Using HL7 and DICOM to Improve Operational Workflow Efficiency in Radiology

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Abstract: Radiology departments are increasingly asked to do more with less annual budget and to remain competitive while managing bottom lines. Identifying opportunities to improve workflow efficiency is an important aspect of managing a department and reducing associated costs. Workflow enhancement tools can be built by making use of HL7 and DICOM messages that are directly related to various workflow steps. In this paper, we discuss the importance of using both HL7 and DICOM to determine more accurate metrics related to granular workflow operations, such as distinguishing between billing and operational exam volumes. Using a production dataset, we also demonstrate how visualization can be used to provide better visibility into routine radiology operations.

1 INTRODUCTION

For many years, a hospital's radiology department has functioned as a key profit center. In 2007, radiology accounted for 37% of outpatient profit, defined as revenue less direct costs, making imaging the most valuable hospital outpatient service line (The Advisory Board Company 2008). However, with significant increases to healthcare related spending in recent years, projected to be close to 20 percent of the US GDP by 2024 (Centers for Medicare & Medicaid Services), there has been a strong emphasis towards moving away from the traditional fee-for-service model to alternative reimbursement models.

In the traditional fee-for-service payment model, providers are reimbursed by insurers for each service provided. Unnecessary imaging alone is reported to waste at least $7 billion annually in the US (peer60). Since each service gets reimbursed, there is no major incentive for hospitals to minimize costs associated with these tests while the insurer has an open-ended economic risk. On the other hand, with capitated payment models, the economic risk shifts to the hospital since the hospital only gets reimbursed a fixed amount to treat a specific condition (Centers for Medicare & Medicaid Services). With specific healthcare reforms currently underway in the US, there has been a strong focus toward integrated care delivery while reducing costs – for instance, under the new Accountable Care Organization payment model, starting from 1st April 2016, hip and knee replacement payments will be based not only on the procedures performed, but on the quality of care delivered as well (Centers for Medicare & Medicaid Services). Similarly, starting from around 2011, various radiology procedures have been getting paid under 'bundled codes' when two or more related studies are performed together.

The American College of Radiology routinely monitors changes to radiology-related payments and recently reported that the bundled code payments are falling short of the payment levels of the predecessor codes and values; for instance, computed tomography (CT) abdomen-pelvis without contract exams were paid at $418.43 prior to using bundled codes; in 2013, under the bundled payment model this was reduced to $306.05 and in 2014, this was further reduced to $241.79. With such changes to reimbursements, and in an attempt to reduce costs associated with unnecessary imaging, radiology has gradually been shifting from one of the primary profit-centers for a hospital to a cost-center. Radiology departments are increasingly being asked to do more with less annual budget and to remain competitive and manage bottom lines. Radiology departments need to optimize quality of care, patient experience, outcomes, efficiency and throughput while reducing costs.

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An important aspect of managing a radiology department is to have meaningful insights into the routine operations. This could include fairly straightforward metrics such as the total number of billable exams and exams by modality over a particular time period. However, to identify workflow improvement opportunities it is important to gain visibility into the more granular metrics, such as the difference between billing and operational volume, total patient encounter duration, imaging systems utilization and number of scans by hour of day and/or day of week.

In this paper we discuss a generic approach using two established healthcare information exchange standards, Health Level Seven (HL7) and Digital Imaging and Communications in Medicine (DICOM), to determine metrics important to the operations in a radiology department. The main contribution is the linking of HL7 and DICOM to determine granular workflow steps and the discussion around specific radiology workflow nuances.

2 METHODS

2.1 Background

Healthcare vendors have embraced the rapid uptake of technology in healthcare and as a result, most hospitals have clinical systems from different vendors to accommodate the needs of various departments – for instance, a computerized physician order entry system (CPOE) may be used for order entry, a hospital information system (HIS) for patient registration, a radiology information system (RIS) for radiology specific functions, an EMR for medical records, a scheduler for scheduling appointments, a billing system for accounting purposes, dictation systems for creating reports and a picture archiving and communication system (PACS) for imaging related tasks. To provide integrated patient care, these different clinical systems need to communicate with each other. HL7 messaging standard is arguably the most widely implemented standard for interoperability in healthcare across the world and allows for the exchange of clinical data between disparate systems (HL7 2016). Similarly, DICOM (The DICOM Standard) is the de facto standard for exchanging medical images. Although system-to-system direct communication may be possible, hospitals often use an HL7 interface engine (HL7 2016) to facilitate information exchange. Figure 1 shows a typical hospital configuration, with a focus on radiology – often, mammography requires dedicated workstations compared to other modalities, such as X-ray (XR) and CT, and as such, is shown separately. In-house systems would typically provide some form of aggregated patient view that combines information from RIS, HIS and laboratory information system.

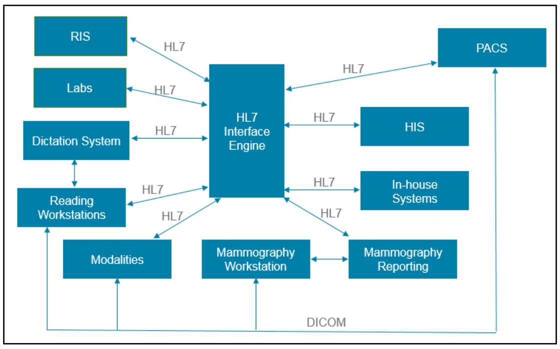

Figure 1: Overview of communication between various clinical systems.

With recent incentives towards increased system interoperability, facilitated by healthcare reforms (e.g., Meaningful Use Stage 2 (HealthIT.gov 2015)), hospitals have been moving towards enterprise electronic health record systems (EHRs) to improve patient care by facilitating sharing of patient data that is typically distributed across multiple clinical systems, and also improve workflow efficiency (e.g., EHRs have a single sign-on where disparate systems will require multiple sign-ons for the same user). However, most clinical systems are ‘closed-systems’ where the data is not directly accessible to external parties, and often, even to hospital IT administrators. As such, developing tools based directly on HL7 and DICOM can have widespread applicability irrespective of the individual hospital setting.

2.2 Reporting for Operational Excellence

There are various systems already in place to provide routine operational reports to radiology department managers, often at a cost center level to which budgets are allocated – definition of a cost center can vary depending on the hospital, but for radiology, it is usually one or more modalities. For instance, high volume modalities such as CT would be a standalone cost center whereas ultrasound (US), nuclear medicine and vascular imaging could be combined into a single cost center. Routine reports may not always be sufficient for operational purposes; for instance, it may be useful to know the machine utilization of a shared US machine and using a cost center based approach will not capture all exams performed on this resource. Additionally, there are often exams which are split into two or more billing codes although they occupy one scheduled slot.

Karami discusses a comprehensive list of metrics important for radiology across seven main categories (Karami 2014) while other investigators (Morgan, Branstetter et al. 2008, Cook and Nagy 2014) have discussed the importance of analytics and other business intelligence software for radiology. The underlying data source for systems that provide such capabilities can be broadly categorized as:

1. Systems used directly in workflow – these systems are used during routine operations and would include systems such as the EHR, RIS, HIS and PACS. Data is entered directly into these systems.
2. Third-party software that subscribe to HL7 messages – these systems are often setup as a 'listener node' where a copy of all, or a selected subset, of HL7 messages will be sent to, often via the HL7 interface engine. Having an interface engine is not so common for DICOM since PACS is often the only destination for images.
3. Third-party software that integrate with systems used in workflow – these systems often have closely-coupled integration with systems used directly in workflow. For instance, a new CT dose monitoring software application may be installed in a hospital as a new DICOM node and all CT machines can be configured to forward a copy of DICOM structured report (which is a way to analyze dose-related data for CT) to this node.

Due to the specialized nature of clinical software, most of the systems often consume only HL7 or DICOM. However, as discussed later in the paper, there are significant benefits to linking data from these two sources for more accurate metric calculation.

2.3 Overview of HL7

An HL7 message is composed of a series of segments with each segment identifying the type of information the message contains (e.g., patient demographics, lab/observation result, diagnosis, insurance and next of kin). In turn, each segment includes one or more composites (also referred to as "fields") that contain the actual information (such as names and result values). Composites can contain sub-composites (or sub-fields) – for instance, patient name is a composite within the 'PID' segment and can contain over six sub-composites (such as family name, given name, middle name and suffix). Composites are typically separated by a "|" character, while sub- composites are usually separated using "^".

Each HL7 message starts with a message header, corresponding to segment MSH, and defines the message's source, purpose, destination, and other syntax specifics like composite delimiters. MSH field 9, denoted by MSH-9, is particularly important since this specifies the type of message that is being transmitted (such as ADT, ORM, ORU, ACK and so on (HL7 2016)). The segments present in a given message vary depending on the type of message that is being transmitted. For instance, Figure 2 shows the composition of an ADT message (used to convey information related to patient admission, discharge

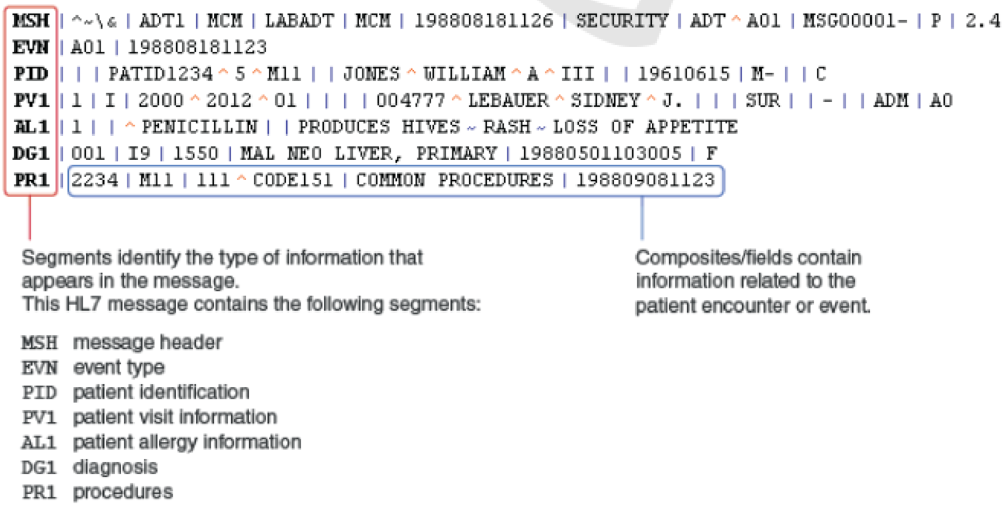

Figure 2: Components of an HL7 ADT message for a fictitious patient (Altova 2016).

and transfers) containing seven segments (MSH, EVN, PID and so on).

Similar to the number of segments within a message type, the number of fields present within a segment can vary as well. For instance, the PID segment can contain over 30 different fields, although it is common for the segments to terminate after the last non-empty field (corresponding to value "C" in Figure 2).

2.4 Overview of DICOM

DICOM is a specification for creation, transmission, and storage of medical images and report data (The DICOM Standard). In addition to the binary pixel data, all DICOM files contain metadata related to patient (e.g., name, gender and date of birth), acquisition setup (e.g., type of equipment used and settings such as source IP address and machine name), and study (such as study description). Metadata is contained in the DICOM header which is essentially a list of key-value pairs – the keys are standardized values in hexadecimal. As an example, tag (0008,1030) corresponds to the study description.

2.5 Typical Radiology Workflow and Information extraction from HL7 and DICOM

At a high level, once a referring physician has ordered an imaging exam, the exam gets scheduled (after necessary pre-procedure steps are completed, such as pre-authorization from insurance). Each imaging exam will be associated with one imaging order. When the patient arrives at the radiology department, the front desk staff would typically 'arrive' the patient in the EHR (could be the RIS or some other system depending on the hospital configuration). At this point, the technologist knows that the patient has arrived for the scan (this could be by looking at a 'technologist view' in the EHR/'modality worklist', or some other means, such as the front desk staff printing out a 'patient requisition form' and handing over to a technologist). When the technologist is ready for the patient, he/she will go to the patient waiting area and call for the patient. After explaining the process, the technologist will start preparing the patient for the scan, for instance, by giving oral contrast if needed. Once ready, the patient will move into the scanning room and around the same time, the technologist will 'start exam' in the EHR. The DICOM images get acquired at this point and sent to a modality workstation. The RIS/EHR/PACS systems typically work independent of the modality workstation. At the end of the scan, the technologist will review and push the images from workstation to the PACS and then 'end exam' in the EHR. At this point, the images are ready to be reviewed by a radiologist. All these workflow steps trigger HL7 messages. The end-to-end radiology workflow from order-to-report is more extensive as discussed by McEnery (McEnery 2013), but the image acquisition process is where combining data from HL7 and DICOM is most relevant. As such, we focus only on this part of the workflow.

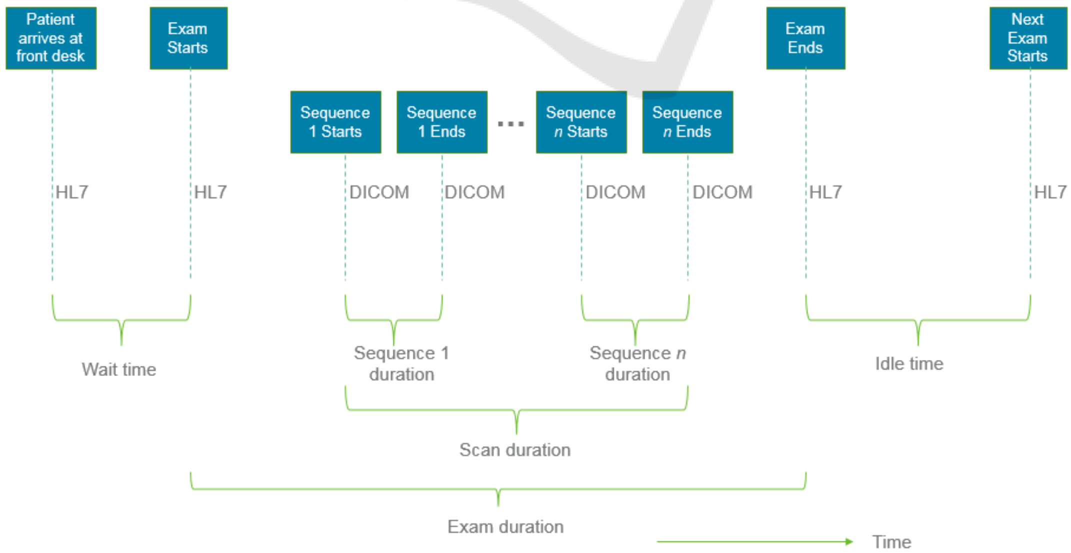

Figure 3: Status messages that get triggered during radiology workflow.

Table 1: Events required to determine workflow metrics for a CT Abdomen-Pelvis exam.

Metric	Data Source	Event(s) / Segment	Comments
Patient wait time	HL7	ORM^001: ORC-5 (order status=ARRIVED); ORM^001: ORC-5 (order status=BEGIN)	Value is difference between the two events; e.g., 25 minutes
Total scan time	DICOM	Acquisition times from 1st and last image in PACS using (0008,0032)	Value is difference between the two timestamps of images; e.g., 18 minutes
Sequence time	DICOM	Acquisition times from 1st and last image in PACS using (0008,0032) for each Series grouped by series UID (0020,000E)	Value is difference between the two timestamps of images for each series; e.g., 4 minutes for Series 1; 7 minutes for Series 2
Begin-to-End time	HL7	ORM^001: ORC-5 (order status=BEGIN); ORM^001: ORC-5 (order status=END)	Value is difference between the two events; e.g., 23 minutes
Arrive-to-End time	HL7	ORM^001: ORC-5 (order status=ARRIVED); ORM^001: ORC-5 (order status=END)	Value is difference between the two events; e.g., 48 minutes
Billing exam volume	HL7	Accession number count based on ORM^001: OBR-3	For a CT Abdomen-Pelvis exam, 2 orders will be placed; exam volume is 2
Operational volume	DICOM	Accession number count using (0008,0050)	For a CT Abdomen-Pelvis exam, only 1 physical scan is performed.
Machine utilization	DICOM	Performed machine is identified using AE Title tag (0073,1003)	Calculated using some interval (e.g., 1hr) minus sum of total scan times per AE Title
Technologist productivity	HL7 + DICOM	ORM, OBR-34 – operator name; accession from DICOM and HL7	Calculated using operational volume per some interval (e.g., 1hr) per technologist

The various status messages that get triggered during the different steps of the radiology workflow are shown in Figure 3. Table 1 shows a few important metrics most radiology department track along with the HL7/DICOM field(s) that can be used to calculate the value.

A radiology exam is identified by a unique accession number. This can be determined using the value in HL7 ORM^001 OBR-3 segment or DICOM (0008,0050) tag. Accession number is then used to join between HL7 and DICOM data to determine the accurate value using one or both data sources.

2.6 Dataset

Through a product co-creation agreement with an integrated care delivery network, we had access to a database that stored all HL7 and DICOM traffic that was sent from the radiology department to the PACS since June-2015. The database was within the hospital premises in a secure data center with restricted user access. All metrics computed were at an aggregate level with no PHI exposed, and no data left the hospital environment. As of 31-May-2016, the database contained over 13 million HL7 messages over 120 million DICOM records.

3 RESULTS

3.1 Workflow Considerations

Here we discuss seven important aspects that need to be considered when specific metrics are calculated for operational purposes, with a focus on the power of combining data from HL7 and DICOM.

3.1.1 Billed vs Performed Exams

Study volume is essentially the number of unique accession numbers. This is the fundamental chargeable unit for a radiology department, and as such, many clinical systems will produce this volume report on a scheduled basis (typically weekly or monthly). These reports are often driven by financial reporting requirements, and as such, will contain only the billing exam volume. As illustrated in Table 1, this means that a CT abdomen-pelvis study where the images are acquired in a single scan will get reported as two billable exams since there will be two orders associated with the scan. However, it is important to know the operational study volume as well since this can have a significant impact on metrics such as number of exams performed on a machine and the number of scans a given technologist has performed

– it takes significantly longer, in fact nearly twice as long, to perform two CT abdomen exams on two patients (due to various changeover and documentation times) than to perform two scans on one patient. As a result, from an operations point of view, it may not be accurate to say that one technologist who has performed two billable exams on the same patient has been as efficient as another technologist who has performed two exams on two different patients (assuming everything else is comparable).

Distinguishing between billable and performed exams may or may not have a significant impact depending on the study mix performed at a given institute. For instance, in our dataset, for a certain day, there were 891 total billable exams based on HL7 messages whereas there were only 829 exams based on DICOM. In general, the difference was between 5-10%.

It should be noted that the ability to use the accession count from DICOM to determine operational volume depends on the particular hospital's workflow. Some hospitals, including the one in our study, typically scan all images under a single accession number, push them to the PACS, and then either split, or link the images to the accession numbers associated with the different orders. Alternatively, the splitting can happen at the modality workstation itself, in which case two accession numbers (in the CT abdomen-pelvis example) will be seen in DICOM. In this case, the reporting engine will need to perform some logic, such as 'same patient, same acquisition times for different accession numbers' to determine which studies should be merged for operational reporting purposes.

3.1.2 Exams with Multiple Modalities

Studies where multiple modalities are involved are identified using the same accession number. A few examples of such studies are PET-CT, PET-MR and interventional radiology exams (which may often involve XR and/or ultrasound and/or CT). In each instance, the complete exam will often be billed under a single accession number, although from an operations point of view, two (or more) resources were utilized to perform the exam. Images acquired from different modalities can be determined using DICOM Source AE Title tag. These exams need to be correctly accounted for when determining relevant metrics (such as operational volume, technologist productivity and machine utilization).

3.1.3 Shared Resources

It is common practices for different departments within radiology to share resources. For instance, a PET/CT machine may be used mainly for PET scans, but due to low PET volumes, the CT department may often make use of this resource to perform certain CT exams during busy periods. If PET and CT are different cost centers, PET and CT volumes will be shown separately for each departments, but for machine utilization, both volumes need to be accounted for.

3.1.4 Manual vs Automated Timestamps

Care must be taken when calculating various turnaround times using timestamps. For instance, per Figure 3, scan duration is calculated using times from the DICOM header. These times will often be reliable since these are machine generated timestamps. On the other hand, depending on the clinical system, exam start and end HL7 messages may be trigged manually. This flexibility is provided often for valid practical reasons, for instance, after acquiring all images for a CT exam, a technologist may have time to 'end exam' in the system only after scanning a new emergency patient (i.e., back-time the value for the previous exam). Similarly, 'start exam' time may be entered manually and may depend on the individual technologist – some technologists may consider the start of exam to be when they call the patient from the waiting room, some may consider the start to be when the patient walks into the scanning room, while others may consider start of the exam when the patient is on the scanner itself. As such, it is important to standardize the terminology associated with granular workflow steps. If the workflow can be standardized so that all technologists start the exam when they go to get the patient from the waiting room, then the time difference between 'patient arrived' and 'exam start' HL7 messages will accurately reflect patient wait time while the difference between 'exam start' HL7 message and 'first DICOM image' timestamp will show the overhead associated with getting the patient on the scanner (which could be significant for obese and/or immobile patients) and adjusting the scanner settings prior to image acquisition.

3.1.5 Same Information in HL7 and DICOM

Some data can be available in both HL7 and DICOM. Either source can be used if the value in both sources is the same (such as the accession number), but there could be instances where same data is entered slightly differently depending on the clinical system in use. For instance, when a technologist completes an exam in the EHR/RIS, the resulting HL7 'end exam' message will contain the complete operator name. On the other hand, the technologist also needs to enter the name into the modality workstation; however, if all reporting is EHR/RIS driven, technologists will often enter only their initials into DICOM since this information is not used anywhere. Therefore, it is important to identify the right data source and merge data from either HL7 or DICOM after identifying the study based on accession number.

3.1.6 Site-specific Business Logic

It is important to give priority to any site-specific business logic since these are used in routine operations. For instance, at the DICOM level, the modality for X-ray may be CR or DR (indicating analog vs digital X-ray respectively) whereas operational managers may consider all of them to be XR. Similarly, cancelled exams and historical data imports should not count towards exam volume, although HL7/DICOM traffic related to such exams may be visible on the network. It is important to accurately capture and implement such site specific business logic when making inferences from raw data.

3.1.7 Workflow Related Nuances

Given the diversity and complexity of various radiology exams, there could be various workflow specific nuances. For instance, certain MR exams may require post-processing of images, which can take up to an hour (post-processing usually happens on a separate machine while the technologist is start scanning the next patient). Radiologists can typically start reading exams as soon as a technologist has ended an exam. If a technologist ends the exam after post-processing is complete, and uses the current time as the end exam time, then it would appear as if the exam took a long time to complete. On the other hand, if the technologists back-times the study end time to when the exam truly ended (ignoring all the post-processing time), it would appear as if the exam has been waiting in the reading queue for a long time which affects the report-turnaround time. As such, it is important to agree upon how to interpret the turnaround times in context.

3.2 Identifying Workflow Improvement Opportunities

Using HL7 end exam messages, we determined the monthly study volumes (Figure 4) as well as the volume by day of week and hour of day (Figure 5) for MR, CT and XR.

For CT and XR, the heatmap representation indicates the times when most scans are completed – as expected, this is during normal business hours – Monday to Friday between 8am to 6pm. On the other hand, the MR heatmap suggests that there is some unusually high activity happening later in the day, between 10 and 11 pm for the months of March and April.

Upon investigation, the MR technologists confirmed that they routinely end exams only towards the end of the day, typically during the shift change.

	MR				CT				XR			
Hour	January	February	March	April	January	February	March	April	January	February	March	April
0	26	30	33	24	48	78	82	88	115	94	95	98
1	32	28	39	40	66	73	60	57	79	84	83	91
2	49	31	26	36	69	55	58	64	45	50	66	56
3	14	17	25	30	40	49	52	56	129	145	210	181
4	8	13	21	20	53	33	65	47	521	389	389	418
5	31	31	23	35	68	42	39	63	439	284	287	266
6	45	27	34	38	52	45	56	37	175	150	207	191
7	45	57	45	44	117	104	113	98	233	228	233	195
8	65	50	62	55	153	126	145	156	467	410	501	484
9	67	75	72	68	186	180	190	184	655	619	700	613
10	71	58	60	65	232	202	224	181	747	769	871	768
11	77	80	77	75	255	226	264	240	799	786	896	774
12	91	74	92	77	263	252	310	288	841	779	913	818
13	101	80	75	88	278	267	300	256	749	726	857	743
14	95	97	95	89	243	258	310	252	778	730	824	742
15	78	85	79	88	260	250	268	229	661	665	705	698
16	101	85	76	75	233	228	278	252	552	507	579	556
17	83	80	103	82	228	221	220	236	384	432	416	399
18	86	91	85	80	189	183	172	210	348	308	362	361
19	91	89	57	78	158	189	166	142	243	291	276	281
20	66	74	64	67	149	151	150	135	223	207	205	217
21	65	66	80	71	102	106	109	145	169	189	191	212
22	68	85	95	92	105	99	129	137	144	142	159	166
23	71	48	40	65	70	84	88	82	92	123	126	113

Figure 4: Monthly exam volume by hour of day.

	MR							CT							XR						
Hour	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
0	6	9	18	25	22	18	15	49	36	39	40	46	40	46	56	44	53	62	61	50	76
1	20	16	20	18	30	22	13	34	38	33	34	25	48	44	44	47	57	50	45	44	50
2	8	8	11	33	29	24	29	50	37	31	38	26	24	40	22	29	27	34	36	37	32
3	9	6	12	11	23	12	13	26	32	31	43	16	28	21	111	87	103	74	78	95	117
4	15	9	5	7	4	14	8	28	29	29	19	29	26	38	219	252	239	198	249	286	274
5	6	12	13	22	27	20	20	36	34	44	34	17	28	19	204	194	176	192	159	175	176
6	12	12	30	23	24	24	19	28	33	27	37	17	24	24	82	75	134	118	123	100	91
7	5	33	29	44	40	35	5	20	80	101	72	64	77	18	29	130	191	159	173	168	39
8	13	51	40	40	37	35	16	29	99	99	109	106	100	38	119	279	404	326	326	265	143
9	22	39	50	41	53	49	28	38	136	107	136	112	152	59	132	438	501	487	422	428	179
10	27	44	34	40	37	41	31	57	152	141	147	130	142	70	130	535	590	631	593	509	167
11	16	53	51	54	53	51	31	73	171	151	174	161	174	81	154	544	636	597	605	562	157
12	51	45	56	52	49	38	43	68	182	190	198	211	186	78	143	573	622	676	625	547	165
13	46	50	49	41	46	54	58	62	187	214	202	173	191	72	133	533	619	558	605	484	143
14	44	55	51	58	60	55	53	65	189	201	172	189	185	62	146	502	658	623	580	431	134
15	43	46	43	46	47	41	64	74	172	167	185	181	156	72	135	485	538	556	467	392	156
16	54	47	40	45	47	47	57	56	158	192	185	180	163	57	120	352	415	447	395	321	144
17	47	51	49	55	47	46	53	62	170	166	139	140	162	66	112	303	297	302	268	238	111
18	44	46	43	45	47	51	66	76	126	124	118	119	117	74	110	254	229	215	251	201	119
19	37	43	53	38	52	39	53	54	97	110	125	94	125	50	80	186	197	188	173	159	108
20	12	39	50	55	44	45	26	46	103	88	91	87	86	84	90	130	128	127	133	126	118
21	16	41	46	60	50	42	27	54	77	57	56	68	96	54	105	116	115	130	116	96	83
22	13	56	62	60	67	61	21	46	63	71	80	67	80	63	82	91	72	92	88	98	88
23	15	34	42	43	37	41	12	51	47	58	53	32	49	34	63	61	70	65	61	78	56

Figure 5: Exam volume by day of week and hour of day.

4 DISCUSSION

In this paper we have discussed the importance of using both HL7 and DICOM to determine various metrics related to the operations of a radiology department. While using a single data source may be a good approximation, it is important to take an integrated approach in order to get better visibility into more granular operations as well as determine more accurate values for the metrics of interest.

A radiology department needs to create clear definitions of metrics; even the seemingly obvious terms such as “start of exam” need to be explicitly tied to workflow steps and the electronic measurements using HL7 and DICOM. This “data governance” is an important aspect of the data analytics and process improvement approach. Data governance should define clearly the metrics, agree on the measurement methodology, understand the exceptions cases where the methodology might be imperfect, and serve as a governing body to increase the acceptance of the process improvement initiatives.

In the context of the MR workflow, we have discussed a specific example where technologists were routinely ending exams towards the end of the shift. This may be acceptable for practical reasons, but at the same time, this affects the data quality, which in turn affect the various metrics that are based on this data. As such, it is important for radiology administrators and Department Chairs to proactively set forth suitable guidelines and educate the technologists on the importance of adhering to such guideline. Providing visible feedback to the technologists on a regular basis on the performance of the department may help improve compliance to such requests.

Despite having access to a large dataset, the current study has one main limitation – the dataset is from a single institution, and as such, the DICOM tags we have used may not always be generalizable. Although vendors are expected to follow the standard, they often use private tags (to exchange vendor-specific information that is not covered by the DICOM standard) instead of public tags, and sometimes populate different public tags instead of the commonly used tags; as such, the mapping may need to be modified depending on the site.

Having access to tools to provide visibility into granular workflow operations is crucial for the success of radiology departments. However, as discussed, developers of such tools need to keep in mind the various nuances associated with hospital workflows in order for such tools to be meaningful and widely adopted by all stakeholders.

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