Informatics in Radiology

Automated Web-based Graphical Dashboard for Radiology Operational Business Intelligence[1]

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TEACHING POINTS
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Radiology departments today are faced with many challenges to improve operational efficiency, performance, and quality. Many organizations rely on antiquated, paper-based methods to review their historical performance and understand their operations. With increased workloads, geographically dispersed image acquisition and reading sites, and rapidly changing technologies, this approach is increasingly untenable. A Web-based dashboard was constructed to automate the extraction, processing, and display of indicators and thereby provide useful and current data for twice-monthly departmental operational meetings. The feasibility of extracting specific metrics from clinical information systems was evaluated as part of a longer-term effort to build a radiology business intelligence architecture. Operational data were extracted from clinical information systems and stored in a centralized data warehouse. Higher-level analytics were performed on the centralized data, a process that generated indicators in a dynamic Web-based graphical environment that proved valuable in discussion and root cause analysis. Results aggregated over a 24-month period since implementation suggest that this operational business intelligence reporting system has provided significant data for driving more effective management decisions to improve productivity, performance, and quality of service in the department.

Abbreviations: DICOM = Digital Imaging and Communications in Medicine, FTP = File Transfer Protocol, HL7 = Health Level 7, MPPS = Modality Performed Procedure Step, ODBC = Open Database Connection, PACS = picture archiving and communication system, RIS = radiology information system

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Introduction

The field of business intelligence, also known as business analytics, has demonstrated significant improvements in industries outside of healthcare (1). Business intelligence tools enable management to make more relevant decisions with greater frequency, facilitating smaller course corrections to keep the business improving and minimizing oversights. The two principal benefits of a business intelligence solution that can affect the culture of an organization are transparency and fact-based decision making (2). Supreme Court justice Louis Brandeis noted that "sunlight is said to be the best of disinfectants" (3) as a remedy for social diseases. Transparency can be used as a powerful tool to provide accountability and ownership of performance improvements.

Teaching Point

A focus on fact-based decision making changes traditional response models based on emotions and anecdotal perceptions of service. Sharing data and analysis is seen as a powerful way to influence other key stakeholders into aligning to a common vision of a problem. Creating an open culture that is willing to take an unwavering look at the "brutal facts" of an organization is seen as a key characteristic of a competitive company (4). Clinical information systems used in radiology today house a treasure trove of operations data that is not currently being used by clinical management to create a culture of quality and enable a more engaged and enlightened management environment.

The need for management reporting in radiology dates back to the 1970s as one of the core components identified in early radiology information system (RIS) implementations. In 1979, Arenson and London (5) described the need for a computer system to provide operations management to perform time-flow analysis to improve efficiency. A RIS provided tabulated reports to be printed out. These would evolve into reports that could be e-mailed for monthly reporting processes.

In 1994, Crabbe et al (6) described a manual extraction methodology for obtaining data from a RIS that provided the means to perform higher-level analysis on data as well as the ability to distribute graphical analysis in the form of Excel files (Microsoft, Redmond, Wash) from a central file server. In 2000, Seltzer et al (7) used a Web site as a digital dashboard to communicate operational parameters. In 2003, our group used automated extraction methodologies to dynamically build Web reporting capabilities for performance and utilization management off a single picture archiving and communication system (PACS) (8).

In this article, we describe a Web-based dashboard that was constructed to automate the extraction, processing, and display of indicators and thereby provide useful and current data for departmental operational meetings. In addition, we evaluate the feasibility of extracting specific metrics from clinical information systems as part of a longer-term effort to build a radiology business intelligence architecture. Specific topics discussed are problems with a paper-based reporting method, data extraction architecture, information visualization, and enabling knowledge discovery.

Problems with a Paper-based Reporting Method

To understand the need for an online dashboard, we first identified the department's many frustrations with the traditional paper-based processes of analysis, reporting, and quality management. Many significant challenges limit the effectiveness of the standard methodology of monthly paper-based reporting. The time and effort required to build reports creates a capture latency that diminishes the value of the information as well as the time the organization then has to take action to identify and implement remedies (2). Paper-based reporting can answer only a relatively small list of questions that must be identified *before* the monthly (or other periodic) meeting that routinely addresses such questions. This finite list limits the focus in such meetings to the data at hand and prevents any attempt to follow outside data, identify disturbing trends that have not yet become true issues, or delve deeper into operations. When questions are asked that cannot be answered, they are taken "off-line" and answered at the next meeting if remembered at all. This cumbersome and sometimes quite subjective process slows the ability of an organization to respond quickly to events or to plan effectively for change.

Teaching Point

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Paper-based reporting lacks the granularity to drill down on a metric and view the original data. The ability to view the actual data from which statistical analyses are derived offers a higher level of confidence in understanding data and making subsequent decisions. It can help detect bias such as skewed distributions or data integrity issues that might affect decisions as well as avoid anecdotal mistrust of the data.

Teaching Point

Metrics Selected for Display on the Dashboard

Metric Label	Group	Description
% Outpatient Arrived	Order and arrival	Compliance metric; tracks percentage of time the front desk enters an arrival time for outpatients
Outpt. % Seen < 15 min	Order and arrival	Performance metric; tracks percentage of patients taken back for their examinations within 15 min
Avg PICC Time to Arrival	Order and arrival	Performance metric; tracks average time in hours for placement of a PICC, from the time an order is received to the patient's arrival at the unit for PICC placement
Avg STAT TAT*	Order and arrival	Tracks average time from receipt of a high-priority order to completion of image acquisition
% Outpatient Begin	Image acquisition	Compliance metric; tracks percentage of time the technologists enter a procedure begin time
% Wait > 1 h	Image acquisition	Performance metric; tracks percentage of patients waiting for more than 1 h to be seen
QC Issues	Image acquisition	Tracks number of quality control issues submitted by radiologists (13)†
Image Quality	Image acquisition	Tracks perceived image quality as determined by means of technologist peer review
Repeat Rate	Image acquisition	Tracks self-reported image reject and retake reasons
Undictated > 1 mo	Interpretation	Billing metric; tracks number of studies performed with no report dictated after 1 mo by interventional radiologists
Average C–P (h)	Interpretation	Performance metric; tracks average time in hours from completion of a study to completion of the preliminary report
% Peer Reviewed	Interpretation	Compliance metric; tracks percentage of reports on which a radiologist performed peer review
Res Review Submissions	Interpretation	Tracks the number of resident reports that were discrepant with the attending physician's report
Unsigned > 2 wk	Reporting	Outlier metric; tracks number of unsigned reports more than 2 wk old
Average P–F (h)	Reporting	Performance metric; tracks average time in hours from preliminary report of a study to the time the report is finalized
EPR Ratio	Reporting	Tracks number of formatting errors detected in the final report sent from the speech recognition system
Critical Findings Delivery	Reporting	Tracks number of critical findings documented

Note.—EPR = errors per report, PICC = peripherally inserted central catheter, TAT = turnaround time.
*This metric excludes the emergency department and shock trauma unit, which have embedded imaging modalities.
†Number in parentheses is a reference.

In addition, paper-based reports are usually constrained to those "canned" reports available in the RIS. These predefined reports represent those topics that RIS vendors expected departments to ask for at the time of software development. These topics and the elements reported often prove inflexible to changing business and operational needs. Creating custom reports is often challenging, preventing departments from answering questions and fully understanding their operational data.

The metrics used at the University of Maryland School of Medicine before implementation of our dashboard efforts were similar to those in most academic radiology departments (9–12). We evaluated the elements of the paper-based report to determine the importance and difficulty of acquiring these metrics from clinical information systems in an automated method. The Table lists the metrics used as key indicators in the department on the dashboard. Continuous quality improvement requires the ability to change the metrics on the dashboard as well as the targets for those metrics. The purpose of departmental operational meetings is to identify problems and opportunities to improve performance. As the department improves, metrics can be retired or the goals can be changed. The dashboard must be able to incorporate the moving-target focus of the meeting.

Teaching Point

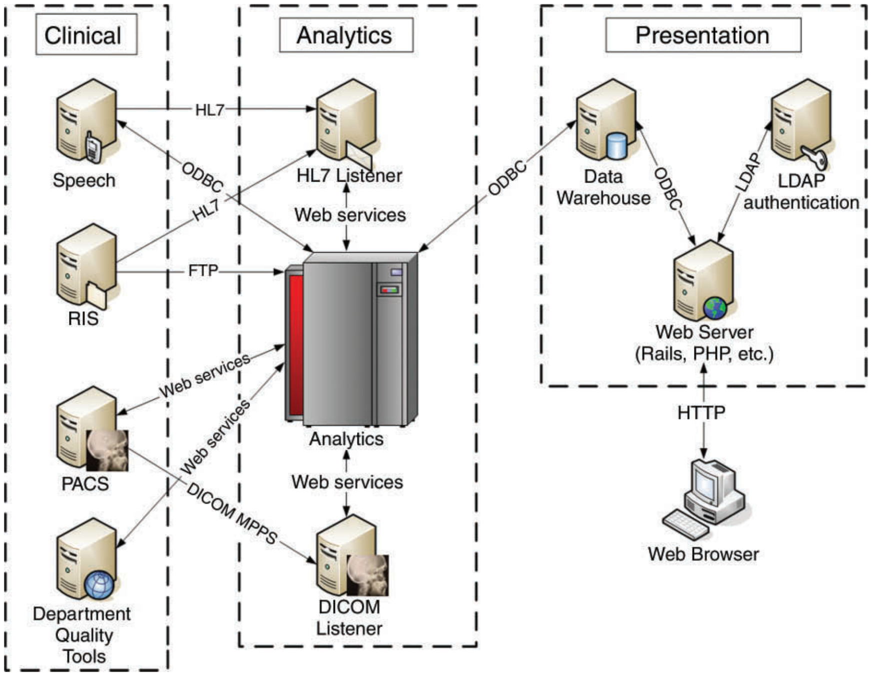

Figure 1. Architecture of the data warehouse infrastructure. Clinical information systems were interfaced using a variety of methods to extract performance and quality indicators. *HTTP* = Hypertext Transfer Protocol, *LDAP* = Lightweight Directory Access Protocol.

Data Extraction Architecture

One of the challenges to providing a comprehensive view of operations is that data are often distributed among several different information systems, each containing only discrete pieces of the work flow. We constructed a platform to collect data from all systems to build a comprehensive view of operations using the MySQL open-source database as the central data repository (14). The key identifier to link the fragments of data together was the unique accession number for each procedure.

Data extraction tools were developed in the Python programming language to acquire operational data from all of our clinical information systems, using standards as well as customized extraction methodologies. We leveraged two powerful open-source tools, the DCM4CHE Digital Imaging and Communications in Medicine (DICOM) archive (15) and the MIRTH Health Level 7 (HL7) server (16). A DICOM repository was created using DCM4CHE to collect DICOM Modality Performed Procedure Step (MPPS) messages automatically routed from a PACS (6.2 IMPAX; Agfa, Brussels, Belgium). HL7 messages of orders and reports were routed from a RIS (IDXRAD 9.0; GE Medical Systems, Fairfield, Conn) to the MIRTH HL7 report repository.

For non–standard-based reporting, the extraction methodology had to be tailored to the type of information and vendor from which the data were derived. Custom reports generated from the RIS using their KBSQL reporting module stored reports in comma-delimited files. An extraction script retrieved those files at regular intervals via File Transfer Protocol (FTP), parsed the information, and uploaded the data into the MySQL database. The PACS was queried using a metadata extraction Web service provided by the PACS to obtain information within the DICOM objects, such as the number of images and the performing physician.

A speech recognition system (RadWhere 2.0; Nuance Healthcare Solutions, Burlington, Mass) provided data via an Open Database Connection (ODBC) with an account restricted to only SELECT Structured Query Language statements for stability and security purposes. Quality tools developed within the department, such as quality control issue tracking, were also incorporated into the architecture of the data warehouse. Because the data warehouse contained personal health information, clinical security precautions defined by the Health Insurance Portability and Accountability Act were necessary, and appropriate security measures were enacted.

The interfaces were developed, specified, and tested over several months. For each interface, the commercial vendors were consulted and the reporting methods were specified. No development was requested from the vendors. The easiest interfaces to implement were those based on open standards, such as HL7 and DICOM. The FTP interface was straightforward, as prepackaged reports were retrieved via FTP. The Web service interfaces used publicly available application programming interfaces that were published and maintained by the vendors. The most difficult were the ODBC interfaces, which required a special understanding of the vendor's database structures as well as constrained permissions and testing to ensure that our interface did not affect the performance of the clinical system. Figure 1 illustrates the architecture and interfaces employed.

The timing of data extraction depended on how frequently the data were being reviewed and how actionable the information was. The goal was to minimize the capture latency of data acquisition. The main tables of the RIS are extracted every evening into the data warehouse for tracking waiting times, turnaround times, and stat order times. Order and report information via HL7 and DICOM MPPS messages via DICOM come across within minutes from the clinical information systems.

Every hour, a report of undictated studies is pulled from the RIS and fed into a global work list for the department. Identified undictated studies are then queried to the PACS in real time using Web services to determine the number of images on the PACS and the performing physician for interventional studies. This method helps alert staff to studies that were completed but have no images on the PACS. Four times each day, a RIS report is pulled for a list of unsigned reports. Signing physicians are sent a text page via e-mail with the number of unsigned reports by location. This eliminated an inefficient process in which radiologists had to log in to multiple RISs to see whether a report was ready to sign. Integrating an alerting mechanism with a dashboard application is valuable to communicate actionable information and ensure a timely feedback mechanism.

Information Visualization

More than a dozen commercial business intelligence platforms that incorporate information visualization are on the market today. The business intelligence industry is undergoing rapid innovation, with several large vendors with complete solutions and a multitude of smaller vendors with best-of-breed components. The two highest-rated solutions as determined in an industry analysis in 2008 are BusinessObjects from SAP (Walldorf, Germany) and Cognos from International Business Machines (Armonk, NY) (17).

We elected to use a commercial Web-based graphing tool and construct our own Web dashboard because of our phased approach and leverage our experience in Web development. The dashboard grew out of several smaller quality projects started in 2004 to monitor unsigned and undictated reports. The multiple projects needed a roof to house them all for direct access and comparison. Although our platform was developed on open-source technologies, significant investment was required to customize the dashboard to our department.

The Web site was developed using the open-source programming language and application framework Ruby on Rails (18). The Web site used the Ruby ChartDirector imaging library (Advanced Software Engineering, Hong Kong) to dynamically generate graphics on demand as bubble charts, histograms, fuel gauges, time trends, and run charts. When a user requests to load a Web page, the Ruby on Rails framework requests the most recent data from the database, which are rendered into a graphic JPEG file. As the database is updated, those changes are immediately displayed within the graphs. Asynchronous JavaScript enables users to click on areas within the graph to select subregions. This allows users to intuitively drill down through the graphs and explore complex dynamics that can affect operations.

The main-level page with the departmental overview was distributed throughout the department as a Web link and showed all the major indicators as fuel gauges (Fig 2). This provided novel transparencies within the department to help align the focus on areas needing improvement. Thresholds were set for each metric in the quality meetings to define a target zone in green, a warning zone in yellow, and a trouble zone in red. Many of the performance targets were derived from yearly departmental goals and objectives. The fuel gauges provide an easy method to review all the metrics at a glance. Each fuel gauge is linked to detailed analysis on that metric so that users can understand the results more fully.

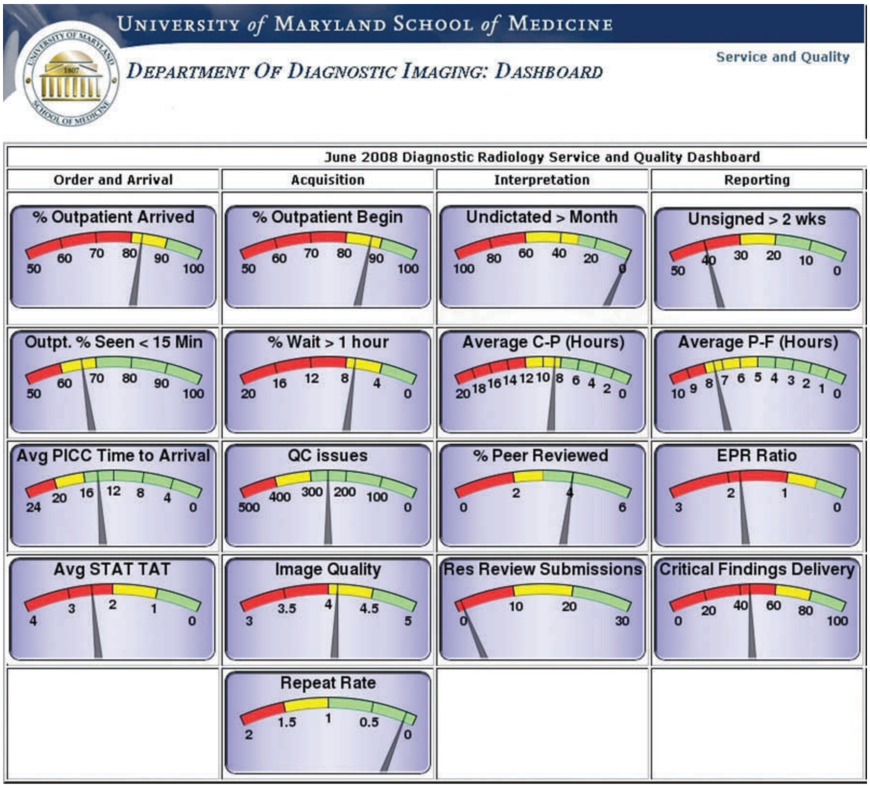

Figure 2. The main page of the dashboard provides an overview of the major key performance indicators. Each gauge is described in the Table. *C-P* = completed study–preliminary report, *EPR* = errors per report, *P-F* = preliminary report–final report, *PICC* = peripherally inserted central catheter, *TAT* = turnaround time.

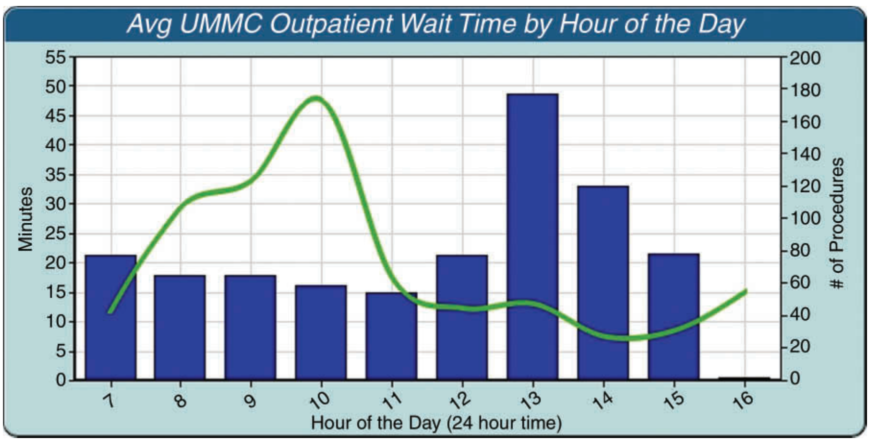

Figure 3. Dual-axis graph shows the average outpatient waiting time for mammography (green line) as a function of the time of day (24-hour clock). Blue bars = patient volume.

A secure log-in is required to access pages that include personal health information. We employed the Lightweight Directory Access Protocol for user authentication and authorization, based out of our PACS. This allowed users to access the dashboard with their PACS log-ins and eliminated the need for separate password management. According to the sensitivity of the data, such as radiologist peer review, data analysis views were restricted to only those staff authorized for management of that metric.

Beginning in July 2006, the dashboard was used as the central focus of our twice-monthly operational meetings. A 60-inch (150-cm) liquid crystal display was installed in the main administrative conference room so that the dashboard could be accessed in real time at all administrative meetings. In addition, staff throughout the department were given access to the site via a Web link.

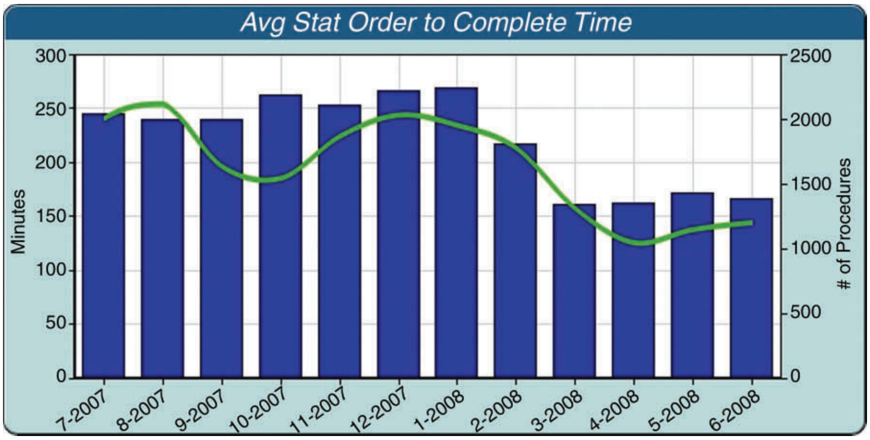

Figure 4. Dual-axis graph shows high-priority inpatient study requests from the time of ordering to the time of procedure completion. Blue bars = monthly volume for one year, green line = average time from order to completion.

Initial results and subsequent experience indicate that the dashboard improved our department's ability to understand performance and enhanced participation in our quality meetings. At the same time, we were able to improve our departmental performance in several key areas. Over a period of 12 months, improvements were observed in the radiology report turnaround time, outpatient waiting times, stat order turnaround times, and quality control resolution times.

It is challenging to attribute improvements to the use of the dashboard. The dashboard drove discussions at the quality meetings and provided context, but it was the management team who used results to initiate additional quality investigations into approaches for improving performance. The dashboard did not enforce change; instead, it enabled improvement by demonstrating problem areas and root causes for those problems and by helping align the efforts in quality initiatives. The dashboard also served as a workbench on which new theories could be tested hypothetically to determine whether they could solve various problems.

Enabling Knowledge Discovery

Each fuel gauge represented a key performance indicator. By clicking on the fuel gauge, the user is taken to an in-depth analysis of that indicator. This analysis attempts to display all the factors that can influence the indicator and may be causes of poor performance. The purpose of the analysis page is to lead a discussion with a successive series of questions that can be answered quickly with a graphic interface. In a traditional paper-based setting, questions frequently cannot be answered immediately and must be followed up in preparation for the next meeting. By providing the ability to sift through data, visualize it both in detail and in a graphical representation, and answer questions immediately, the dashboard not only accelerates the time to fixing problems but also leads a group rapidly through the data discovery process, which aids in their buy-in and accountability for the analysis and results.

Figure 3 is an example of one of the levels of analysis on our dashboard and shows average outpatient waiting times for mammography in minutes (green line, plotted as a function of the hour of the day) and number of procedures (blue bars). This graph shows a steep rise in waiting times from 10 minutes at opening to more than 45 minutes by 10 AM. This is a common type of queuing problem that can be caused by scheduling, staffing levels, room utilization, or examination durations. In this example, the quality committee determined that the high waiting times were the result of scheduling a high number of diagnostic mammography procedures in the morning, requiring more resources and longer individual examination times than did screening mammography procedures.

Figure 4 shows the average time from the ordering of a stat study for an inpatient to the time the procedure was completed. (Emergency department and shock trauma studies were filtered out because both areas have embedded imaging equipment, operate on an almost continuous stat basis, and do not involve hospital patient transport.) The overview graph demonstrates the performance of this indicator (green line) over a period of several months, overlaid with the number of procedures performed (blue bars). Other

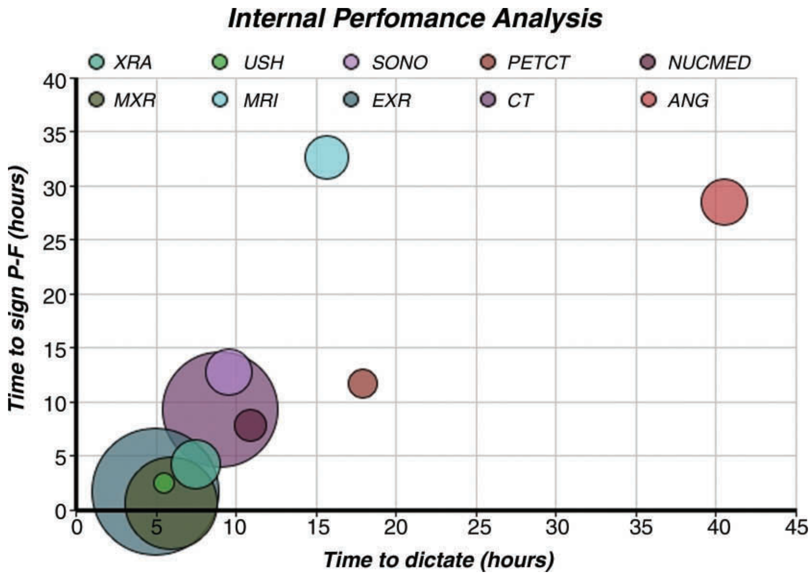

Figure 5. Bubble chart shows radiologists' report turnaround time for 1 month by departmental section. *ANG* = angiography, *CT* = computed tomography, *EXR* = emergency x-ray, *MRI* = magnetic resonance imaging, *MXR* = trauma x-ray, *NUCMED* = nuclear medicine, *PETCT* = positron emission tomography/CT, *P-F* = preliminary report–final report, *SONO* = ultrasonography, *USH* = satellite hospital, *XRA* = x-ray.

graphs tied to this indicator demonstrated dependent factors, such as patient location, time of day, day of the week, requesting physicians, requested procedure, and modality resources. In February 2008, a change was made to the order entry system, with ordering physicians required to enter a pager number to be called back for high-priority orders. This change caused a subsequent drop in orders with a corresponding improvement in response time for ordered studies.

The purpose of data collection and graphical display is to allow viewers to quickly detect trends or dips in service and then be able to zoom in on trouble spots to understand the cause. The process provides an overview of the indicator in a dynamic way that allows a tighter focus on specific factors affecting performance. This allows the user to drill down through the graphs to see the underlying detailed information for each study, thus helping explain specific problems.

Figure 5 is a report turnaround bubble chart displaying the sections within the department. A bubble chart is a useful information visualization tool for displaying three dimensions of data. The x axis represents the average time from the completion of the study to the time of the preliminary report. The y axis is the time from preliminary signing to final signing. Each section is represented by a different color, and the size of each bubble is directly related to the number of procedures that section performed for that month.

Figure 6 is a trending analysis showing departmental radiologist reporting time over 2 years as a percentage of studies in the department that were reported within 2-, 8-, 24-, and 48-hour windows. The timeliness of radiology reporting has received significant attention in the process improvement literature (19,20). Our department has conducted several initiatives to reduce the turnaround time, and the dashboard was able to plot the effects. The department began automatically paging radiologists daily for unsigned reports in March 2005, implemented speech recognition throughout 2006, and in January 2007 instituted a new system to synchronize study status between the RIS and the PACS. A graphical dashboard can act as an instrument on which to conduct experiments in process improvement.

Conclusions

Radiology management is under considerable pressure to do more with less (21). A perfect storm is forming, created by declining reimbursement rates, rising expectations of patients and clinicians for faster turnaround times, and national initiatives to improve the quality in radiology to enhance outcomes. These forces are driving radiology professionals to look for ways to improve efficiency and productivity without sacrificing quality. Business analytics is a proven tool to help a business become more competitive (22).

Using informatics extraction techniques, we were able to capture the majority of indicators routinely used in our quality meetings and drive

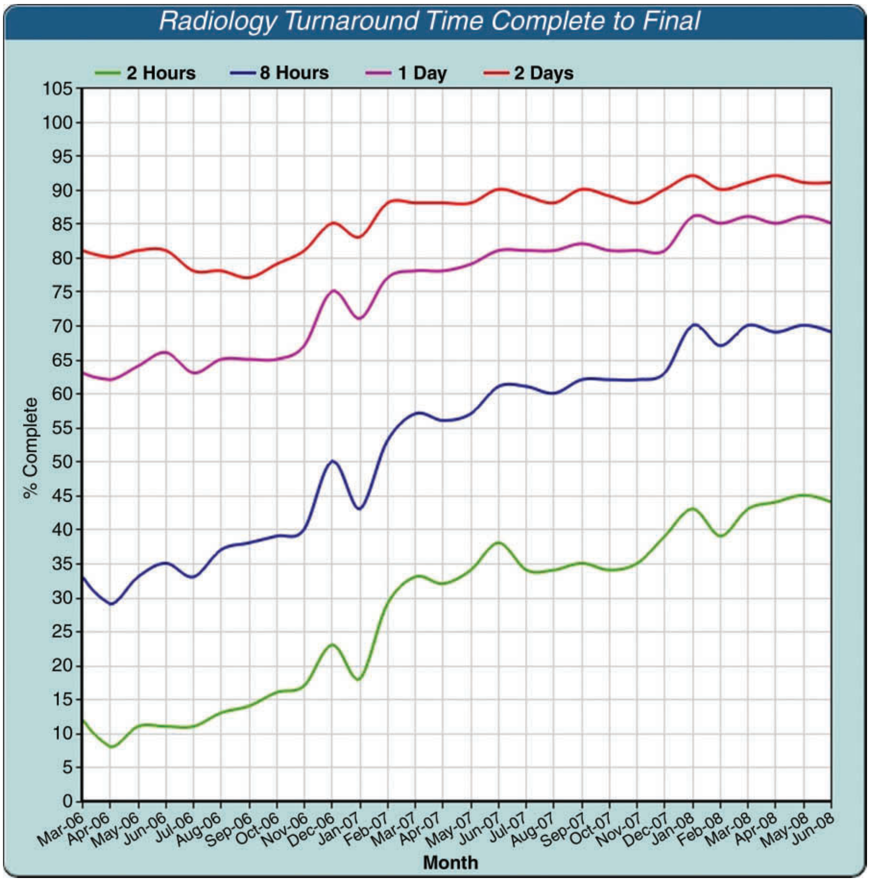

Figure 6. Graph shows the 2-year progression in the percentage of reports that were signed promptly in the radiology department after implementation of automated quality control and dashboarding tools.

the process in a paperless, automated fashion. This was viewed as a significant improvement that made the meetings more effective and provided a better understanding of the operations of the department.

Significant effort was required in extraction of the metrics from clinical information systems. Although some vendors provide reporting packages and a few provide a Web service programming interface, no standard methods have been defined for extracting metrics in radiology. We have added components to our purchase requirements for new clinical information systems that request the vendor to expose internal operational business logic using a service-oriented architecture based on Web services. This allows other systems to gather data for business intelligence applications. We encourage other consumers of clinical information systems to consider their interoperability needs for business intelligence.

For an energized leadership committed to service excellence and quality, a dashboard can be a powerful tool to help improve performance in radiology. Continuous quality efforts are widely recognized as crucial elements in the successful radiology department (23). However, quality committees and leadership too often lack the tools to effectively drive change and remain relevant.

A Web-based graphical dashboard provides a level of transparency of operations to empower effective management. Management in our department found this to be a useful alignment tool by exploring data as a group on a projected screen. Supervisors, section chiefs, and administrators were provided with access to the Web site. Another important benefit has been the reduction in the effort and time previously required to collect and prepare reports.

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