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Workflow Optimization: Current Trends and Future Directions

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In an attempt to maximize productivity within the medical imaging department, increasing importance and attention is being placed on workflow. Workflow is the process of analyzing individual steps that occur during a single event, such as the performance of an MRI exam. The primary focus of workflow optimization within the imaging department is automation and task consolidation, however, a number of other factors should be considered including the stochastic nature of the workload, availability of human resources, and the specific technologies being employed. The purpose of this paper is to determine the complex relationship that exists between information technology and the radiologic technologist, in an attempt to determine how workflow can be optimized to improve technologist productivity. This relationship takes on greater importance as more imaging departments are undergoing the transition from film-based to filmless operation. A nationwide survey was conducted to compare technologist workflow in film-based and filmless operations, for all imaging modalities. The individual tasks performed by technologists were defined, along with the amount of time allocated to these tasks. The index of workflow efficiency was determined to be the percentage of overall technologist time allocated to image acquisition, since this is the primary responsibility of the radiologic technologist. Preliminary analysis indicates technologist workflow in filmless operation is enhanced when compared with film-based operation, for all imaging modalities. The specific tasks that require less technologist time in filmless operation are accessing data and retake rates (due to both technical factors and lost exams). Surprisingly, no significant differences were reported for the task of image processing, when comparing technologist workflow in film-based and filmless operations. Additional research is planned to evaluate the potential workflow gains achievable through workflow optimization software, improved systems integration, and automation of advanced image processing techniques.

INTRODUCTION

THROUGHOUT THE PAST DECADE, as the American economy continued through a period of unprecedented growth and prosperity, pundits repeatedly pointed to a new economic era of sustained growth through continuous productivity gains. We were told that traditional economic theories were no longer valid in this new digital world, largely because of the automation of previous manual tasks by computers. Inflation was in check, the economy was expanding, and productivity measures continued to grow. Hospital and radiology department administrators adopted a productivity mantra, as a means to balance competing pressures of reduced technologist staffing and economic restraint. In an attempt to maximize efficiencies, imaging department administrators asked their employees to work harder, faster, and longer. For a short time, this strategy of "trimming excess fat" from personnel payrolls appeared to work, but this strategy was somewhat myopic and temporary at best. Employee morale suffered, the job market continued to decline, and hospitals found it increasingly difficult to maintain staffing and services.

A preferable method to improve productivity centers on the science of workflow analysis, which studies the individual steps that occur during a single event, such as the performance of an magnetic resonance imaging (MRI) examination. Whereas the industrial engineering literature has devoted significant time and

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resources to this endeavor,[1] which is termed *process analysis*, little to date has been published in the radiology literature about workflow optimization. Without a thorough understanding of workflow within the medical imaging department, productivity gains will be incomplete and ineffective. This is especially true for those seeking productivity gains by undergoing the transition from film-based to filmless operation.

Workflow redesign initiatives are achieved commonly through the bundling of jobs, consolidation of individual tasks, and employee empowerment.[2] One must realize, however, that workflow redesign must be customized to the unique and idiosyncratic nature of each individual organization. Whereas automation and task consolidation remain the cornerstone of workflow optimization, a number of extraneous factors must be considered including the stochastic nature of the workload, availability of human resources, and the specific technologies being used. The end goal is to improve productivity while reducing cycle time, which can take on a number of forms within a medical enterprise including report turnaround, examination backlog, or length of hospital stay. The end goal is the delivery of information and data in a more timely fashion so that decision making can occur expeditiously, with the objective to improve patient care and outcomes.

The purpose of this study was to determine the relationship between medical imaging–related information technology (IT) and technologist workflow. The information technologies considered in this study include the hospital information system (HIS), radiology information system (RIS), and picture archival and communication system (PACS). In addition to these information technologies, the relationship between filmless operation and technologist workflow was evaluated. In an attempt to better understand the interaction between technology and workflow within a medical imaging department, the existing medical literature was reviewed. The combined information was synthesized into a detailed discussion, in an attempt to provide an overview as to how current and future digital technologies (PACS, information systems, digital radiography, and electronic medical record) can be utilized to enhance workflow in a filmless/paperless medical imaging department.

MATERIAL AND METHODS

The development of the survey instrument, data collection, and quality control were described in the first report of the 3-part series in detail.[3] Technologist workflow was assessed by defining the individual tasks performed during a typical working day and by determining the percentage of overall working technologist time allocated to these tasks. The individual tasks assessed included examination scheduling, patient transportation, patient preparation, data access, examination acquisition, image processing, retrieval of historical comparison studies, image duplication, and repeat examinations because of technical factors or loss.

Given that the primary function of the technologist is to produce medical images, we chose the percentage of time devoted to examination acquisition as our index of technologist workflow efficiency. Therefore, optimization of workflow would increase the percentage of time spent in image acquisition (i.e, optimized workflow = 100% of time spent in image acquisition).

In the administered survey, the degree of film printing was expressed as a percentage of total examinations for that modality. A univariate analysis was performed to determine the distribution of responses. These values were plotted along a frequency distribution and separated into quartiles to determine values for cut points. The top quartile was designated "film-based" and the bottom quartile was designated "filmless." These values were similar for all modalities. "Film-based" was designated if greater than 75% film printing occurred for that modality. "Filmless" was designated if less than 25% film printing occurred for a specific modality.

The technology profile analysis was as follows. The differences in procedures per FTE were compared based on the presence or absence of a RIS, HIS, HIS-RIS interface, and modality-specific PACS. These values were also compared based on the degree of film printing (film-based and filmless), with analyses performed for each of the 7 individual modalities. The significance of these differences was determined using a *t* test. Because some categories had a small number of facilities, and outliers may skew the means, we also compared medians between these groups using the Mann-Whitney U test (a nonparametric procedure).

A more focused comparison was performed for all subtasks between film-based and filmless facilities for the modalities of general radiography, computed tomography (CT) and MRI, because these modalities were felt to represent the domains in which technologist workflow would most likely be affected by film printing. The mean and median values were calculated for each subtask, comparing filmless and film-based facilities, and the differences were assessed using Mann-Whitney U and *t* tests.

RESULTS

The time allocation data are presented in Table 1 with both mean and median values in-

Table 1. Technologist Responsibilities: Breakdown of Time Allocated for Each Modality

	Modality						
Responsibility	Radiography	CT	US	MRI	NM	MAM	IA
Examination scheduling							
Mean	1.0	2.4	2.2	2.2	4.1	2.1	3.8
Median	0.0	0.0	0.0	0.0	2.0	0.0	1.0
Patient transport							
Mean	3.2	3.1	2.4	2.2	2.3	0.8	2.8
Median	2.0	1.0	1.0	0.0	1.0	0.0	1.0
Patient preparation							
Mean	5.2	7.9	5.1	6.8	8.1	5.2	8.7
Median	5.0	6.0	5.0	5.0	8.0	5.0	10.0
Accessing data							
Mean	4.6	6.0	5.4	5.1	5.6	6.2	6.3
Median	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Performing examination							
Mean	65.4	63.9	69.2	63.2	60.4	61.7	58.2
Median	68.5	68.0	72.5	67.0	63.0	65.0	60.0
Image processing							
Mean	11.0	10.4	8.4	11.7	13.0	11.0	10.1
Median	10.0	10.0	5.0	10.0	10.0	10.0	9.0
Retrieval of old examination							
Mean	3.1	3.1	3.2	2.6	2.7	5.6	2.5
Median	1.0	1.0	1.4	1.0	2.0	5.0	1.0
Repeat examination (because of loss)							
Mean	1.3	0.9	0.5	0.7	0.4	0.8	0.4
Median	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Repeat exams (because of Technique)							
Mean	3.2	0.8	0.9	1.1	0.8	2.7	0.6
Median	3.0	0.0	0.0	0.0	0.0	2.0	0.0
Duplicating images							
Mean	1.1	1.5	0.5	1.9	0.5	0.5	0.5
Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Abbreviations: US, ultrasonography; NM, nuclear medicine; MAM, mammogram; IA, interventional angiography.

cluded. Although the mean represents the arithmetic average obtained by adding all individual data points, this is subject to distortion by extremely high or low values. For this reason, median values are a preferable measure of central tendency that are not affected by extreme high or low values. For many of the individual tasks reported in table 1, respondents reported no technologist time allocated, resulting in a median value of 0. Please note that the median values frequently add up to less than 100%.

Nuclear medicine (NM) and interventional/angiography (IA) technologists reported a greater percentage of their working time devoted to examination scheduling than their counterparts in other imaging modalities. General radiography technologists spent a greater proportion of their time performing patient transportation than other types of technologists, resulting in a decrease in their overall productivity. Another task that negatively affects technologist productivity is patient preparation, which encompasses a number of individual steps, depending on an individual department's workflow and the modality. Angiography/interventional technologists spent a disproportionately large amount of time in patient preparation, which can be explained by the fact that this was required as part of the routine involved in setting up for the procedure. This setup includes the individual steps involved in achieving intravenous access, creating a sterile field, explanation of the procedure to the patient, obtaining informed consent, and preparing the work area with the appropriate supplies and equipment needed for the procedure. These tasks are unique to the subspecialty and are

Table 2. Technologist Workflow Based on Deployment of Medical IT and Film Printing Status

	Rad	CT	US	MRI	NM	MAM	IA
With RIS	67 (82)	65 (82)	71 (82)*	65 (69)	62 (79)	62 (67)	59 (66)
Without RIS	59 (22)	59 (23)	62 (22)*	57 (20)	56 (22)	58 (19)	52 (14)
With HIS	66 (94)	64 (95)	70 (94)	63 (78)	62 (92)*	62 (76)	61 (74)*
Without HIS	57 (10)	65 (10)	64 (10)	65 (11)	46 (9)*	59 (10)	26 (6)*
With HIS-RIS	67 (76)	64 (76)	70 (76)	63 (60)	62 (74)	61 (62)	62 (62)
Without HIS-RIS	63 (28)	63 (29)	68 (28)	63 (29)	57 (27)	63 (24)	53 (18)
With PACS	66 (35)	63 (41)	72 (39)	66 (34)	62 (25)	NA	64 (17)
Without PACS	65 (69)	65 (64)	67 (65)	61 (55)	60 (76)	NA	57 (63)
With Modality worklist	66 (37)	64 (37)	71 (35)	65 (32)	64 (20)	NA	66 (16)
Without Modality worklist	65 (67)	64 (68)	68 (69)	62 (57)	60 (81)	NA	56 (64)
Filmless (25% printing)	66 (16)	69 (27)	71 (32)	69 (22)	65 (21)	NA	67 (9)
Film based (75% printing)	65 (73)	62 (67)	67 (61)	62 (56)	59 (73)	NA	59 (59)

Note. The values in each cell are the mean percentage of time spent performing image acquisition with the value in parenthesis being the number of facilities in that category.

*Significant difference (*P* value < .05).

Abbreviations: RAD, diagnostic radiography; US, NA, not applicable.

unlikely to be affected by demographic and technology profile differences.

The amount of technologist time spent accessing data was consistent among all modalities. Approximately 5% of technologist time was devoted to this task. Image processing accounted for 9-10% of technologist time, with the exception of ultrasound. Although retrieval of old examinations traditionally has been considered the responsibility of the file room personnel, a significant percentage of mammography technologist time (5%) is spent in performing this task, which is far greater than for other modalities. Technologist time spent repeating examinations (because of loss and technical factors), is greatest for diagnostic technologists, accounting for approximately 4% of their allocated working time. This, in part, may reflect the fact that unlike other modalities, repeat analyses often are performed as part of general radiography practice.

The amount of time spent in image acquisition is critical because this is the primary and most important function of the technologist. If one's goal is to maximize technologist productivity, then the ideal would be to have an environment in which the technologists are able to spend 100% of their time on this task. In our survey, ultrasonography technologists spent the greatest proportion of their time in image acquisition (72.5%), whereas interventional/angiography technologists spent the least (60.0%).

The impact of medical IT and film printing on technologist workflow by modality is presented in Table 2. In general, those facilities with the deployment of medical IT had more efficient workflow (ie, technologists spent a higher percentage performing image acquisition) compared with facilities without IT. Those modalities that show a statistically significant improvement in workflow with IT implementation included ultrasound (RIS), nuclear medicine and interventional/angiography (HIS), and CT (filmless). In many cases, such as general radiography, statistical significance was not achieved despite fairly substantial differences between filmless and film-based operations. This was a reflection of the relatively small sample size within the subgroups because only a relatively small percentage of facilities reported filmless operation.

In evaluating the potential relationship between technologist time allocations and technology implementation, a comparison of film-based and filmless operation was undertaken for general radiography, CT, and MRI technologists (Table 3). For all 3 modalities, the trends were similar with regard to increased time spent on performing examinations, decreased repeat examinations because of loss, decreased time spent accessing data, and decreased time spent on patient transportation. The differences for repeating examinations because of loss were statistically significant for CT and MRI and approached statistical signifi-

Table 3.

	Radiography		CT		MRI	
Responsibility	Film based	Filmless	Film based	Filmless	Film based	Filmless
Examination scheduling	0.9	1.3	2.6	1.8	2.1	2.1
Patient transport	3.3	2.8	3.3	2.5	2.5	1.0
Patient preparation	5.4	5.0	8.2	7.6	6.8	7.1
Accessing data	4.9	2.9	6.6	4.7	5.3	4.0
Performing examination	64.8	66.4	61.8	68.6	61.3	69.3
Image processing	10.6	13.0	10.5	9.9	12.1	10.4
Retrieval of old examinations	3.1	3.4	3.2	2.8	2.4	3.3
Repeat examination (because of loss)	1.4	0.75	1.1*	0.3*	0.9*	0.3*
Repeat exam (because of technique)	3.3	2.8	0.8	0.7	1.2	1.1
Duplicating images	1.1	1.4	1.6	1.2	2.0	1.4

cance for radiography. The differences in time allocated for performing examinations was borderline significant for CT and MRI. Repeating examinations because of technique only affected radiography, which is consistent with the known advantage of digital radiography over film-screen radiography with respect to exposure latitude. Interestingly, there was no consistent effect on time devoted to examination scheduling, patient preparation, image processing, retrieving historical comparison studies, and image duplication.

DISCUSSION

In this investigation we evaluated the effect of medical related–IT and degree of filmless operation on medical imaging technologists' workflow. The baseline data from the SCAR survey suggest that facilities with medical IT and facilities approaching filmless operation have improved workflow, as defined by the proportion of technologists' time allocated to the primary task of image acquisition. Technologist time allocation is an underutilized index of efficiency, which has a profound overall effect on productivity.

Unfortunately, analysis of time allocation is fraught with a number of confounding variables, which limit the ability to derive a cause and effect relationship between medical IT implementation and improved technologist workflow. The data and analysis presented in this report therefore is intended to provide insight into the complex relationship between technologist productivity, workflow, and technology implementation. It is not our intent to determine cause and effect relationships, but instead to compare the observations of the SCAR survey data with other published data. It is hoped that with additional longitudinal data collection, these complex relationships will be delineated further. The implications for this project are significant, given the shortage of radiologic technologists in the current imaging environment.[3]

Technologist time allocation as a function of individual modality was evaluated in Table 1, which represents pooled data of all survey respondents, independent of medical IT implementation. Several responsibilities have disproportionate time allocations, which vary according to the individual imaging modality. Examples of disproportionate time allocations can be seen with the tasks of examination scheduling, prior examination retrieval, and repeat examinations. Although each imaging department's scheduling process is somewhat idiosyncratic, nuclear medicine and angiography/interventiaonal technologists tend to spend disproportionately greater amounts of time scheduling examinations. This is believed to be a reflection of the fact that these types of examinations are complex and tend to be customized to the specific examination indications, and thereby require analysis with regard to the patient history, diagnostic options, and technology availability. An understanding of these issues often is beyond the capabilities of clerical staff or computer-based scheduling programs, and therefore requires the direct input of the technologists.

Another example of disproportionate technologist time allocation is observed with mammographers and prior examination retrieval. Whereas this function typically is assigned to file room personnel, comparison studies frequently are misplaced or lost and not available to the radiologist at the time of dictation. Whereas interpretation of imaging studies often is provided without historical comparison with other imaging modalities, it is considered essential for mammography. This is largely because subtle mammographic changes often are the hallmark for early cancer detection and cannot be assessed properly without serial inspection. At the same time, previous mammographic studies often have been performed outside of the parent institution and require time-intensive inquiries for their disposition. These tasks commonly are given to the mammographer, who also is responsible for overseeing the quality assurance program. This combination of factors results in additional unique time requirements for the mammography technologist.

The time allocated for repeat examinations owing to technical factors was higher for general radiographic and mammography technologists. This is in part because these imaging studies are primarily analog in nature, unlike their cross-sectional counterparts such as CT, MRI, ultrasound scan, nuclear medicine, and digital subtraction angiography. At the same time, general radiography and mammography tend to have more stringent quality assurance programs in place, which call for more intensive scrutiny, which, in turn, leads to higher examination retake rates. As the use of digital radiography and mammography become increasingly common, one would expect the retake rates for these modalities to decrease, because of the wider exposure latitude and greater dynamic range of digital radiography and mammography compared with film-screen.

In spite of these differences, the overall technologist time allocated to performing the examination (i.e, image acquisition) was within a fairly narrow range, with all modalities reporting less than 70% of technologist time allocated to this important function. The effect of medical IT implementation on technologist time allocation is addressed in Table 2, which reports the percentage of technologist time specifically allocated to image acquisition. Although statistical significance was achieved infrequently, (owing to the relatively small sample sizes), an overall trend was observed for all imaging modalities suggesting a synergy between IT and technologist workflow. The conversion from a manual to an automated environment (with RIS and HIS implementation), translates into technologist time savings through the elimination of time-consuming steps for data entry along with reduction in data entry errors. In addition, technologist time spent accessing data should be reduced in a digital environment. Without the advent of HIS and RIS, technologists access data via paper forms and telephone. This manual process of data acquisition is transformed into an automated process with HIS/RIS implementation, thereby saving the technologist valuable time and energy.

The adoption of PACS was not associated with large differences in efficiency of technologist workflow as represented by the time allocated in image acquisition. One would expect that these technologies would reduce many of the time-intensive tasks experienced by film-based technologists such as image processing, retrieval of old examinations, repeat examinations (owing to loss and technique), and image duplication. This lack of an expected improvement in technologist efficiency may be caused by a number of factors including the timing of PACS implementation, lack of integration between PACS and HIS-RIS, and equipment down time.[4] When comparing filmless and film-based operations (as defined by the percentage of images printed to film), the cross-sectional imaging modalities (CT, ultrasound scan, MRI, and nuclear medicine) all report improved technologist workflow with filmless operation. This would be expected because technologists no longer are required to print hard-copy images and can alleviate many of the time-consuming steps associated with film processing. General radiography, however, did not show similar improvements with filmless operation, which may be partly because our definition of "filmless" included all of the facilities in which 25% or fewer of the examinations were printed. This means that many of these "filmless" departments were hybrid in nature, operating with some residual film-based operation. It is interesting to note that of the subset of the 16 "filmless" sites for general radiography, 4 reported that they were "100% filmless." For these 4 filmless sites, the percentage of technologist time allocated to image acquisition was 74%, compared with only 66% for the entire "filmless" group and 65% for the film-based group. Although additional data collection is required, this suggests that there are likely to be distinct differences in technologist workflow, depending on the degree and transition rate of filmless operation.

Technologists' time allocations for individual tasks are listed for film-based and filmless operations for general radiography, CT, and MRI in Table 3. It is interesting to note that the 3 individual tasks that are most affected by the transition to filmless imaging are data access, image acquisition, and repeat of lost examinations. These observations are in keeping with the theoretical considerations previously outlined and show that filmless operation for all 3 modalities are associated with improved technologist workflow. For the 3 collective modalities, the other tasks of examination scheduling, patient transport, patient preparation, examination retrieval, repeat examinations secondary to technique, and image duplication are not affected greatly by filmless operation. It is interesting to note that the reported technologist time allocations for image processing did not greatly differ when comparing film-based and filmless operation. This may be partly because film processing entails responsibilities other than the printing and transfer of images for radiologist interpretation. Additional technologist responsibilities are associated with the task of image processing including multiplanar reconstruction and processing for CT and MRI as well as manual window/level adjustments and application of advanced image processing algorithms (such as nonlinear lookup tables and edge enhancement) for general radiography.

Replacing conventional film-based imaging with digital radiography and PACS results in a number of effects, both in and outside of the imaging department. The major organizational effects within the imaging department can be classified into 2 categories:[5] (1) improved handling of clinical information, resulting in time savings in the performance and reporting of examinations and (2) net reductions in staffing through the elimination of film-handling tasks and fewer lost exams and reports.

The major organizational changes that occur outside of the imaging department focus on the clinical effects PACS has on patient care and include (1) faster and more accurate diagnoses, resulting in reduced time to initiate clinical action; (2) potential reduction in average length of stay; and (3) potential improvements in overall health outcomes.

Whereas these latter changes have been suggested based on preliminary reports,[6-8] it is important to realize that no definitive clinical outcome study has been performed to date that has clearly shown a cause and effect relationship between PACS and improved patient care. PACS justification, therefore, likely will continue to be focused on organizational effects more proximate to the image acquisition and reporting tasks.

In a traditional film-based imaging department, technologists have a number of responsibilities that overlap with those of the clerical and file room staff. This results in technologists performing additional manual processes that significantly add to the number of workflow steps. These additional steps can include examination scheduling, patient transportation, patient preparation, accessing data (laboratory, demographic, historical), and retrieval of prior imaging studies and/or reports.[9] These additional time-consuming steps are illustrated in Table 1 of our study, which details the breakdown of time allocation among technologists for all imaging modalities. The various tasks of patient preparation, data access, image processing, and retrieval of old examinations account for significant time demands for all technologists, regardless of the individual modality. Several additional tasks tend to be particularly intensive for certain imaging modalities such as examination scheduling (nuclear medicine and interventional/angiography), patient transportation (diagnostic radiography), and retrieval of prior examinations (mammography). To optimize workflow, one must have a comprehensive understanding of

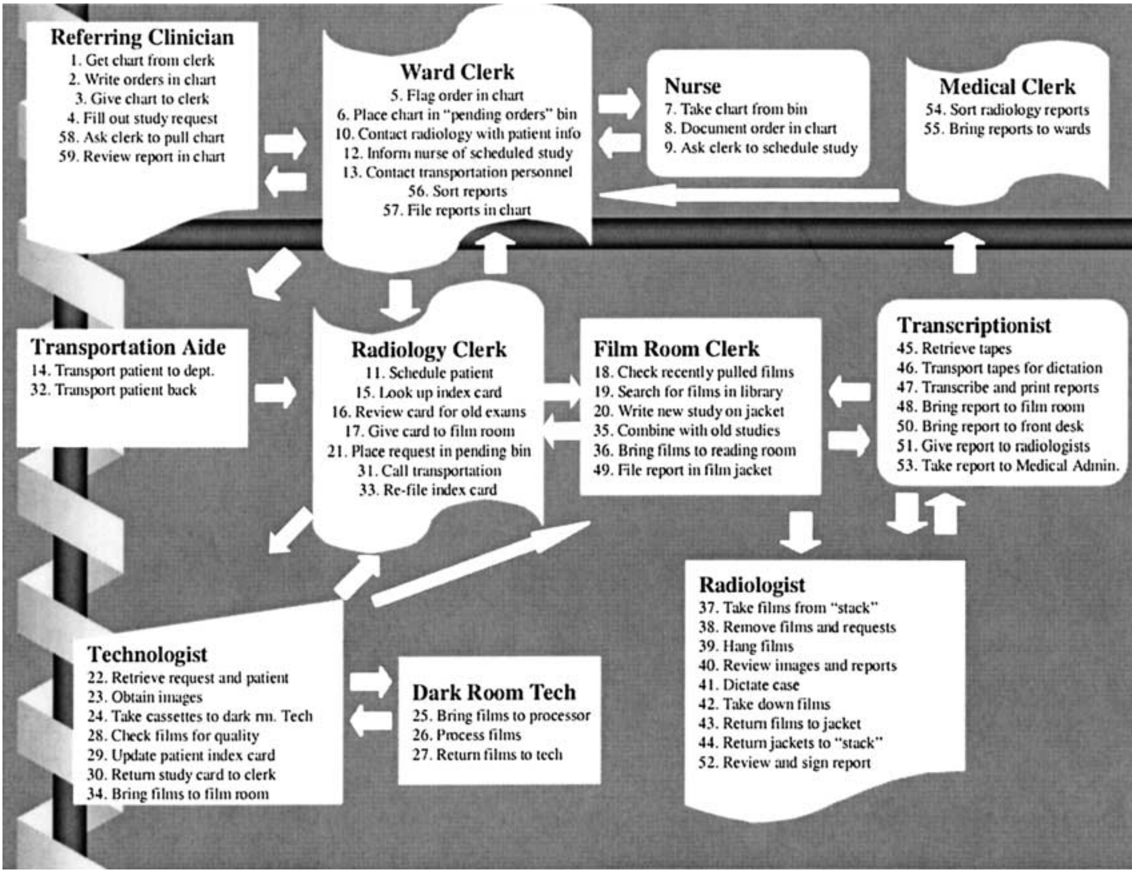

Fig 1. Individual workflow steps in ordering, acquisition, and reporting for a general radiographic examination in a film based environment. (Printed with permission from the American Journal of Roentgenology, AJR 2002, 178:564).

these individual technologist functions and the time required to perform them.

A formal workflow analysis was performed at the Baltimore Veterans Affairs Medical Center (BVAMC),[10] which evaluated the individual steps involved in the ordering, acquisition, and reporting of a diagnostic imaging exam (ie, chest radiograph). During film/paper-based operation, process analysis identified 59 individual steps for this entire process (Fig 1), which began with the physician order and ended with the report available in the patient's chart for review. After implementation of a filmless/paperless imaging department with computed radiography, PACS, and a fully integrated HIS/RIS, process analysis showed the same process required only 9 individual steps (Fig 2). This improved workflow resulted in 50 fewer steps performed by 7 fewer staff members.

An additional time-motion study was performed at the BVAMC, specifically evaluating workflow and time requirements for technologists to perform general radiographic examinations, comparing filmless and film-based operations.[11] Time savings of 31% to 58% was observed with filmless operation when compared with film-based operations at 2 other facilities. As illustrated in the workflow diagram (Fig 3), 7 to 14 additional steps were required for film-based diagnostic technologists, depending on the individual department's technology (conventional versus daylight processor), workflow, and ancillary staffing.

The improvement in productivity at the BVAMC has not been reported consistently by other filmless facilities, which raises the question as to why other filmless facilities have not achieved similar operational efficiency gains.

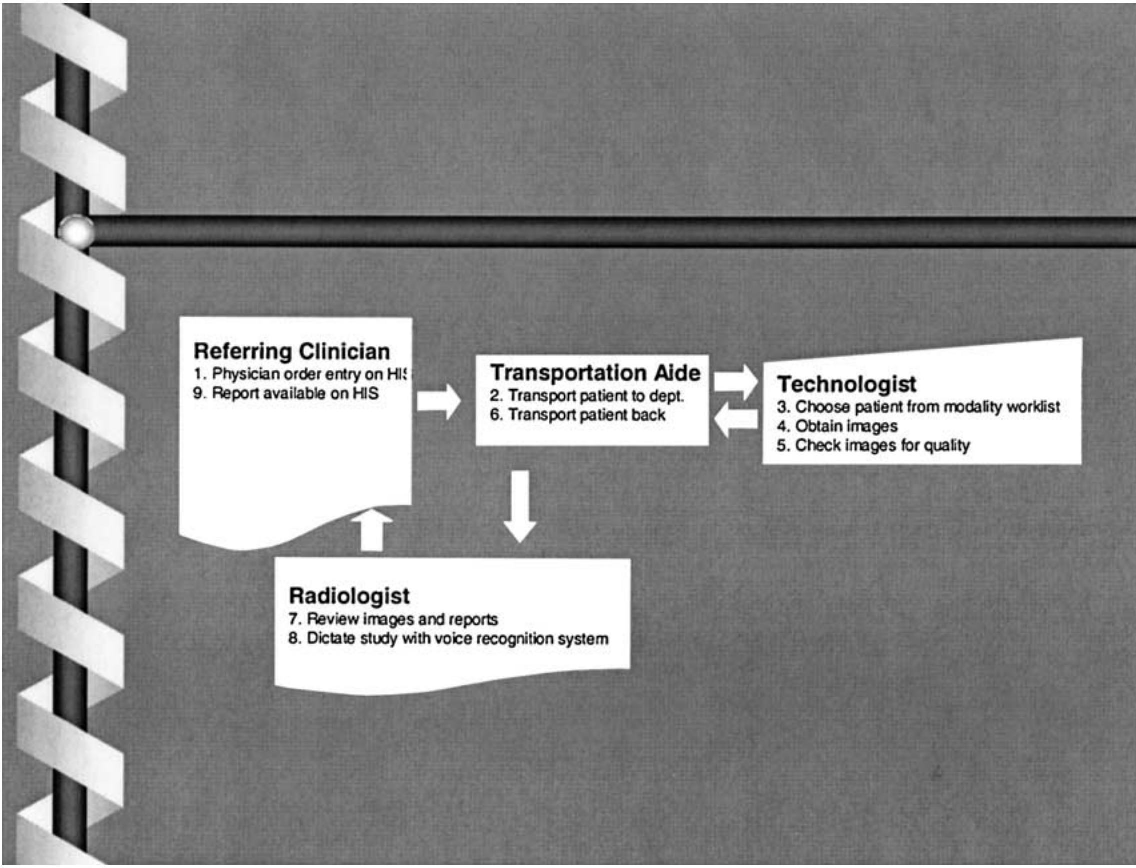

Fig 2. Individual workflow steps in ordering, acquisition, and reporting of a general radiographic examination in a filmless/ paperless environment. (Printed with permission from the American Journal of Roentgenology, AJR 2002, 178:565).

One of the most common mistakes made by facilities implementing PACS has been underestimating the potential major role PACS can play in the redesign of departmental and enterprisewide workflow. Without proper integration of PACS, information systems, and the individual imaging modalities, potential gains in productivity will not be realized.

To this end, many PACS adopters have operated their filmless imaging departments in a manner similar to their pre-existing film-based departments, with few changes in departmental workflow. Examinations still are being ordered using paper requisitions that require manual reentry of patient and examination information (by clerical staff) into the RIS. This paper-based information subsequently is printed out and given to the imaging technologist who manually retypes patient and study information into his or her modality acquisition workstations (eg, CT operating console). These operational inefficiencies are illustrated in Table 2, which compares diagnostic and CT technologist time allocations for film-based and filmless operations. In spite of the transition to filmless operation, a significant percentage of technologist time was reported for the tasks of patient preparation, data access, and image processing. With proper workflow optimization after PACS implementation, one would expect further reduction in time allocations for these tasks, with more time spent in image acquisition and less time performing clerical and ancillary tasks.

Little has been written about technologists' perception of medical IT or about strategies to minimize medical imaging technologist errors. In a study by Carrino et al,[12] a currently existing PACS environment for CT was evaluated before and after the implementation of a PC-based QC station co-located with each acquisi-

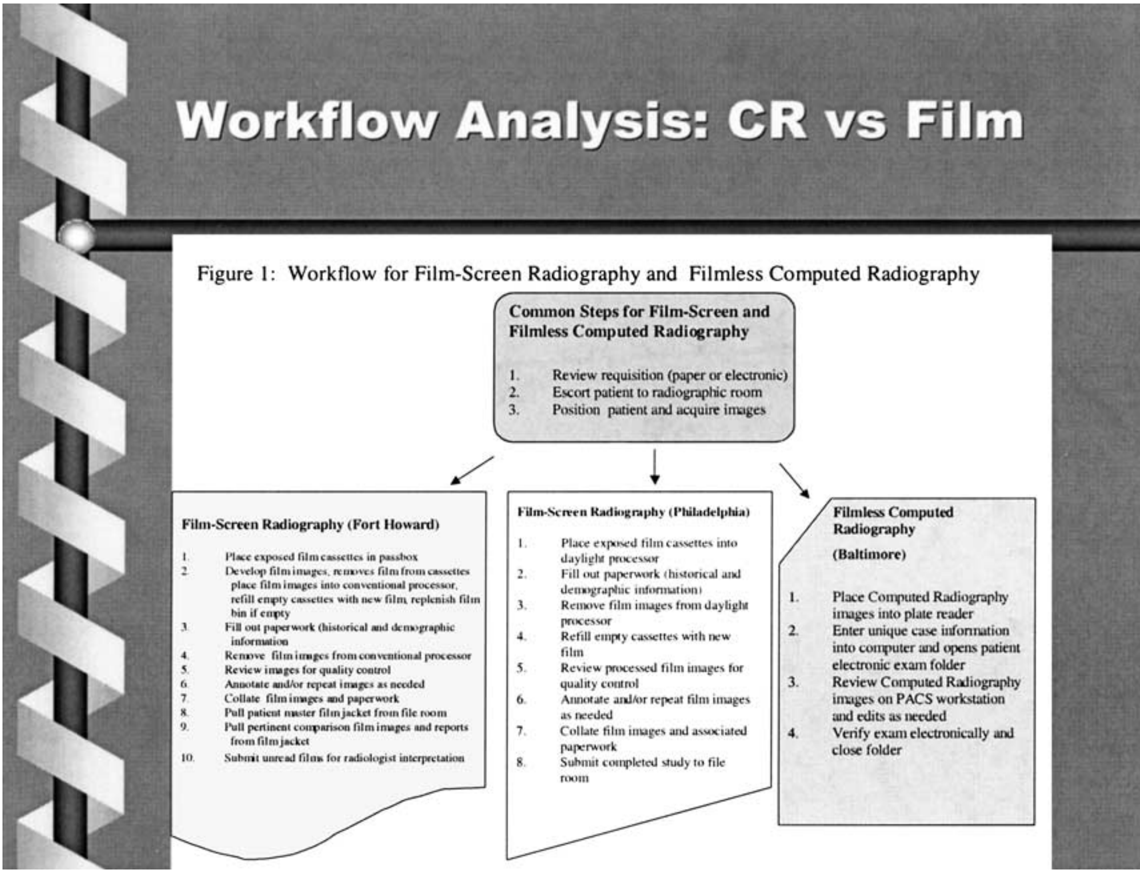

Fig 3. Individual workflow steps for general radiographic examination, comparison of filmless operation using CR with film-based operation. (Printed with permission from the American Journal of Roentgenology, AJR 2002, 179:34).

tion device. The demographic error rate was reduced markedly from 14.0% to 0.55% ($P < .001$, χ^2). The technologists' perception was favorable, with a substantial majority indicating that a positive impact was made in the number of demographic errors (90%), facilitating QC (67%), and ensuring proper routing (77%). A majority also felt the user interface was intuitive (93.3%) and preferred the use of the QC workstation (90%) to film handling. The time required to perform tasks were favorable for the QC workstation (1 to 5 minutes) versus film production and handling (5 to 15 minutes). This was an example of how a relatively low-cost scalable technology could enable more appropriate workflow providing advantages to technologists, radiologists and patients.

A number of other workflow optimization software enhancements are available to further augment technologist productivity by increasing system functionality and operational efficiency. One of these workflow enhancers is *modality worklist*, which allows for orders residing in the information system (RIS or HIS) to be automatically distributed to and from various imaging modalities. In interfaced systems, the patient metadata from the information system automatically populates the relevant demographics fields within the modal-

Table 4. Factors Contributing to System Functionality in a Filmless Imaging Medical Imaging Department

a. Support for DICOM service classes
b. Systems integration and redundancy
c. Archival strategy
d. Network topology
e. Workflow optimization software
f. Number, type, and distribution of workstations
g. Vendor technical support and product development
h. IT service and support

ity's computer. After images are acquired at the local modality and reviewed for quality assurance, they are transferred automatically to the enterprise wide PACS. An additional software function, referred to as *modality performed procedure step* (MPPS), electronically notifies the information system (RIS or HIS) that image acquisition has been completed. This can help avoid the additional time-consuming steps required for examination verification on the part of the technologist.

The concepts of functionality and system performance frequently are overlooked, largely because these are difficult to quantify. A number of factors (Table 4) must be considered when making the transition to the use of medical imaging information systems, all of which will affect the overall functionality and performance of operation. Until system integration is entirely seamless, there will be further complicating factors when attempting to integrate different technologies from different vendors. The end result is that each individual institution has its own inherent "system functionality," which will significantly affected productivity and workflow. In future studies, we will attempt to better quantify these factors that contribute to system functionality and show the complex relationship this has on technologist productivity and operational efficiency.

The two most common existing standards used in this communication of patient and study information are the Digital Imaging and Communications in Medicine (DICOM) and Health Level Seven (HL-7). In spite of the near-universal support for DICOM among modality vendors, many HIS-RIS vendors have provided limited DICOM support in their systems. As a result, many imaging providers (ie, technologists) have been unable to take full advantage of the workflow savings made possible by the implementation of the DICOM modality worklist function and modality performed procedure step (MPPS). A recent initiative of the Radiological Society of North America (RSNA) and the Health Information management Systems Society (HIMSS) has focused on increasing connectivity and systems integration, by bringing together imaging and HIS-RIS vendors. This initiative, known as Integrating the Healthcare Enterprise (IHE), already has resulted in the creation of a consensus among multiple vendors on the use of DICOM and HL-7 to communicate information among modalities, information systems, and PACS. The IHE initiative is likely also to facilitate communication of information systems between different enterprises, which should allow improved collaboration and sharing of resources among multiple facilities or different delivery networks. These ongoing efforts should provide improved system functionality and performance, resulting in improved productivity within the imaging department.

FUTURE CONSIDERATIONS

Productivity likely will continue to improve in the future as workflow-enhancing software developments occur and systems integration continues to coalesce into a fully functional electronic medical record. This trend toward data consolidation will continue on a macro level as market forces create stronger incentives to increase operational efficiency, productivity, and cost savings through the formation of multi-facility networks. These integrated delivery networks will offer the potential for increased economies of scale through centralization of administrative functions (scheduling, purchasing, benchmarking), enhanced workload distribution (for general coverage as well as the utilization of subspecialty expertise among technologists and radiologists), and information technology consolidation (shared networks, system redundancy, disaster recovery, and technical service and support).

Information system integration (within and between institutions) will continue to improve as communication protocols and standards are adopted universally. Future software developments will record and analyze workflow patterns of all personnel (clerical, technical, administrative, ancillary) and act to facilitate further productivity gains by incorporating new technologic developments, such as specialized image processing algorithms for digital radiography, speech recognition and structured reporting, and three-dimensional processing for CT and MR imaging.

We believe that these refinements in hardware and software may facilitate a shift from external to imbedded technologies in the not-too-distant future. With the advent of this paradigm shift, referred to as *ubiquitous computing*,[13] hundreds of electronic devices will be connected to the Internet and distributed throughout the everyday physical environment (walls, chairs, desktops). This will mark a transition from "thin clients" to "thin servers," where each individual wireless component will function as an individual Internet server and become invisible by its ubiquitous nature, like electricity. In this futuristic environment, many of the current technologist job responsibilities will disappear, such as examination scheduling, data access, and retrieval of old examination and reports. These tasks will be performed automatically "in the background" by an intelligent ubiquitous computing network. This network will provide technologists with periodic updates and pertinent information through this interconnected array of computers, which respond to speech and other types of inputs. Advanced image processing will be performed automatically, based on a complex set of rules and algorithms, and these postprocessed images will be stored automatically and distributed within the enterprisewide electronic medical record. By removing these "ancillary" tasks from the technologists, a greater amount of time and energy will shift from clerical to clinical tasks, which should improve morale, productivity, workflow, and overall job performance.

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