to construct the web interface include HTML5 [8], Cascading Style Sheets (CSS) [9], JavaScript [10], NGINX [11], and Passenger [12].

This project did not specifically require new server resources, as the equipment utilized already existed within the department to support other projects. Both the web and database systems are virtual machines in a VMWare environment. The Red Hat Enterprise Linux system resources include 1 Intel Xeon E5-2680v2 processor core, 2 GB of RAM, and 35 GB of storage. The Microsoft 2012R2 SQL Server resources include 2 Intel Xeon E5-2680v2 processor cores, 8 GB of RAM, and 790 GB of data space. A pair of E1000 Enterprise Mirth Appliances service the practice HL7 feeds and are copied on the EMR/RIS HL7 messages for sites we provide service for. This includes ORM/ORU messages that encompass the radiology visit workflow through the phases ordered, canceled, imaging begun, completed, dictating, preliminary/draft report, finalized, and addendum.

Access to Pipeline for end users is web-centric. Following log-in, the browser displays a menu of selectable worklists. The system is user-aware and tailors this menu to display only selections to which a user's role is granted access. Each worklist conveys work-in-progress information that is filtered,

Fig. 1 Pipeline is a multi-tiered data flow system. Created using Lucid Chart

sorted, and formatted for a specific purpose, such as to display stat emergency room (ER) exams being performed at a specific facility. Each worklist automatically updates itself to display up-to-the-minute information. Worklists use a row-column display format. Each row contains information about a single exam. Each column contains exam-centric data such as textual elements and a hyperlink to additional information. The columns displayed for each exam include (1) exam priority, (2) site code and visit class, (3) technologist, (4) exam accession number, (5) patient name, (6) exam description, (7) exam status, (8) elapsed time within that status, (9) number of images in PACS, (10) the dictating and attending radiologists once dictation has begun, and (11) a hyperlinked icon which when clicked will display as available: radiologist's report; ordered, completed, dictated, and finalized timestamps; telephone contacts; reason for study; and technologist notes. Displayed phone numbers are matched to an exam's workflow state such as the CT control room (for a CT scan in progress) and the radiology reading room (for a scan ready to read or already reported). Clicking the patient's name invokes display of that patient's PACS folder. Clicking the accession number invokes display of the exam itself. Hovering the mouse cursor over other displayed data elements will invoke additional pop-up information. Entries automatically drop off a worklist after a predetermined period of time according to the list's purpose, with one objective being to keep the size of each list manageable for users. For example, worklists that monitor ER workflow will drop exams with final reports after 2 hours. Unreported exams are dropped after 12 hours. Most ER exams transition from unreported to finalized status within a few minutes. The unreported stragglers are color-coded to alert radiologists and assistants that attention is warranted.

A Pipeline display provides several ways to manipulate its worklist. Column-header pick lists enable filtering by exam status, exam priority, site code, and visit class. Columns containing textual data, such as exam description and patient name, can be filtered such that only matching exams are displayed. The display can be sorted by column. A filter and/or view applied to a worklist is saved so that upon the next visit, the user is presented with the same view as on the previous visit.

Defined roles for Pipeline include administrator, radiologist, clinician, and reading room assistant. Location-centric worklists enable an ER clinician working at a given facility to see only exams pertaining to that facility's ER patients and/or any stat radiology exams at that facility. Reading room assistants and radiologists can view all worklists, including global worklists, and additionally can enter informational notes into the expandable panel for any exam. These notes are visible to other users. For example, a note might convey information such as, "patient became unstable, CT scan delayed."

User access is managed through our hospital information services in-house-developed, secure online automated routing permission system. This allows users to submit access requests, which are then approved by their supervisors and content owners. Users can request a specific Pipeline role, and once approved, the user account is added to the active directory group that will authorize access to Pipeline for that role. The permissions system will automatically alert Pipeline administrators to user job status changes. Users are automatically removed if they depart our workforce. The infrastructure and application supporting Pipeline are scanned on a monthly basis by Qualys Enterprise [13] scanning tool. The Qualys tool provides an output showing security vulnerabilities and resolution recommendations in PDF and CSV formats. We remediate vulnerabilities the week they are released to us. These range from minor code changes to application updates.

Results

Pipeline dashboards have been deployed for a variety of purposes, including:

- 1) Displaying stat radiology work-in-progress exams for our multi-institutional radiology department filtered by combinations of facility and workflow status. For example, a global "Stat ER Exams" worklist is shown in Fig. 2. Radiologists most often use a dashboard scoped to their coverage responsibility, utilizing a relevant real-time display with color-coded elapsed time since each examination was completed by the technologist.
- 2) Detecting examinations "lost" in workflow (LIW) is shown in Fig. 3. At our institution, this can happen when a technologist has executed an exam-complete transaction within the RIS, but an extraneous event has caused an examination to not populate the Unread Worklist on the PACS. The Pipeline list consequently displays LIW examinations with an ever-increasing elapsed time in imaged status. Over a typical 24-hour period comprising roughly 3000 examinations, Pipeline revealed an average of 5–10 completed examinations was LIW daily for one reason or another. Stat examinations with prolonged latency between ordered and imaged are another example of examinations LIW.
- 3) Displaying exams flagged for potentially missing verbiage in the radiology report that is required for compliance and/or billing. For example, a report pertaining to an incorrect needle count in which there is no apparent mention of direct notification of operating room personnel or a report pertaining to a CT angiographic study in which the radiologist forgot to mention the generation and review of 3D reconstructions.

HELP ER Monitor (Newes at Top): ER Exams Waiting To Be Read,
Mon April 02 2018 2:22:10 PM
Last Mirth message was less than 1 minute ago.

☒ Ordered ☒ Imaged ☒ Dictating ☒ Reported

Pri	Org	Patient	Procedure	Order Age/ Image Age	RIS Status	PACS Status	Imgs	Radiologist	Info
2	EX	Patient1	CT Abdomen and Pelvis W/ IV Contrast	1min	Ordered				
2	EX	Patient2	XR Chest PA AP Portable	6min	Ordered				
0	EX	Patient3	CT Head W/o IV Contrast	2min	Ordered	Started	75		
0	EX	Patient3	CT Cervical Spine W/o IV Contrast	3min	Imaged	Sent	913	Radiologist1	
2	EX	Patient4	XR Chest PA AP Portable		Reported	Dictated	2	Radiologist2	
0	EX	Patient5	CT Maxillofacial Area/Sinus W/o IV CNT		Reported	Dictated	721	Radiologist3	

Accession: CT123456789 Reading Room Contact: 123-456-7890

Ordered: 2018-04-02 12:03 Imaged: 2018-04-02 13:52 Dictating: 2018-04-02 13:40 Finalized: 2018-04-02 13:50

Note: ☒ Hide exam from worklist.

Report:
EXAM: CT Head W/o IV Contrast, CT Maxillofacial Area/Sinus W/o IV CNT, CT Trauma CTA Neck / CT Cervical Spine
DATE: 04/02/2018 13:32.
COMPARISON: None.
TECHNIQUE: Multiple CT images were obtained of the head without IV contrast and formatted at 5 mm thick intervals in the axial plane. CT images were obtained of the maxillofacial area without IV contrast and formatted in the axial, coronal and sagittal planes.
FINDINGS: Lorem ipsum dolor sit amet, consectetur adipiscing elit.
Sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.
IMPRESSION: Head. 1. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.
Thank you for consulting Radiology. Healthcare providers wishing to discuss this case further can contact the Reading Room at 123-456-7890.
Electronically Signed by: Radiologist3 Dictated on: 4/2/2018 1:40 PM

Reason for Study:
Trauma

Technologist Notes:
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Fig. 2 “Stat ER Exams” worklist. Among the information displayed are (1) order age, (2) phone number relevant to exam workflow status, (3) quick view of report details

- 4) Displaying subsets of routine exams for specific patient-safety and/or quality-of-care objectives. For example, a dashboard tailored for the musculoskeletal section displays all unread routine outpatient examinations of the pelvis or hips on patients over 60 years old. The objective is to ensure that such exams, especially late-day exams, on patients with symptoms of potential incomplete hip fracture are interpreted that day.

The Pipeline application has been well received by clinicians and radiologists. To date, most usage has been by radiologists in our ER section. We have observed an adoption curve among ER clinicians. Substantial enthusiasm for Pipeline was expressed during collaborative planning and

development meetings. However, adoption for ongoing use has been slower than expected. We believe a major contributor is one of habit, forgetting to log on to the new application and use it as an adjunct to less fully integrated information provided by other systems to which clinicians are accustomed. A July 2018 survey of the top 20 radiology staff Pipeline users resulted in 8 respondents, the majority of which were reading room assistant staff. Responses were varied, with half of the users reporting that they preferred Pipeline over other clinical workflow tracking systems. No users felt that Pipeline was difficult to use, with 62.5% indicating the software was an overall “medium” difficulty when compared with other applications. Six of the 8 users had utilized the system within the last week. The survey included an open comment response field. Some comments indicated

Stat ER Exams: ORDERED more than 4 hours ago, but not yet performed.									
Pri	Org	Patient	Exam	Order Age/	RIS Status	PACS Status	Imgs	Radiologist	Info
2	EX	Patient, One	CT Abdomen and Pelvis W/ IV Contrast	4hr 1min	Ordered				
2	EX	Patient, Two	CT Abdomen and Pelvis W/ IV Contrast	4hr 5min	Ordered				

All Unreported P0 / P1 /P2 Exams Marked as “Completed” in Cerner for at Least 90 Minutes									
Pri	Org	Patient	Exam	Order Age/	RIS Status	PACS Status	Imgs	Radiologist	Info
2	EX	Patient, Three	XR Chest PA AP	4hr 50min	Imaged	Completed	1		

Exams with reports more than 4 hours old not finalized.									
Pri	Org	Patient	Exam	Order Age/	RIS Status	PACS Status	Imgs	Radiologist	Info
5	EX	Patient, Four	CT Coronary Calcium Eval W/O IV Contrast	4hr 2min	Dictated	Dictated	147	Attending, One Resident, One	
5	EX	Patient, Five	XR Chest PA AP Portable	4hr 6min	Dictated	Dictated	1	Attending, Two Resident, Two	

Fig. 3 Stacked dashboards focusing on exams lost in workflow

frustration with ongoing development of the system including occasional crashes and slow downs. One reading room assistant left a very positive comment, “I find the Pipeline to be very useful. I use it to watch what the ER orders and inform the Radiologist of what is pending when they ask. I also find it very helpful to watch the status of exams. A lot of times technologists will complete an exam before all the images have been sent across and this changes the status back to sent. Now instead of having an upset caller because their study hasn’t been read due to the Radiologist not being able to see it I can call the Tech and ask them to complete them out again.”

Discussion

We envisioned a real-time system providing a variety of workflow-centric dashboard displays to improve time management, efficiency, communication, and patient safety. Advantages that we perceive from Pipeline are:

- 1) Improved communication and time management for radiologists and clinicians, reducing and/or eliminating the need for phone calls or reading-room visits in order to determine where an exam is in workflow and when it will likely be performed or reported.
- 2) Improved patient safety via early detection and notification regarding stat radiology exams that are delayed or have become LIW.
- 3) Improved compliance with billing and reporting requirements by automatically flagging reports with missing information.

Each Pipeline worklist displays exams that reflect a specific workflow-monitoring objective. Each list is continually updated in order to reflect the current status of radiology exams that are ordered, in progress, or recently reported. Pipeline implements a “single-page application” user interface whereby only changed elements of data in a web page are updated rather than re-rendering entire pages. The need for these capabilities drove the architecture of the system. For example, the Mirth interface engine can communicate with multiple real-time data sources and store inbound data to a relational database suitable for use as our data authority. The analytics engine that generates the worklists is designed to facilitate creation of new worklists with minimal effort. The user interface employs Asynchronous JavaScript and XML (AJAX) [13] to provide continual updates on a web page. A web-centric application facilitates software maintenance because all updates are pushed from the web server.

Looking forward, we plan to integrate Pipeline with our secure messaging systems. This will enable clinicians

to subscribe to notifications of changes of status in urgent radiology exams of interest and would enable immediate alerting of a radiologist when expected verbiage is missing from a just-signed radiology report so that an addendum can be made. Additionally, we plan to use Pipeline to select examinations matching specific criteria and transmit them through an automated de-identification process into ancillary storage systems used for research and education.

Conclusion

Analysis of real-time workflow-centric data streams offers multiple “just-in-time” opportunities to improve time management, efficiency, communication, and patient safety in a radiology department.

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