Optimizing MRI Logistics: Prospective Analysis of Performance, Efficiency, and Patient Throughput

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OBJECTIVE. The objective of this study is to optimize MRI logistics through evaluation of MRI workflow and analysis of performance, efficiency, and patient throughput in a tertiary care academic center.

SUBJECTS AND METHODS. For 2 weeks, workflow data from two outpatient MRI scanners were prospectively collected and stratified by value added to the process (i.e., value-added time, business value-added time, or non–value-added time). Two separate time cycles were measured: the actual MRI process cycle as well as the complete length of patient stay in the department. In addition, the impact and frequency of delays across all observations were measured.

RESULTS. A total of 305 MRI examinations were evaluated, including body (34.1%), neurologic (28.9%), musculoskeletal (21.0%), and breast examinations (16.1%). The MRI process cycle lasted a mean of 50.97 ± 24.4 (SD) minutes per examination; the mean non–value-added time was 13.21 ± 18.77 minutes (25.87% of the total process cycle time). The mean length-of-stay cycle was 83.51 ± 33.63 minutes; the mean non–value-added time was 24.33 ± 24.84 minutes (29.14% of the total patient stay). The delay with the highest frequency (5.57%) was IV or port placement, which had a mean delay of 22.82 minutes. The delay with the greatest impact on time was MRI arthrography for which joint injection of contrast medium was necessary but was not accounted for in the schedule (mean delay, 42.2 minutes; frequency, 1.64%). Of 305 patients, 34 (11.15%) did not arrive at or before their scheduled time.

CONCLUSION. Non–value-added time represents approximately one-third of the total MRI process cycle and patient length of stay. Identifying specific delays may expedite the application of targeted improvement strategies, potentially increasing revenue, efficiency, and overall patient satisfaction.

Keywords: delay, efficiency, focused process improvement, lean, logistics, MRI, patient satisfaction, quality improvement, throughput, value, wait times, workflow

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Future trends and predictions regarding the use of advanced imaging techniques are currently facing an all-time upsurge in uncertainty. In the early years of the past decade, a substantial increase in the development and usage of imaging practices occurred, surpassing similar increases in all other physician services [1]. However, in more recent years, trends have flattened and have even begun to decline [2]. Many factors could have influenced current deviations, particularly the controversial implementation of the Affordable Care Act, which reduced reimbursements and decreased imaging volume, although it did achieve coverage of millions of previously uninsured individuals, which is now bound to increase the demand for imaging in the near future [3].

Regardless of expectations regarding advanced imaging utilization, we are currently facing a shift from the traditional volume-based approach to an approach where patient value is dominant. Therefore, radiology departments have responded by implementing process analysis procedures and improvements for increased imaging utilization efficiency. Process improvements have been used in many aspects of radiology to reduce wait times, increase volume, and improve patient throughput, among other metrics [4–8].

One of the biggest burdens affecting MRI patient throughput and most other service industries is scheduling patients and determining how to avoid long wait times, with patients currently enduring extended wait times to receive proper care. Waiting rooms and long wait periods have been common practice in medicine, but since the implementation of new patient care process improvements, they are no longer acceptable [5]. In fact, timeliness is one of the six aims in improving U.S. health care, as reported by the U.S. Institute of Medicine [9]. Another aspect of MRI workflow efficiency that could benefit from analysis is the ratio between MRI scanner utilization (gradient time) and scanner idling (nongradient time).

Therefore, we designed this study to apply lean methods to MRI workflow by classifying all processes present in patient flow in our tertiary care academic center, by value weighting all steps, and by pinpointing non–value-added time (NVAT) segments by which inefficiencies could potentially be identified.

Subjects and Methods

Approval for this prospective study was granted by the institutional review board at Beth Israel Deaconess Medical Center and was deemed compliant with HIPAA. Because this study was classified as a quality assurance activity providing no added risk to the patient, no additional interaction with the subjects, and no recordings of identifiable information, written consent from patients was waived.

Facility

Our medical center is a large tertiary care academic facility performing approximately 3000 MRI examinations per month over a broad range of subspecialty protocols. Over the past 5 years, the department has experienced substantial growth in the volume of MRI examinations performed and has had difficulty incorporating additional examinations utilizing the same number of MRI scanners (seven clinical scanners).

Additionally, our MRI leadership perceived multiple inefficiencies in the current patient throughput and requested a process improvement analysis; therefore, a comprehensive quality improvement program was initiated. A team was formed that involved the MRI clinical director, the MRI division manager, the application specialist lead MRI technologist, and two research fellows. The team used the lean approach born from the Toyota Production System and discussed in a 1998 publication [10]. Even though this lean approach originated in the automotive industry, it has been proven to be well suited for application in any service industry, including radiology [5–8, 11–15].

Lean Methodologic Framework

The lean philosophy focuses on eliminating waste by using a distinct set of tools, including identification of waste (*muda*) in the work environment and flow where the real work takes place (*gemba*), workplace organization, and use of visual controls. These tools allow members of an organization or team to identify and solve productivity and efficiency issues while embracing continuous transformations [5]. Application of the lean philosophy is crucial in industries that rely on customer flow and equipment function, revealing opportunities to reduce clinical and technical errors and mistakes, reduce patient and report waiting time, improve patient outcomes, increase staff productivity, decrease cost, and improve employee and customer satisfaction [11], by effectively applying continuous improvement measures perfected in the service industry and quality assurance science [7, 8, 11, 12].

Our institution currently owns and uses seven clinical MRI scanners, two of which were granted to our research team for the purpose of this study. These two adjacent scanners were chosen not only because they historically had the largest patient throughput and volume but also because only outpatients were examined. Each scanner requires two technologists to function; thus, four technologists were present, as was a technologist aide who helped with patient transport and cleaning methods. However, the presence of the technologist aide was variable throughout the totality of the

Suppliers	Input	Process	Output	Customer
Receptionist	Identification Appointment confirmation RIS and EMR	Patient arrival and registrations	Paperwork becomes available	Patient Technologist
Technologists Technologist aides Waiting room	Room preparation	Wait for room	Supply gown Changing room Establish point of care	Patient Technologist
Patient Technologists	Room Review orders Signed consent Place IV if needed for contrast administration	Enters preparation and consent room	Signed consent Patient IV or port in place Room ready	Patient Technologist
Technologists Technologist aides	Enter scanning room Place patient on table Coil placement Provide breathing and safety instructions Positioning Acquire image Images sent to PACS	Scanning process	Images in PACS	Patient Technologist Radiology Residents
Technologists	Provide discharge instructions EMR	Exit scan room and discharge patient	Patient reviewed instructions	Patient Technologist

Fig. 1—SIPOC (suppliers, inputs, process, outputs, customers) diagram. RIS = radiology information system, EMR = electronic medical record.

measurement period, which also reflects common clinical practice.

Initially, the project observation team, which comprised two research physicians, observed the processes directly as they occurred (going to the *gemba*), gathering preliminary information to develop the patient and MRI utilization flowchart and define the project strategy and studies. During this period, all MRI flow processes were identified, and a SIPOC (suppliers, inputs, process, outputs, customers) diagram was formulated (Fig. 1), which helped to identify all stakeholders in the process and provided a visual link from the supplier to the customer. In addition, data collection sheets were developed (Fig. 2), all personnel were informed of the principles and requirements for an inclusive lean process overview, sources of process variation were examined, and a flowchart of every step necessary for acquisition of each scan was developed (Fig. 3).

Sample Population

To create an efficient record of flow between MRI scans, the project team developed a data collection sheet (i.e., SIPOC diagram) (Fig. 1). The times measured were simultaneously collected from the two adjacent 1.5-T MRI scanners (Magnetom Aera [Siemens Healthcare] and Signa Twinspeed [GE Healthcare]) between June 13 and June 24, for a total of 10 working days that ranged from 7:00 am until 9:00 pm, resulting in a total sum of 150 working hours during which a total of 350 individual patients were scheduled. This resulted in 305 total patient stay length observations, after the exclusion of 45 patients (12.86%) who were scheduled for but did not arrive for scanning. For these 305 patients, we were able to calculate 286 utilization process cycle observations after excluding the last observation of each day for which the cycle was incomplete (Fig. 3).

Measuring Phase

Using the standardized data collection sheet, time-series data were successfully recorded for the completion of the value-weighted flowchart. For the purpose of including all possible time intervals where NVAT was present, we separately observed two time intervals, the first of which focused on MRI utilization where the total process cycle was calculated from the starting point of the first scan of the day until the start of the following scan, to fully assess the time when the scan room was idle as NVAT (with differentiation made between gradient time versus nongradient time), and the second of which focused on the patient's complete length of stay, starting from the time of arrival in the MRI department until discharge from the department and identifying patient wait time as NVAT. Both time intervals were measured in detail, assessing for times when each subprocess started and finished, noting all delays and their causes, including duration of the delay and personnel involvement, the MRI room studied, staff involved in each process step, and other factors that may affect timely execution, including all possible delays and their respective source (i.e., bottlenecks).

Data Stratifications

To determine how length and variation of the MRI stream flow varied, additional data were included in the standardized collection sheet to show contributing factors that may alter complete process time. These factors included the need

MRI Data Sheet Date:		**MRI room**
Patient information	Patient order #:	Aera Twin
Name:	MRN:	Coil used:
Gender: M F Age:	Interpreter: Yes No	Procedure:
Type of patient:		
Scheduled time		
Scheduled time slot (min)		15 30 45 60 75 90 120 >120
Process steps (time)	**Start time**	**Notes**
Patient arrival		
Late arrival reason:		
Patient starts prep		
Enter scan room		
MRI scan begins		
MRI scan ends		
Exit scan room		
Tech done with room tear down		
Excessive table time reason:		
Delays:	**Start time**	**Notes**
External delays:		
IV access Port access Interpreter		
Other:		
Discovery		
Request		
Resolution		
Notes:		
Internal delays:		
Safety/Implant concern Radiologist unavailable Patient not ready		
Other:		
Discovery		
Resolution		
Notes:		
Other Delays		
Discovery		
Resolution		
Notes:		

Fig. 2—Data collection sheet for patients undergoing MRI. MRN = medical record number.

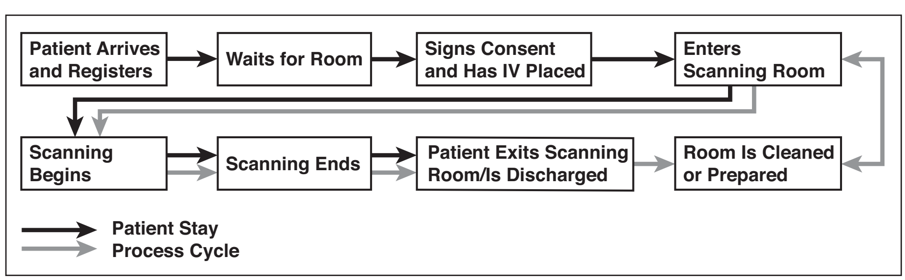

Fig. 3—MRI process flowchart of every step necessary for acquisition of each MR image.

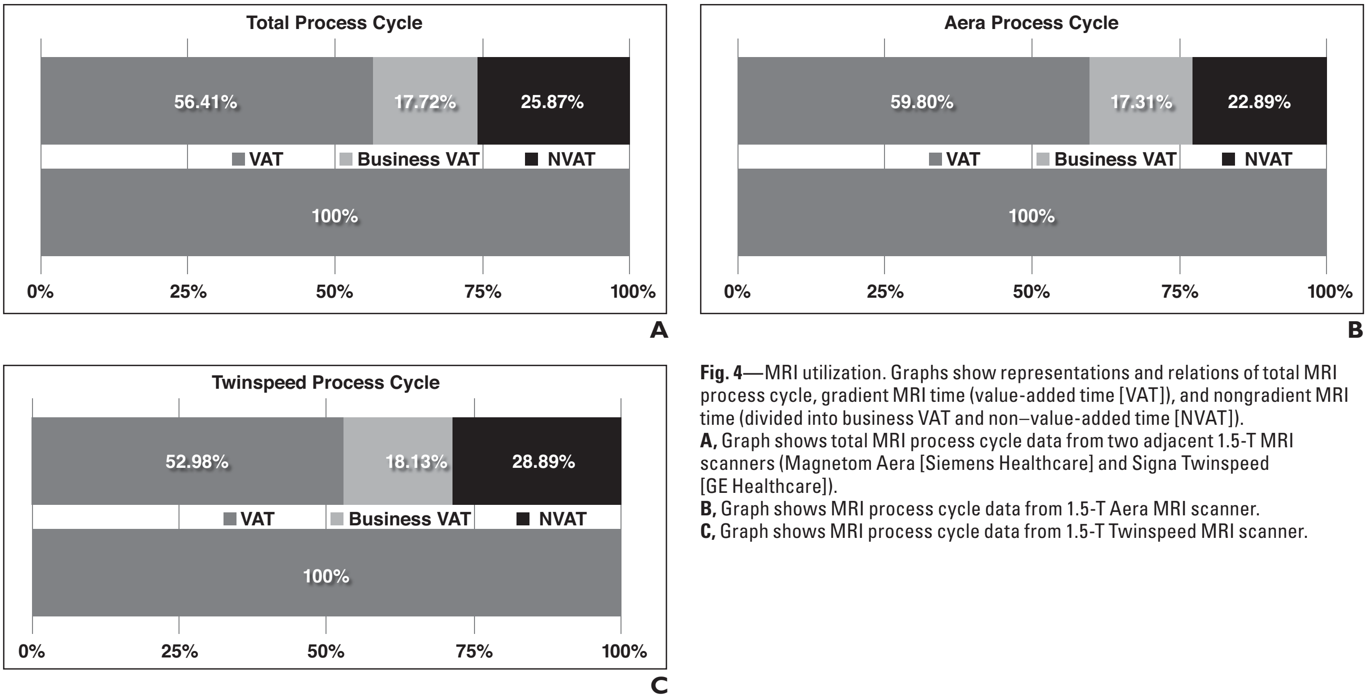

Fig. 4—MRI utilization. Graphs show representations and relations of total MRI process cycle, gradient MRI time (value-added time [VAT]), and nongradient MRI time (divided into business VAT and non–value-added time [NVAT]).
A, Graph shows total MRI process cycle data from two adjacent 1.5-T MRI scanners (Magnetom Aera [Siemens Healthcare] and Signa Twinspeed [GE Healthcare]).
B, Graph shows MRI process cycle data from 1.5-T Aera MRI scanner.
C, Graph shows MRI process cycle data from 1.5-T Twinspeed MRI scanner.

for an interpreter, type of protocol, specific MRI room, day of the week, and use of IV contrast medium. All stratified groups were compared using the Fisher exact test or ANOVA to establish a statistical significant difference.

MRI Acquisition Analysis

The total process cycle, defined as the interval between the beginning of one MRI scan to the beginning of the following scan, was then analyzed using the lean framework, with a flowchart of every process necessary established and inefficient steps marked that seemed to add little value to the overall process but could substantially delay the patient's stay. In accordance with the framework of the lean philosophy, we divided the total process cycle into three value-weighting intervals: value-added time (VAT) spent on activities that benefitted the patient directly (i.e., gradient time), business value-added time (business VAT) that did not directly influence patient care but included process steps technically required in the current state (i.e., in-room nongradient time and preparing or cleaning the room), and, finally, NVAT that provided no direct benefit to the patient (e.g., time when the scanner was idle), which we identified as waste. The percentages of VAT, business VAT, and NVAT were calculated as fractions of the total process cycle, and these measures were calculated for each patient.

The large SD observed in NVAT throughout our study is mainly attributed to delays and not variation in scanning time. When workflow was not interrupted by delays, the NVAT range was diminutive (i.e., 0–5 minutes). Conversely, when interruptions were present, NVAT ranged from 6 to 112 minutes. This resulted in a positively skewed sample, which, however, accurately represented the variable nature of delays inherent in the numerous types of studies offered.

Patient Stay Analysis

Total patient stay was defined as the interval between the arrival of the patient and patient discharge. Similar to the previous analysis, a distinct flowchart identifying all steps was generated, dividing patient stay into three value-weighting intervals: value-added time (VAT), which was the time the patient was inside the scanning room; business VAT, which was the time when the patient was receiving preparation for, providing consent, or was at any other point of care needed for the study; and NVAT, which was measured from the time of the patient's arrival until the patient was moved to the preparation room and was identified as waste (e.g., waiting for a room). The percentages of VAT, BVAT, and NVAT were calculated as fractions of the patient stay. These measures were calculated for each subject to assess the role of the waiting period in the total patient stay in all data stratification.

Results

MRI Throughput Analysis

Total process cycle—The mean process cycle measured, calculated from a total of 285 complete cycle intervals, was 50.97 ± 24.4 (SD) minutes (median, 44 minutes;

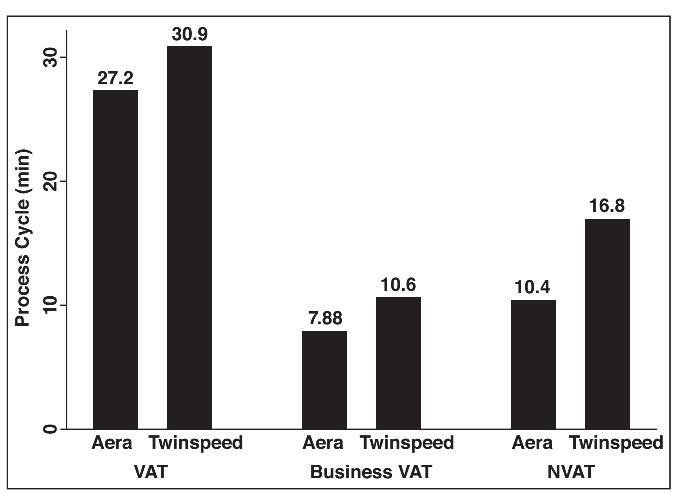

Fig. 5—Value-weighted intervals by scanner. Bar graph shows representation of actual time in minutes for value-added time (VAT), business VAT, and non–value-added time (NVAT) across the Magnetom Aera (Siemens Healthcare) and Signa Twinspeed (GE Healthcare) 1.5-T MRI scanners.

range, 18–161 minutes). If data were stratified by room, the room with the 1.5-T Magneton Aera scanner (henceforth referred to as the Aera room) accounted for a total of 161 total observations (56.49%) for which the mean process cycle was 45.43 ± 20.12 minutes (median, 42 minutes; range, 18–139 minutes). The room with the 1.5-T Signa Twinspeed scanner (henceforth referred to as the Twinspeed room) accounted for a total of 124 observations (43.51%) for which the mean process cycle was 58.16 ± 27.45 minutes (median, 50 minutes; range 24–161 minutes). All protocols from both scanners were included, which explains in part the large SD and variability in duration time and the scanner brand, model, and software, representing the normal variations in the daily workflow at our institution. Also, breast biopsy procedures (n = 7) were performed in the Twinspeed room only and accounted for only a small part of the difference in mean time and variation between scanners. Moreover, the types of protocols scheduled in each room were not equivalent; thus, mean values could be compared when the performance of each model was evaluated.

Utilization value-added time—The mean total VAT was 28.81 ± 11.18 minutes, representing 56.41% of the mean total process cycle time (median, 27 minutes; range, 10–77 minutes). For the Aera room, the mean VAT was 27.22 ± 9.67 minutes, representing 59.8% of the mean Aera process cycle time (median, 27 minutes; range, 10–59 minutes), whereas for the Twinspeed room, the mean VAT was 30.88 ± 12.63 minutes, representing 52.98% of the mean Twinspeed process cycle time (median, 28 minutes; range, 10–77 minutes).

Utilization business value-added time—The mean total business VAT was 9.05 ± 5.15 minutes, representing 17.72% of the mean total process cycle time (median, 8 minutes; range, 2–39 minutes). For the Aera room, the mean business VAT was 7.88 ± 3.67 minutes, representing 17.31% of the mean Aera process cycle time (median, 7 minutes; range, 2–25 minutes), whereas for the Twinspeed room, the mean business VAT was 10.57 ± 6.28 minutes, representing 18.13% of the mean Twinspeed process cycle time (median, 9 minutes; range, 2–39 minutes).

Utilization non–value-added time—The mean total NVAT was 13.21 ± 18.77 minutes, representing 25.87% of the mean total process cycle time (median, 5 minutes; range, 0–112 minutes). For the Aera room, the mean NVAT was 10.42 ± 16.14 minutes, representing 22.89% of the mean Aera process cycle time (median, 3 minutes; range, 0–81 minutes), whereas, for the Twinspeed room, the mean NVAT was 16.84 ± 21.25 minutes, representing 28.89% of the mean Twinspeed process cycle time (median, 8 minutes; range, 0–112 minutes). This interval represents waste occurring during MRI utilization, where improvement measures could reduce and improve overall utilization periods.

All value times are shown in Figure 4 (with percentages denoting total process time with VAT, business VAT, and NVAT), which shows that NVAT, or waste time,

TABLE 1: Frequency of Subspecialty Examinations and Most Common Procedures Performed Among 305 MRI Examinations

Type of Subspecialty Examination	Frequency (%)	No. of Procedures Performed	Time Allotted (min)
Body (n = 104)	34.1		
MRCP		32	30
Liver mass		24	30
Abdomen and pelvis		23	45
Neurologic (n = 88)	28.9		
Routine brain		47	30
Routine lumbar spine		14	30
Routine cervical spine		11	30
Musculoskeletal (n = 64)	21.0		
Routine knee		18	30
Routine shoulder arthrography		13	60
Routine shoulder		7	30
Breast (n = 49)	16.1		
Routine mass		42	30
Breast biopsy		7	75

Note—Data do not equal 100% because of rounding.

TABLE 2: Findings From a Cost-Benefit Analysis to Estimate the Potential Benefits and Profits Associated with Reducing Non–Value-Added Time and Increasing Magnet Capacity, Volume, and Flow Overall

Finding	Value
IV competency improvement	
Potential no. of additional examinations	22
Time for additional examinations	775.2 min or 13 h
Proper arthrography scheduling	
Potential no. of additional examinations	14
Time for additional examinations	422 min or 7 h
Additional examinations per month	
Total no.	36
Time for additional examinations	1197 min or 20 h
Additional examinations per year	
Total no.	432
Time for additional examinations	13,050 min or 217 h
Potential increase in MRI revenue (U.S. dollars)	
Per month	16,200
Per year	194,400

Note—The dollar value was set from a low-tier price average for MRI throughout the year 2016.

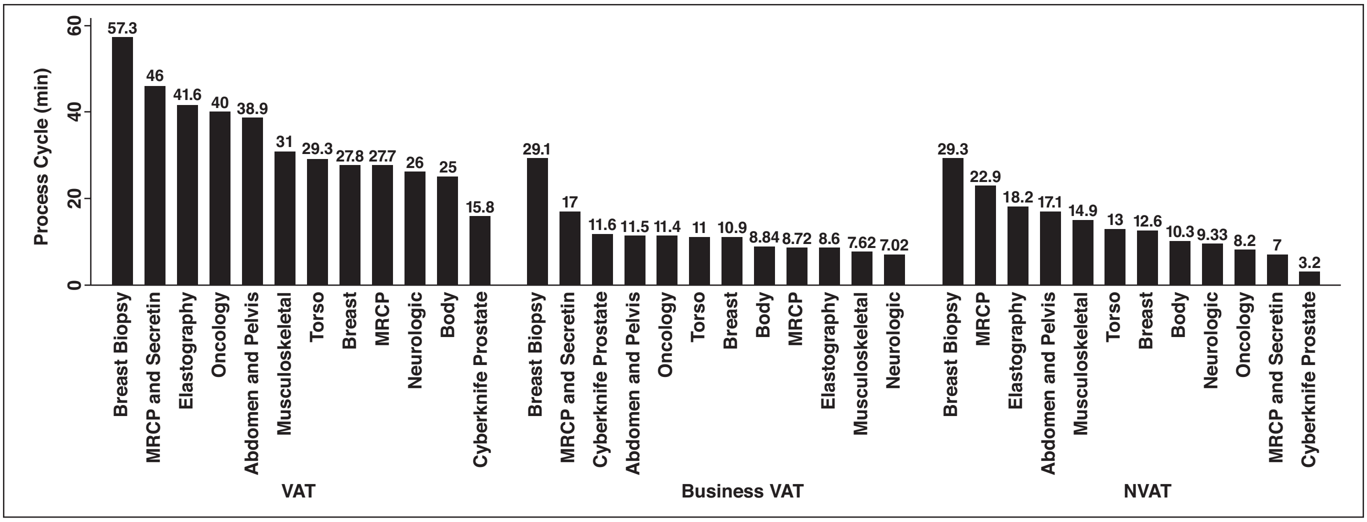

Fig. 6—Value-weighted intervals by type of protocol. Bar graph shows large variance in value-added time (VAT), business VAT, and non–value-added time (NVAT) among protocols.

accounts for a substantial 25.87% of the total process cycle time. A visual representation of actual time in minutes showing VAT, business VAT, and NVAT across both scanners is shown in Figure 5.

Other Data Stratifications

Stratification by MRI protocol type—A total of eleven types of protocols were used by both scanners and one procedure in the Twinspeed room. A complete list of protocols and procedures and their frequency of use is presented in Table 1. VAT, business VAT, and NVAT were compared by protocol to properly assess the large variance in protocol times (Fig. 6). From the visualization, we conclude that the length of VAT or business VAT does not relate to longer NVAT or waste time.

Stratification by use of contrast medium—As expected, the use of contrast medium increased complete process cycle time with a statistically significant difference of 10.2 minutes per examination ($p < 0.0023$). A complete visualization is shown in Figure 7, with the use of contrast medium compared with the use of no contrast medium as stratified by weighted value times.

Patient Stay Analysis

Total patient stay—For our 305 patients, the mean total patient stay was 83.51 ± 33.63 minutes (median, 77 minutes; range, 30–251 minutes). This analysis focused on identifying extended wait times for patients by classifying time values as VAT (i.e., patient in scan room), business VAT (i.e., time used for IV placement and patient consent), and, most notoriously, NVAT (i.e., wait time). The mean NVAT was 24.33 ± 24.84 minutes, representing 29.14% of the total patient stay (median, 17 minutes; range, 1–217 minutes), as shown in Figure 8. Large variability was expected because wait time depends on patient arrival time and numerous delay factors. It is crucial to note that a total of 271 patients (88.85%) arrived at or before their scheduled time, whereas 34 (11.15%) arrived late. However, patients who arrived after a late patient did not have a significant dif-

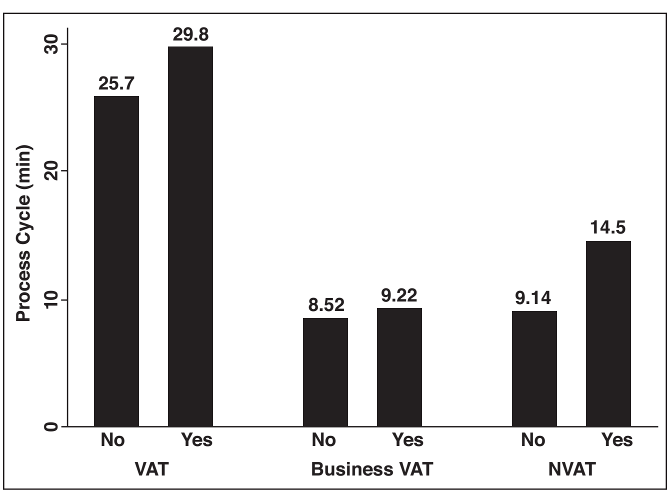

Fig. 7—Effect of use of contrast medium on complete MRI process cycle times. Bar graph shows comparison of use of contrast medium (Yes) versus no contrast medium (No) on complete process cycle times (value-added time [VAT], business VAT, and non–value-added time [NVAT]).

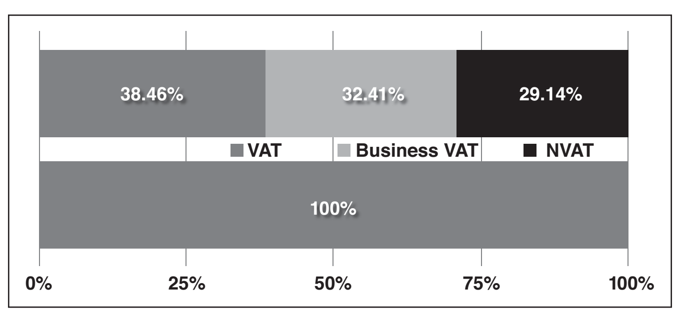

Fig. 8—Patient stay breakdown. Graph shows time values of total patient stay. VAT = value-added time, NVAT = non–value-added time.

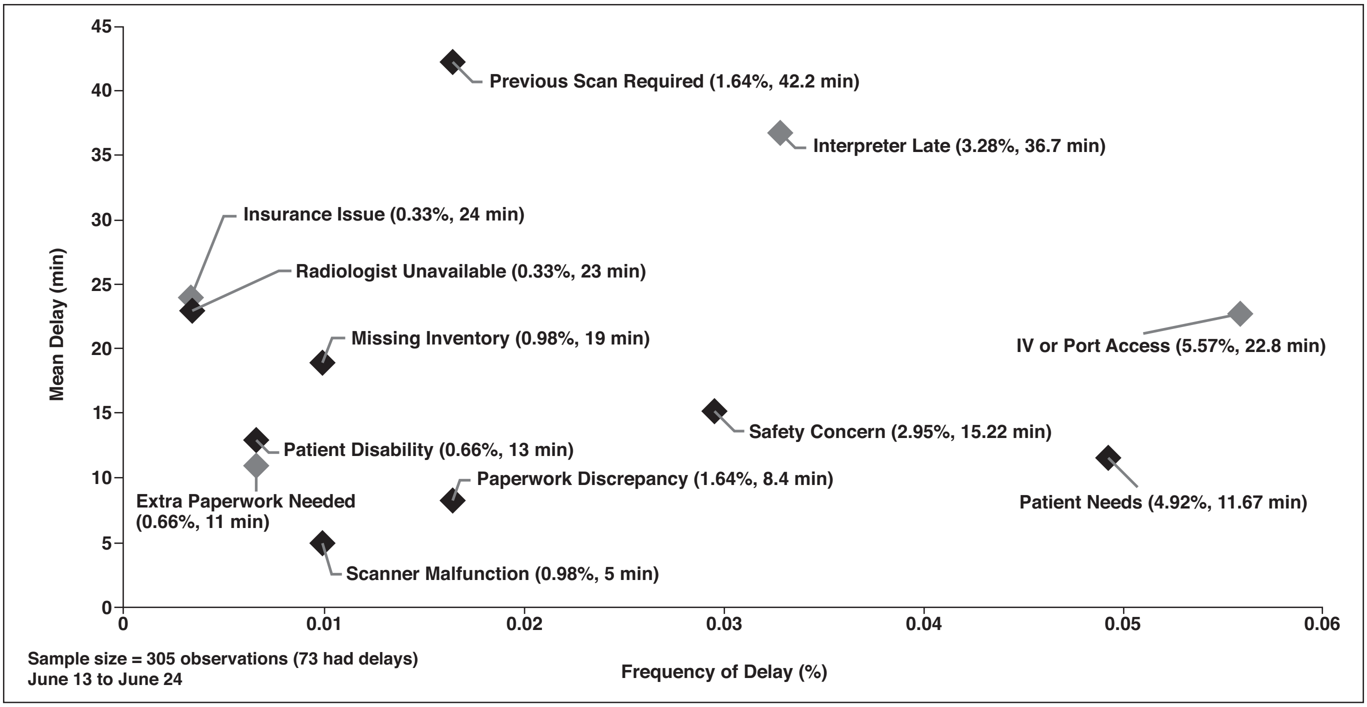

Fig. 9—Frequency and impact of delays. Graph shows all measured delays and their mean length and frequency. Data shown in parentheses after each delay denote frequency expressed as percentage and length of delay expressed in minutes.

ference in mean wait time and length of stay, compared with all other patients who arrived at or before their scheduled time; therefore, we did not classify arrival after a late patient as a substantial source of delay.

Stratification by the need for an interpreter—A total of 28 of 305 patients (9.18%) who were included in the study needed to schedule an interpreter before arrival because they were not sufficiently fluent in English to communicate or provide consent without an interpreter present. No statistically significant difference in patient length of stay was noted for patients needing an interpreter compared with patients speaking English fluently.

Common Delays

At the early stage of observation (going to the *gemba*), our team defined delay as any process or part of the patient stay duration that did not contribute to patient preparation, room setup, or patient scanning. Consequently, during the measuring phase, observers identified when a delay occurred and promptly registered the reason for and time of discovery and time of resolution of the delay. Once all delays were categorized, the mean duration of each type of delay was calculated, as was the frequency of patient stay durations in which the delay occurred. This determined the relative frequency and impact of each delay type and is shown in Figure 9. The following sections offer descriptions of the delays that had a moderate-to-high impact on total patient stay duration (presented from most common to least common delay), with remaining uncommon delays shown in Figure 9.

Need for IV or port access—IV or port access issues arose when the patient was scheduled for a study requiring contrast medium but the MRI technologist was not able to place the IV line or access the port, resulting in a specialized nurse being summoned to travel to the preparation room for correct placement of the IV or port.

Delays caused by IV or port access occurred in 5.57% of all observations of patient stay length; the mean delay for securing a proper IV or port line was 22.82 ± 15.90 minutes. IV or port issues had a high impact on total patient stay length and were the most frequent source of delay overall.

Patient needs—A patient needs delay was documented when the particular needs of a patient caused a lengthening of the total patient stay. These delays occurred when, for example, a patient had several questions for the staff, issues with the paperwork, claustrophobia, or was uncomfortable in the machine or if a patient had not yet put on his or her gown when the scanning room was ready.

Delays caused by patient needs occurred in 4.92% of all observations of patient stay length; the mean delay to ensure that patient needs were met was 11.67 ± 10.62 minutes. Patient needs had a moderate-to-high impact on total patient stay and was the second most-registered delay.

Late arrival of interpreter—Delays caused by late interpreter arrival involved patients who did not speak English and required an interpreter for proper consent. Most of these patients already had an interpreter scheduled at the time of the study, but actual delay was measured when the interpreter was unavailable or failed to present at the time of the patient's appointment.

Delays caused by the interpreter arriving late for the appointment or by failure to schedule an interpreter at the time of patient consent occurred with a frequency of 3.28% over the total patient stay length observations. Waiting for an interpreter resulted in a mean delay of 36.7 ± 24.14 minutes, had the second highest impact on total patient stay length, and occurred with moderate frequency compared with all other delays.

Concerns about safety or implants—Safety concerns were discovered during the consent phase, and communication with the scheduling physician was required for approval of and progression with scanning. Safety or implant concerns occurred for 2.95% of all observations regarding patient stay length; the mean delay until approval was received to continue scanning was 15.22 ± 15.05 minutes. High variability was attributed to the fact that when a safety concern arose, if the patient had recently undergone MRI, approval for scanning after investigation was expedited, whereas if the patient had no previous scan identified, the physician who ordered the examination had to be contacted. Safety concerns had a moderate impact on total patient stay and occurred with moderate frequency.

Preceding intervention needed—Delays regarding this issue only concerned patients scheduled for MR arthrography for which joint injection of contrast medium and confirmation with fluoroscopy were necessary before MRI but were not accounted for in the work plan of the day. MR arthrography that required a previous unscheduled injection of contrast medium confirmed by fluoroscopy occurred with a low frequency (1.64%) among all examinations; nonetheless, it required the longest resolution time and had the greatest impact on total patient stay length (mean, 42.2 minutes ± 32.86 minutes).

Cost-Benefit Analysis

In addition, we performed a cost-benefit analysis to estimate the potential benefits and profits associated with reducing NVAT and increasing capacity, volume, and flow overall (Table 2).

Discussion

Radiology workflow has been studied for more than 40 years and has been proven to streamline and improve patient care [6, 13–15]. A fundamental principle of the lean approach focuses on the application of lean tools for collection and analysis of data to improve radiology system processes [12], such as advanced image acquisition flow into its component parts. Division of workflow differentiates process steps that add value by affecting medical care decisions from steps that do not have the potential to affect medical care decisions directly and can trump efficiency and timeliness. Thus, identification of the workflow steps where NVAT is present, in conjunction with identification of the triggers for these delays that increase the length of the inefficient steps, can be the aim for future improvement in workflow and patient satisfaction.

Access to engineers and efficiency experts to examine daily radiology patient workflow is limited by the protection of patient privacy afforded by HIPAA. Therefore, in an effort to limit the intrusion of data collection on patient care, it benefits health care personnel who understand the complexity of image acquisition and the value of implementing workflow improvement strategies to perform patient flow analysis and lead discussions on radiology workflow optimization [7].

In this study we used lean methodology to quantify and assess MRI workflow and utilization in two scanning rooms at our institution during regular scheduling and current workflow, to identify and analyze sources of inefficiencies. The amount of time that a patient spends waiting or the amount of time that the scanning room is in an idle state was considered NVAT and was identified as waste. NVAT intervals for both patient workflow and MRI scanner utilization proved to have substantial influence over the total intervals measured; for an idle MRI room, the mean was 25.87% over the total process cycle and the mean patient wait time was 29.14% of the total patient stay length. By identifying delays, classifying their respective sources, and assessing their impact over the total process time, we are able to propose improvements to decrease overall patient stay, increase MRI utilization and turnaround, streamline workflow, and reduce patient waiting periods for greater efficiency and process improvement.

This study also showed that the source of delay with the highest frequency was issues with IV or port placement that required a specialized nurse to be summoned and the process to be halted until the nurse arrived at the preparation room and completed proper placement of the IV or port access. On the other hand, the delay that had the greatest impact on total patient stay length was that attributed to MR arthrography for which joint injection of contrast medium and confirmation with fluoroscopy were necessary but were not accounted for in the schedule. With these results, our team intends to implement a competency course in IV placement to address two principal objectives: first, to increase the IV placement skills of all technologists and, second, to recognize the most capable technologists to ensure that each shift of technologists has at least one highly skilled worker who could potentially ease IV placement for patients for whom cannulization is difficult, thereby decreasing the overall delay in IV placement as well as the need for an IV nurse.

Furthermore, a department-wide initiative has been enacted to focus on the improvement of all perceived potential delays. This initiative has four main aims. First, continuous education is provided to staff regarding the scheduling and booking processes, including a thorough review of all fluorography and MRI examinations for the identification and resolution of potential conflicts. Second, technologists who are on duty now review patient scheduling 3 days in advance of the appointment to identify potential issues (i.e., protocol, incorrect scanner booking, identification of patients with claustrophobia, addressing patient needs, and other issues). If a discrepancy is identified, they are instructed to notify the scheduling office, which will then implement the change and notify the patient. Third, implant concerns are now reviewed along with scheduling, with the purchase and utilization of a new MRI safety database (Mag Resource Database, version 2_A, Mag Resource) that provides comprehensive and prompt implant safety information. Fourth, the MRI scanning manager is currently working alongside interpreters to successfully map the exact arrival time and required interaction time with patients for interpreters across all protocols, improving their overall time management as well as implementing a three-way conversation line to aid in diminishing travel time and delays.

Our results show how a third party of experienced clinicians can apply lean principles and tools to analyze MRI workflow simply by following the process as it occurs. Dissecting its components can give tremendous insight into possible inefficiencies, which may be imperceptible to the regular staff during the process, and can pinpoint issues, such as where delays and clusters can alter the process, resulting in variable quality and occasionally wasteful imaging. Forthcoming studies may prove how the proposed measures could improve patient flow and increase imaging volume, but this was beyond the scope of the present study. Furthermore, increased patient satisfaction, which likewise is outside the scope of this study, can be expected as a result of reduced wait times and increased accuracy of IV placements by more experienced personnel.

Moreover, our estimates show noteworthy prospects for the financial health of a practice and how quality measures can result in additional revenue growth. However, actual cost and revenue effects heavily depend on practice cost structure, the reimbursement model, and existing fleet utilization.

Limitations concerning our results and methodology must also be taken into account. First, because the process is observed as it occurs, an inherent inclusion of Hawthorne bias is expected, although we assume that our presence in the process only improved the performance of the technologist, underestimating possible waste. As stated previously, scheduling for procedures was not altered for the purpose of measuring the normal current state, limiting the opportunity to compare both scanners, which differ in make and model and possibly in scanning length. Also, the presence of a technologist aide was highly variable and could increase the variability in our results, an issue that should be analyzed more conclusively in the near future. Last, in terms of applying the outcomes of our study to regular practice, one of the biggest pitfalls was the length of the measurement phase, which allowed only 10 working days during which to properly detail each step and identify all delays.

Even though these difficulties may be regarded as pitfalls to future implementations of similar process improvement in other practices, they should be viewed as opportunities that provide valuable insight into future change, a valuable asset of the lean approach to the MRI division in any advanced imaging center.

Conclusion

This study provides evidence of how systematic implementation of process analysis can significantly aid in streamlining patient throughput and imaging volume. Our findings suggest that almost one-third of the total patient stay length and MRI utilization is composed of NVAT that can be shortened by identifying the source of inefficiency and implementing change. For this purpose, specific delays were measured and analyzed to pinpoint specific bottlenecks in the overall patient flow, most notably identifying IV placement and an omission in scheduling as sources of a greater impact on delay. Process analysis improves the understanding of how the scanning process operates and determines potential targets for improvement. Ongoing continuous improvement, if applied systematically, can potentially cut costs and increase efficiency and patient satisfaction.

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