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Improved Screening Mammogram Workflow by Maximizing PACS Streamlining Capabilities in an Academic Breast Center

Ramya Pham [1] · **Daniel Forsberg** [1,2] · **Donna Plecha** [1]

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Abstract The aim of this study was to perform an operational improvement project targeted at the breast imaging reading workflow of mammography examinations at an academic medical center with its associated breast centers and satellite sites. Through careful analysis of the current workflow, two major issues were identified: stockpiling of paperwork and multiple worklists. Both issues were considered to cause significant delays to the start of interpreting screening mammograms. Four workflow changes were suggested (scanning of paperwork, worklist consolidation, use of chat functionality, and tracking of case distribution among trainees) and implemented in July 2015. Timestamp data was collected 2 months before (May–Jun) and after (Aug–Sep) the implemented changes. Generalized linear models were used to analyze the data. The results showed significant improvements for the interpretation of screening mammograms. The average time elapsed for time to open a case reduced from 70 to 28 min (60 % decrease, $p < 0.001$), report turn-around time with preliminary signature decreased from 151 to 107 min (29 % decrease, $p < 0.001$), and report turn-around time final signature from 153 to 139 min (9 % decrease, $p = 0.002$). These improvements were achieved while keeping the efficiency of the workflow for diagnostic mammograms at large unaltered even with increased volume of mammography examinations (31 % increase of 4344 examinations for May–Jun to 5678 examinations for Aug–Sep). In conclusion, targeted efforts to improve the breast imaging reading workflow for screening mammograms in a teaching environment provided significant performance improvements without affecting the workflow of diagnostic mammograms.

Keywords Mammography · Workflow · PACS · Teaching

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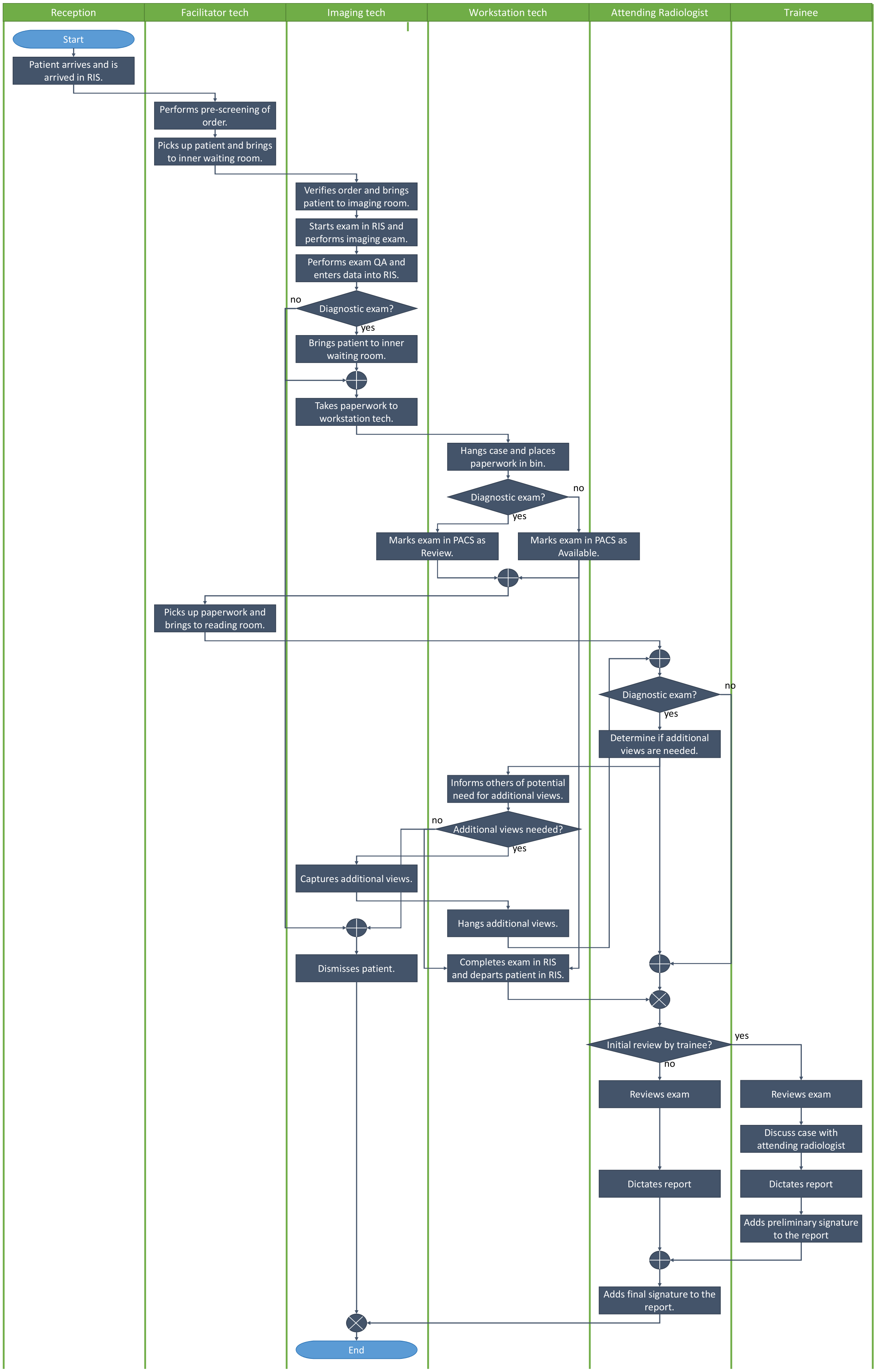
Introduction

In recent decades, the radiological workflow has at large undergone highly disruptive changes through the transition from analog to digital imaging and the introduction of new technology (e.g., new modalities, picture archiving and communication system (PACS), radiology information system (RIS), and other IT systems) with subsequent outcomes such as added clinical value and improved efficiency [1–4]. Although the initial development of digital mammography dates back to the 1970s, it was not until 2000 that the first digital mammography unit was approved for clinical use in the USA [5]. Despite approval for clinical use, adoption of digital mammography was initially slow. Aided by various clinical trials studying the effect of digital mammography [6–8], adoption rates eventually increased and in 2010, about half of the women participating in a national breast cancer detection program received digital mammograms [9]. Four years later in 2014, it was estimated that digital mammography constituted 90 % of US breast screening market [5]. During this period,


Reception
Facilitator tech
Imaging tech
Workstation tech
Attending Radiologist
Trainee
Start
Patient arrives and is arrived in RIS.
Performs pre-screening of order.
Picks up patient and brings to inner waiting room.
Verifies order and brings patient to imaging room.
Starts exam in RIS and performs imaging exam.
Performs exam QA and enters data into RIS.
Diagnostic exam?
no
yes
Brings patient to inner waiting room.
Takes paperwork to workstation tech.
Hangs case and places paperwork in bin.
Diagnostic exam?
no
yes
Marks exam in PACS as Review.
Marks exam in PACS as Available.
Picks up paperwork and brings to reading room.
Diagnostic exam?
no
yes
Determine if additional views are needed.
Informs others of potential need for additional views.
Additional views needed?
no
yes
Captures additional views.
Hangs additional views.
Dismisses patient.
Completes exam in RIS and departs patient in RIS.
Initial review by trainee?
yes
no
Reviews exam
Reviews exam
Discuss case with attending radiologist
Dictates report
Dictates report
Adds preliminary signature to the report
Adds final signature to the report.
End

◀ **Fig. 1** The original workflow involving multiple technologists and both trainees and attending radiologists

new technology was also introduced, digital breast tomosynthesis, approved for clinical use in 2011 [10].

Apart from the added clinical value brought forth through digital mammography as compared to film-based mammography [11], other advantages have been made possible as well, for example, improved workflow efficiency, better management of examinations, digital transmission of images for teaching and consultation, integration with computer-aided detection systems, and improved integration with RIS, PACS, and reporting systems [12, 13]. However, in terms of workflow improvements, few aspects apart from the acquisition time of the technologists and the interpretation time of radiologists have been studied to any extent [14–16]. This is despite the fact that timestamp data is most often readily available to allow an in-depth analysis of the workflow efficiency. Hence, there is a need as well as an opportunity to further analyze and identify potential improvements in the breast imaging workflow.

There are ongoing changes within the US healthcare at large, for example, the increased rate of acquisitions and consolidations between healthcare entities, and the transition from fee-for-service to a value-based healthcare delivery model and meaningful use. Various efforts have been launched to better position the healthcare providers for these changes. Within radiology, the American College of Radiology (ACR) launched the Imaging 3.0 initiative to address these challenges [17]. An important aspect of Imaging 3.0 is to move beyond the simplistic notion of radiology as merely providing an interpretation of a set of images and instead consider all components which constitute the radiological value chain. Herein, workflow optimization becomes a crucial aspect, not only from the radiologists' perspective but also more importantly from the perspective of patients themselves.

In this work, we set out to determine if consolidating PACS worklists from multiple sites, eliminating wait time for batches of paperwork before reviewing mammogram cases, and using electronic assignment of cases for even distribution among trainees improve reading workflow efficiency in an academic breast program.

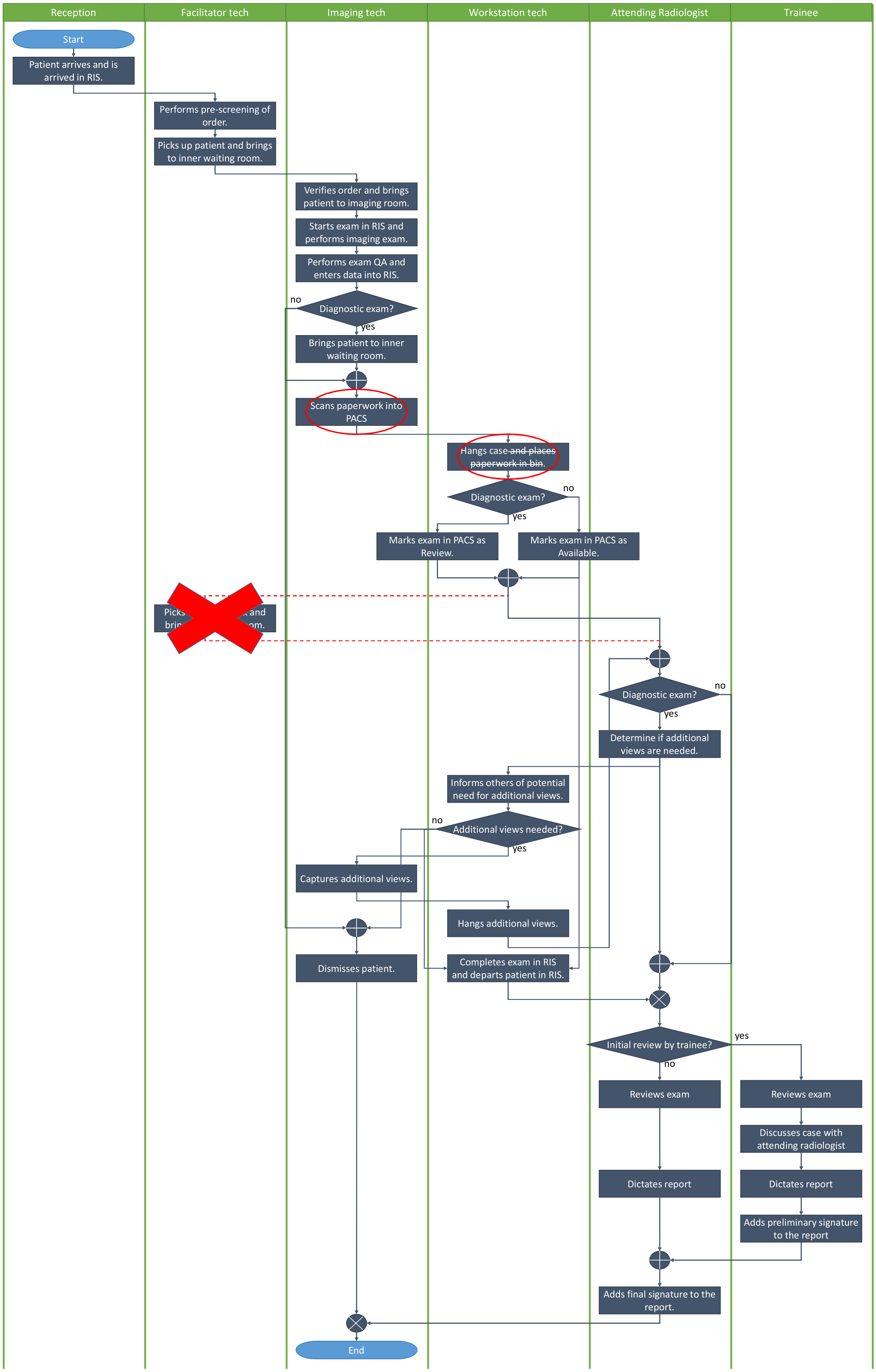
Material and Methods

At our academic medical center, the attending radiologist together with trainees (residents and fellows) reviews screening and diagnostic mammograms, breast ultrasounds, and breast MRIs at the PACS workstations. After a case has been reviewed by a trainee, pertinent findings and recommendations are discussed with the attending radiologist. With a growing notion of potential existing bottlenecks in our reading workflow and a lack of oversight of our work (two breast centers with on-site radiologists but also covering additional remote sites), we set out to map and analyze the reading workflow for mammograms. In addition, the radiologists' workspace in the PACS was also analyzed. The analysis identified the following issues:

- *Stockpiling of paperwork*—A number of steps were found to rely on paperwork including a tracking sheet(s) with accession number for the case, requisition form from the ordering physician, and the history intake form. A radiologist or trainee would not open a case, even if it was completed and ready for interpretation, until the paperwork was provided to them. This was not an issue for diagnostic mammograms, since associated paperwork would immediately be brought to the radiologists by a technologist after completion of the examination in order to allow a swift response as to whether additional imaging would be needed or not. In contrast, the screening mammogram paperwork would be given to the radiologist in batches, usually when the technologist was going to the reading room with paperwork for a diagnostic study. The same applied to the paperwork from the remote sites which were batch-faxed to the site of the reading radiologist at different times during the day.
- *Multiple worklists*—Once a study was completed in the RIS by a technologist, the study would become "Completed" and available to the radiologists and automatically populate a worklist based on location in the PACS. Each location/site had its own worklist. While viewing one worklist, a radiologist would be blind to the other worklists and would not know if screening studies were accumulating or if diagnostic studies were waiting for interpretation.
- *Work distribution*—At breast center 1, there were three to four trainees working with one attending radiologist on any given day and add to this the multiple worklists, there was resulting randomness and disorganization in the distribution of cases. When the technologists brought the paperwork into the reading room, some attending radiologists would divide the cases up equally between the trainees, while others would let the trainees pick and choose their cases. Either way, no one knew who was reviewing any given case on the multiple worklists.

Figure 1 displays the mapped workflow involving technologists, trainees, and attending radiologists. Note the step halfway through the workflow, where a technologist needs to manually bring paperwork from the technologist area to the reading room.

The anticipated additional workload of reading more mammographic volume from two additional remote sites, the larger amount of paperwork, and the mounting chaos from moving



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Marks exam in PACS as Available.
Diagnostic exam?
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Informs others of potential need for additional views.
Additional views needed?
no
yes
Captures additional views.
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Completes exam in RIS and departs patient in RIS.
Initial review by trainee?
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no
Reviews exam
Reviews exam
Discusses case with attending radiologist
Dictates report
Dictates report
Adds preliminary signature to the report
Adds final signature to the report.
End

◀ **Fig. 2** The changed workflow where the technologists no longer manually bring the needed paperwork to the reading room

between multiple worklists guided the initial efforts to restructure the workflow, a joint effort between radiologists, technologists, and the PACS IT team. Thus, the following actions were decided upon:

- *Scanning of paperwork*—All pertinent paperwork was scanned into the PACS as soon as the technologist was finished with them. Hence, the paperwork would be permanently stored in each patient's record and easily accessible at the time of image interpretation.
- *Worklist consolidation*—At the two main breast centers, there was consolidation of all the worklists down to a single worklist, to allow the radiologists to read off one master list that included all the remote sites. That meant that all breast imaging modalities that the radiologist was responsible for including screening and diagnostic mammograms, breast ultrasounds, and breast MRIs were viewed on the same worklist.
- *Chat functionality*—The "chat" function is similar to a text message as a form of communication between the technologist and radiologist without requiring the technologist to visit the reading room. The technologists used the chat function in the PACS to notify the attending radiologist if there was a diagnostic study ready for viewing which was not promptly attended to.
- *Work distribution among trainees*—A new column labeled "Reading Radiologist" was added to the consolidated worklist. Trainees could assign their names to studies from any site, and the attending radiologist could readily access work distribution among trainees on the list and keep track of which trainee was assigned to a particular study. This allowed the attending radiologist to have more control of the daily workflow.

Figure 2 displays the changed workflow, with the major change being that paperwork is now scanned and instantly available in the PACS instead of having to be manually carried to the reading room.

Evaluation

During the course of our study, the same five rotating breast imaging attending radiologists read screening and diagnostic mammograms from eight sites during the 2 months before and from ten sites (two additional sites) after the implementation of workflow optimization changes. Mammograms from all sites were read only on weekdays at the two main breast centers, and at both breast centers, studies were interpreted from other satellite sites. At breast center 1, there were one attending radiologist daily, three to four residents daily, and one fellow 4 out of 5 days. At breast center 2, there were one to two attending radiologists daily, one fellow 4 out of 5 days, and no residents.

The suggested changes were implemented in July 2015. Production data in the form of timestamps collected from the RIS and PACS along with PACS usage data was collected from two time points: May 1 through June 30 2015 (PRE) and from August 1 through September 30 2015 (POST). The time stamp data collected was compared between the pre and post workflow optimization changes time points.

The following timestamps were collected: (1) *patient arrival*, (2) *exam begin*, (3) *exam complete*, (4) *patient departure*, (5) *exam available/review notification* (associated with a flag set in the PACS to notify the radiologists that screening mammograms are ready for interpretation/that diagnostic mammograms are ready for review to determine if additional imaging is needed), (6) *exam first open in PACS by radiologist* (by attending radiologist or trainee), (7) *exam add/no add views notification* (associated with a flag set in the PACS to notify the technologist whether to perform additional imaging or complete the examination), (8) *preliminary signature* (issued by a trainee), and (9) *final signature* (issued by an attending radiologist). Timestamps (1)–(4) and (9) existed for all performed examinations, whereas (8) only existed for examinations where a trainee had performed the initial interpretation. Timestamps (5)–(7) were dependent on their availability in the collected PACS usage logs. The timestamps were used to compute the metrics: *patient stay* (4)–(1), *exam length* (3)–(2), *report turn-around time* (TAT) (9)–(3), *report TAT preliminary* (8)–(3), *time to open* (6)–(5), and *time to decision* (7)–(5) (only applicable for diagnostic examinations).

Only data from the examination type screening mammography (with and without tomosynthesis) and diagnostic unilateral/bilateral mammography (with and without tomosynthesis) and signed by the five attending mammography radiologists were extracted for subsequent analysis. Any breast exams signed by a radiologist outside of the five breast imaging specialists were excluded. In addition, all breast MRI and ultrasound studies were excluded from the subsequent statistical analysis.

Statistical Analysis

All timestamp metrics were analyzed separately for the two examination categories (screening and diagnostic) using generalized linear models (GLMs) with a gamma distribution and an identity linking function to assess the effect of the implemented workflow changes between the two time periods. In addition, the GLMs accounted for the factors location and radiologist along with the interaction effects location * radiologist, location * time period, and

Table 1 Reviewed cases per location and month [screening/diagnostic]

	May	Jun	Jul	Aug	Sep	May–Sep
Breast center 1	291/191	270/233	277/210	266/163	268/160	1372/957
Breast center 2	717/371	804/454	803/440	797/388	781/442	3902/2075
Satellite site 1[a,b]	0/0	1/0	26/0	135/44	172/46	334/90
Satellite site 2[b]	67/0	89/0	61/0	77/0	92/0	386/0
Satellite site 3	108/62	164/77	248/92	300/82	278/105	1098/418
Satellite site 4[b]	74/1	60/6	44/4	52/2	62/0	292/13
Satellite site 5[b]	63/0	88/0	65/0	50/0	70/1	336/1
Satellite site 6[b]	61/2	64/8	58/2	67/10	64/4	314/26
Satellite site 7[a,b]	9/2	6/0	3/3	16/0	43/3	77/6
Satellite site 8[a,b]	0/0	0/0	249/9	295/12	329/12	873/33
All	1390/630	1546/778	1877/758	2065/701	2159/753	9037/3620

[a,b] Sites not included in the statistical analysis for screening and diagnostic examinations, respectively

radiologist * time period. An effect was considered as significant if the p value was <0.01.

Note that only data from satellite sites with an adequate production both PRE and POST were included in the statistical analysis. This was done in order to ensure that a relevant volume for both PRE and POST would be available (>20 exams performed during both the PRE and POST time periods, respectively).

Results

Table 1 describes the number of reviewed cases per location and month, categorized as either screening or diagnostic. As can be noted, the number of screening and diagnostic mammograms continuously increased throughout the conducted study.

Table 2 provides the results from the statistical analysis employing the GLMs, but only for the effect of the factor Time Period. Note that the estimated p values are computed taking into account the potential effect of the other factors and interaction effects as well (see the supplemental material for the full results). These results show that the implemented workflow changes had a significant effect on all three relevant metrics for the screening mammograms, where report TAT decreased by 14 min (9 %, $p = 0.002$), report TAT preliminary by 43 min (29 %, $p < 0.001$), and time to open by 42 min (60 %, $p < 0.001$). p values for patient stay and exam length are reported as well and show significant improvements for both metrics, $p < 0.001$, but where the practical impact is negligible since the differences in mean values are only 2, respectively, in 1 min. For the diagnostic mammograms, it was only for the metrics patient stay and report TAT that a significant effect of the factor Time Period was found. For the diagnostic mammograms, the patient stay increased by 3 min (5 %, $p = 0.009$) and the report TAT by 21 min (28 %, $p < 0.001$).

The effects of the implemented changes were not uniformly distributed across the locations or the radiologists. For example, for the screening mammograms, both breast centers and the satellite sites showed significant improvements for time to

Table 2 Estimated p values as obtained from the GLMs for the main effect of the factor Time Period along with the corresponding marginal means ± standard errors

Examination category	Metric	p value	PRE marginal means ± standard errors [min]	POST marginal means ± standard errors [min]
Screening mammograms	Patient stay	<0.001	37.5 ± 0.3	35.7 ± 0.3
	Exam length	<0.001	20.3 ± 0.2	19.0 ± 0.2
	Report TAT	0.002	153.3 ± 3.3	139.1 ± 2.9
	Report TAT prel	<0.001	150.7 ± 3.5	107.4 ± 2.1
	Time to open	<0.001	70.2 ± 2.1	28.2 ± 0.8
Diagnostic mammograms	Patient stay	0.009	60.6 ± 0.8	63.5 ± 0.8
	Exam length	0.263	40.0 ± 0.7	41.0 ± 0.7
	Report TAT	<0.001	74.2 ± 2.8	95.0 ± 3.4
	Report TAT prel	0.473	43.2 ± 4.1	40.0 ± 1.9
	Time to open	0.336	6.4 ± 0.3	6.0 ± 0.2
	Time to decision	0.036	10.6 ± 0.3	11.5 ± 0.3

open, though to varying degrees (14–71 min), and where only breast center 1 and the satellite sites showed significant improvements for report TAT preliminary, decreasing 42 and 85 min respectively for breast center 1 and the satellite sites. More details on these matters are provided in Table 3 and Table 4 in the supplemental material.

Discussion

There is a national trend toward consolidation of multiple small hospitals and health centers resulting in larger health systems with multiple satellite centers spread over larger geographical areas. Rising pressure to read more screening and diagnostic mammography volumes from multiple sites, while trying to educate trainees in academic breast centers, has necessitated the need for improving efficiency in daily workflow. We were able to significantly improve workflow of screening mammogram readings in both of our busiest academic breast centers by implementing specific changes in the way we process and present patient information, communicate between technologists and radiologists, and set up worklists within our PACS environment. This was accomplished even when the volume of cases increased after the improvements were made. We were able to significantly reduce the time to open a case, time to preliminary report, and final sign off which all lead to reduced turn-around times for screening examinations. Any improvements in TAT for screening results will improve the timeliness of communication of results to the patient. This is not only impactful when considering timely results to referring providers, and there is more downstream impact on patient satisfaction especially with the advent of patient access to their own electronic health record. Results of diagnostic mammograms are routinely communicated to the patient in person by the technologist or radiologist at the time of the exam, before the patient leaves the department. Therefore, changes in TAT for diagnostic mammograms are less impactful to the patients.

Overall, the results for the screening examinations show that significant improvements for report TAT, report TAT preliminary, and time to open have been achieved through the implemented changes. The improvements are the largest for report TAT preliminary (decreasing by 43 min, $p < 0.001$) and for time to open (decreasing by 42 min, $p < 0.001$). It can be noted that these two improvements are of the same magnitude, which indicate the direct effect that a quicker opening of a case has on the preliminary signature. The biggest impact of the work flow changes made is on the trainee opening the case and dictating a preliminary report, which is viewable by referring clinical providers even before the report is finalized by the radiologist. In comparison, the report TAT did not show the same magnitude in its improvement, only 14 min, which is due to the habit of most attending radiologists signing reports later in the day. Further, the results suggest that the effect and the magnitude of the changes were not the same across all locations and all radiologists. For example, the improvements of report TAT preliminary and time to open were smaller for the breast center 2 than breast center 1 and the satellite sites. This is expected since the implemented change of consolidated worklists was expected to have larger impact at the main campus (breast center 1) than at breast center 2. There are a larger number of sites ($n = 6$) on the worklist for the main campus breast center vs the other main breast centers ($n = 2$). The fact that the length of stay and report TAT increased in the diagnostic setting is not surprising since there was an increase in volume between the two time points.

Altogether, the results show that reading workflow performance improvements have been achieved for the screening mammograms evidenced by the fact that the radiologists and trainees are quicker to open studies awaiting review, resulting in shorter report TATs. This has been achieved while leaving the performance of diagnostic mammogram workflow essentially unaltered and at the same time the overall mammogram volume increased by 31 % (from 4344 examinations during May–Jun to 5678 during Aug–Sep).

In terms of limitations of the performed analysis, the most significant is associated with the reliability of the utilized timestamps, especially the timestamps for exam completed and patient departure. All the examinations at any given site are channeled through a technologist who then manually enters into RIS the timestamps for exam completion time and patient departure time. Thus, if there is any inaccuracy in these timestamps entered by the technologist, the associated actions in the RIS triggering these timestamps are not necessarily occurring at the correct time point but might be delayed. Since these two timestamps are involved in most metrics (except time to open and time to decision), this affects their reliability as well. However, in our analysis, we have considered this issue as negligible, since its effect is likely to have been similar both before and after the implemented changes. However, this might explain some of the observed differences between the multiple sites. Also, the report TAT preliminary and time to open are not directly linked to the attending radiologists, since it is most likely a trainee who will trigger the associated timestamps. The perceived patient value of reduced report TAT is unknown, as we lack data on patients' impression of customer service.

Further, it can be noted that our work has focused on a subset of the overall radiological workflow in breast imaging, i.e., the reading workflow (interpretation and reporting of mammograms). Other issues considered, such as erroneous orders, paperless order entry, and centralized scheduling, were neglected since they have limited relevance to the reading workflow. However, some of these other issues may be of relevance when analyzing the overall workflow. In addition, we decided to limit our analysis of time aspects to before and after the implementation of workflow changes. For example, we did not look at the change in TAT depending on what time of the day the mammograms were interpreted.

In conclusion, our study demonstrated that changes in the form of mitigation of unnecessary physical paper transport along with the consolidation of the radiologists' reading worklists showed significant improvements in reading workflow efficiency for screening mammograms while not affecting the workflow of diagnostic mammograms. These results were achieved while at the same time the overall screening and diagnostic mammogram volumes increased considerably.

Compliance with Ethical Standards

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