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A STUDY OF THE CT SCAN AREA OF A HEALTHCARE PROVIDER

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ABSTRACT

Ancillary departments, which include radiology services, are among the important factors that affect the efficiency of patient care in a hospital. This paper presents results from a collaborative research effort with a healthcare provider that is in the process of implementing a digital image archiving system within its radiology services. The objective of this study was to identify the changes to the existing workflow at the CT Scan area with the implementation of the digitized archiving system to maximize patient throughput and minimize report generation time. Process mapping was used to identify the initial flow of operations. A simulation model was then built to evaluate the different what-if scenarios that were expected to 'optimize' the aforementioned response variables. Several key suggestions were also presented and validated using simulation. These include increasing the number of reading radiologists, re-allocation of CT Scan machine resources and the addition of a patient holding area.

1 INTRODUCTION

Wilson Memorial Regional Medical Center, a part of United Health Services (UHS), is a leading healthcare provider in Broome County, New York. It is a 296-bed teaching hospital that provides a full range of medical-surgical services. Its radiology department offers services in diagnostic X-ray, CT Scan, Nuclear Medicine and Ultrasound testing. Statistics show that 60% of the patients visiting the Emergency Department (ED) require service from the radiology department. The hospital houses 3 CT Scan machines, 8 Radiology rooms, 4 Nuclear Medicine facilities and 3 Ultrasound rooms. In addition to the ED patients, the radiology department also serves inpatients and outpatients. During the fiscal year 2003, the CT Scan area alone served 17,000 patients. The radiology services at the hospital were in the process of identifying factors that would improve their performance and consequently increase their revenue as well as enhance patient and physician satisfaction. One of the steps in this direction, involved the idea of transitioning from the conventional film based archiving system to a digital image archiving system. The digital system offers significant tangible benefits such as faster retrieval of historical images and provides greater accessibility to image data from various locations (Smedema 2000). However, these benefits need to be quantified in order to evaluate their effectiveness. The quantification of benefits and subsequent analysis would address issues such as the feasibility of implementing the digital image archiving system and workflow modifications that are absolutely required to accrue all the benefits that could result from implementing the system.

This study focused on two key performance measures, namely, patient throughput and the report generation time, while implementing the digital image archiving system in the CT Scan area. The time saved at each stage of the workflow; the system's efficiency; and the impact on the workload of archiving staff, technologists, radiologists and the physicians were studied. The modifications to the workflow that became necessary with the transition to the digital system were identified.

Section 2 discusses the motivation behind this research. Section 3 summarizes the methodology followed for the simulation study. Section 4 presents the details pertaining to process mapping. Section 5 discusses the development of the simulation model. Finally, various alternatives and recommendations that were studied are summarized in Section 6.

2 MOTIVATION

Presently, in most hospitals, the radiology images are typically printed only on films. This method has several drawbacks such as delays due to film developing, transportation and time-consuming searches to access the archived film folders (Dombrowski and List 1988). This has a direct impact on the patient care and the treatment times, especially at the emergency and trauma care departments (Aggarwal et al. 1976). The early 1990s saw the arrival of a Picture Archiving and Communications System (PACS), which accommo-

dates the enterprise-wide soft-copy imaging and archiving requirements of a healthcare provider. PACS could potentially help with the elimination of films in the radiology department (Gillespie 2003). It could provide for seamless workflow among modalities, technologists, radiologists, and physicians. However, the transformation from the current film-based system to PACS requires systematic planning. Modifications in the workflow, within the various radiology services, is an important aspect that needs to be considered during the implementation of a PACS system.

While mathematical models serve to evaluate solutions for problems such as workflow modifications, simulation serves as an excellent tool to study the outcomes from different 'what-if' scenarios (Proctor 1996, Lowery 1998). Several researchers have modeled the radiology department with a view to increase the overall efficiency of the services (Centeno et al. 2000). Aspects such as the times required by technologists to perform examinations and the times required by radiologists to dictate their findings have been addressed in detail (Shuman 1992). On the other hand, this research endeavor involved designing a simulation model that considered all the stages in the workflow at the CT Scan area. This approach would offer advantages such as increased accuracy of the simulation model and the freedom to simultaneously and proactively evaluate a variety of different solutions.

3 METHODOLOGY

The methodology followed for the research is listed below:

a. Study of the CT Scan area and understanding its flow through the use of process mapping;
b. Review of data available from the Radiology Information System (RIS);
c. Conduct time studies at various stages to validate the data from RIS and to obtain additional data for developing the simulation model;
d. Develop the baseline simulation model which would accurately reflect the existing workflow at the CT Scan area;
e. Model the modified workflow with the digital image archiving system;
f. Study the performance measures in the modified workflow model and compare them with the baseline model;
g. Sensitivity analysis to suggest alternative scenarios with the modified workflow model;
h. Determine solutions that were rigorously evaluated and validated.

4 PROCESS MAPPING

There are three classes of patients who visit the CT Scan area, namely, patients from the ED, the inpatients and the outpatients. The ED and inpatients are examined at the CT Scan '1', whereas the outpatients are examined at CT Scan '3'. Currently, CT Scan '2' acts as a back-up unit.

When an ED patient or inpatient examination is ordered, the requisition is printed from the RIS and the patient is brought to CT Scan '1'. The patient remains in the waiting area until the examination. Simultaneously, once the examination order is entered in the system, the file clerk retrieves the previous images, if any, from the archives. Studies showed that approximately 37% of all the patients visiting the CT Scan area had prior records. Once the examination is completed, the transportation aide takes the patient back to the ED/floor, while the technologist formats and prints out the examination films. The folders that are retrieved from the archives would be delivered to the radiologist along with the patient's current images. The radiologist refers to records from prior studies for interval comparisons, reads the current images and dictates the report into the transcription system and once typed, the report is signed off. For the outpatients, the procedure remains the same, except that the examination is performed at CT Scan '3' and the previous records, if they exist, are retrieved the previous day.

With the introduction of PACS, since the images are available on-line and in real-time, the time to retrieve the images and the waiting time at the radiologists become negligible. This would result in the faster generation of reports. Figure 1 and Figure 2 represent the current workflow and the modified workflow with the digital image archiving system at the CT Scan area respectively.

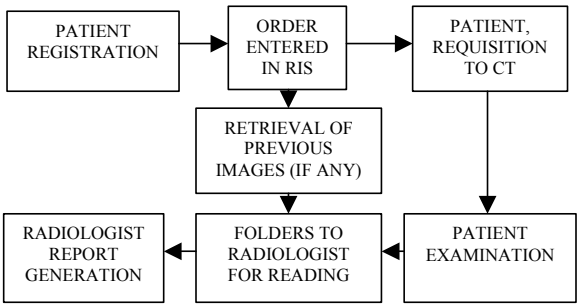

Figure 1: Current Workflow

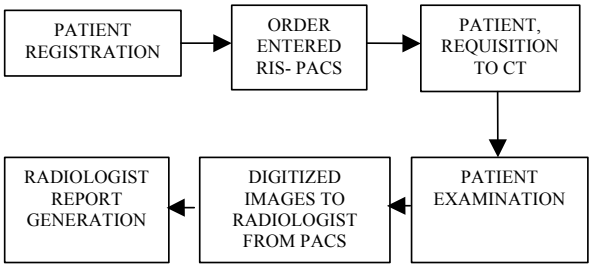

Figure 2: Modified Workflow

5 SIMULATION MODEL

5.1 Data Collection

The data was collected over period of four months from the RIS. The data was collected and studied to find the arrival

rates of three types of patients, from the ED, the inpatients and the outpatients. The distributions for the waiting time of the patient at the CT Scan, the durations of the examinations, times taken to retrieve folders, waiting times of the images at the radiologists desk, and report generation times were determined based on the data obtained from time study. The data from the time study was also used to validate the data obtained from RIS. The availability of the CT Scan machines and the staff was recorded. The distributions that were obtained based on the data that was collected are summarized in Table 1.

Table 1: Distributions of the Major Stages

Stage	Emergency	Inpatients	Outpatients
Examination time	0.999 + ERLA(44.9, 2)	0.999 + ERLA(44.9, 2)	17.5 + 21 * BETA (2.56, 2.58)
Report generation time	5 + LOGN(76.7, 168)	NORM(25.1, 18.2)	2.5 + 60 * BETA(1.72 ,0.827)
Folder extraction time	NORM(18.6, 7.4)	NORM(18.6, 7.4)	NA

5.2 Assumptions

The following assumptions were made during the development of the simulation model.

- CT Scan '1' is operational for 24 hours a day, including weekends.
- CT Scan '3' is operational from 8:00 am to 11:00 pm, Monday through Friday.
- CT Scan '2' is not utilized.
- The previous images for the outpatients are retrieved the previous day.
- Transportation times and delays are embedded in the statistical distributions that are obtained from the time studies.
- The nurses, who administer contrast to the patients, do not impose or become a constraint in the model.

5.3 Model Development

The simulation model was developed using Arena® 7.0 based on the information obtained from the process mapping activities and time study. The baseline model essentially simulated the original film-based workflow at the CT Scan area. The flow of activities was modeled for each category of patients entering the system. Table 2 shows the simulation model's characteristics.

This baseline model was verified and validated against a different set of historical data that was collected over a period of 8 months. The arrival rates of patients to the model were varied in a cyclic manner to replicate the actual scenario. The flow of entities was monitored to ensure that the logic of the model was error free. Validation ensured that the outputs from the simulation model were consistent with the real-world scenario.

Table 2: Simulation Model Characteristics

Entity	CT Scan Patient
System Type	Steady state non-terminating
Attributes	Existence of previous CT Scan records Type of patient Time of arrival Modality (CT Scan 1 or 3)
Resources	Radiologist Technologist File clerk
Inputs	Inter arrival times Examination times Waiting times at modality and radiologist Report generation times
Outputs	Throughput Average report generation time Utilization of resources
Replication Length	365 Days (ED, Inpatient) 255 Days (Outpatient)
Number of Replications	40

Statistical tests, including the hypothesis test and paired t-tests, were conducted (Kelton et al. 2000). At a confidence level of 95%, it was observed that the simulation model was statistically identical to the actual scenario. Throughput and the report generation time were used as the performance measures. The results obtained are summarized in Table 3 and Table 4. The model was presented to the radiology services team and their suggestions were incorporated into the model.

Table 3: Throughput per Year (Number of Patients)

	Historical Data	Simulation Model	Difference
ED	7568	7503	-0.86%
Inpatients	3469	3492	0.66%
Outpatients	5406	5461	0.01%

Table 4: Average Report Generation Time (Hours)

	Historical Data	Simulation Model	Difference
ED	2.53	2.44	-3.68%
Inpatients	25.1	25.7	2.23%
Outpatients	5.03	4.96	-1.41%

The baseline model was then used to develop another model to simulate the modified workflow with the digital image archiving system. The arrival patterns of patients were not altered. The service times for the digital image archiving system were extracted from the available industry standards. This model was then studied vis-à-vis the following parameters:

- Number of patients
- Time per patient
- Average waiting time at modality
- Average waiting time at radiologist
- Time for radiologist report
- Utilization of modality and radiologist

The results obtained from simulating the model for the digitized system are summarized in Table 5 and Table 6. The tables also present the percentage change in the results from the baseline model. The three types of patients, namely emergency, inpatients and outpatients were studied separately .

Table 5: Throughput per Year (Number of Patients)

	Current Workflow	Modified Workflow	% Change
ED	7503	8976	19.68
Inpatients	3492	4116	17.86
Outpatients	5772	7104	23.08

Table 6: Average Report Generation Time (Hours)

	Current Workflow	Modified Workflow	% Change
ED	2.44	1.74	-28.69
Inpatients	25.7	18.51	-27.91
Outpatients	4.96	2.85	-42.50

It was observed that there was a significant increase in patient throughput and a reduction in the report generation time with the digitized system. On the other hand, no significant increase in the utilization of any of the related resources was observed. Therefore, it can be concluded that modifying the workflow with the implementation of the digital archiving system has the potential to increase the overall efficiency and revenue of the CT Scan area at Wilson Memorial.

6 SENSITIVITY ANALYSIS

Once the study on the impact of the digital image archiving system on the workflow at CT Scan was completed, additional alternative scenarios which could further improve the quality of service provided were studied. This section discusses the alternative scenarios with the corresponding experiments that were considered in this research endeavor.

6.1 Scenario 1: Increased Utilization of CT Scan '2'

It was interesting to note that CT Scan '2' was significantly under-utilized in the original system. This CT Scan machine is traditionally used as a back-up for CT Scans '1' and '3'. An experiment, as shown in Figure 3 was designed to estimate the benefits if CT Scan '2' were to be used along with CT Scan '1'. Similar experiments were conducted for other scenarios.

		PACS (2	
		W/O	**WITH**
CT SCAN (2	**CT 1**	CT1, W/O	CT1, WITH
	CT 1, 2	CT1, 2, W/O	CT1, 2, WITH

Figure 3: Design of Experiment for Scenario 1

The Analysis of Variance (ANOVA) results indicated a significant difference in the report generation time (Law et al. 2000). The test also showed that by having the digital archiving system in conjunction with the above set up, the report generation time decreased even further. Figures 4 (a), 4(b) and 4 (c) show the effects on the report generation time per patient (in hours) for the various options that were assessed.

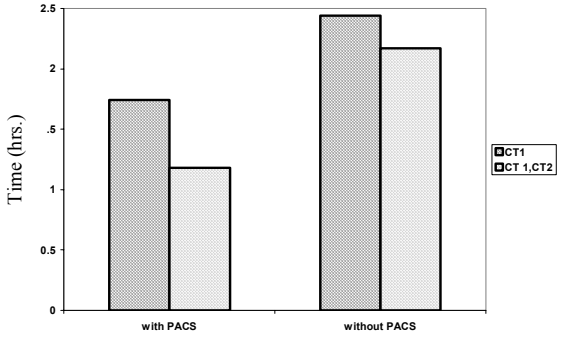

Figure 4(a): Effect of PACS on Report Generation Time

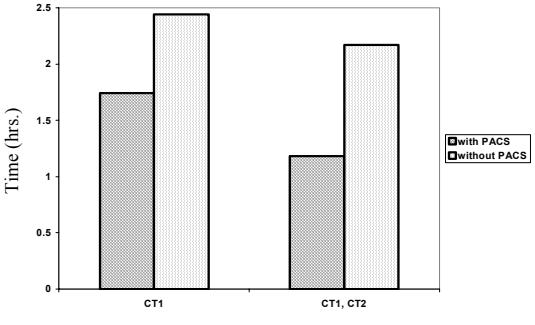

Figure 4(b): Effect of CT 2 on Report Generation Time

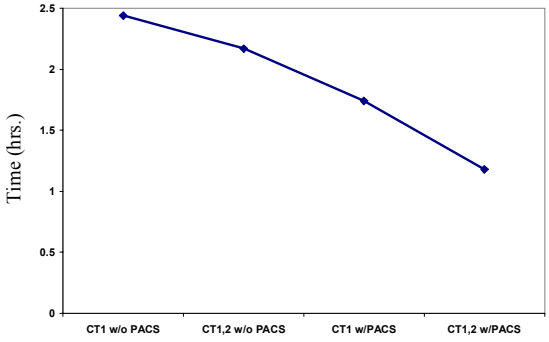

Figure 4(c): Report Generation Time per Patient in Scenario 1

It was observed that by having CT Scan '2' in the model, the total report generation time for the inpatients and ED patients decreased by more than 10%. With the implementation of the digital image archiving system, the report generation time was reduced by almost 30%. By combining these two factors, the report generation time was reduced by almost 50%. This saving in time is very critical, especially for the ED patients. The overall throughput of the patients could potentially increase by 31%.

6.2 Scenario 2: Decrease Waiting Time for Outpatients

A patient holding area was proposed with the intention to decrease the patient waiting times for examinations. The function of the holding area would be to perform the preparatory activities before the examination, such as obtaining patient history and starting the IV contrast. In the original set-up, the preparatory activities were performed as a part of the examination process in the CT Scan room itself. The provision of a holding area was expected to reduce the time of patients inside the CT Scan room, and consequently ensure faster patient flow.

Simulation and a subsequent ANOVA test was used to verify as well as quantify the benefits associated with implementing a holding area. Results showed that the examination time per patient would decrease by almost 3 hours (for scenario 2) as compared to the existing system if a holding room was put in for the outpatients. The other important benefit of implementing a holding area is that more patient examinations could be scheduled per day, which could potentially eliminate a large segment of the scheduling delays that are experienced at the Wilson Memorial Hospital. Figures 5(a), 5(b) and 5(c) show the total report generation time per patient in hours for scenario 2 .

From this experiment, it can be concluded that by the addition of a hold area and having the digital archiving system, the report generation time would decrease by a significant amount.

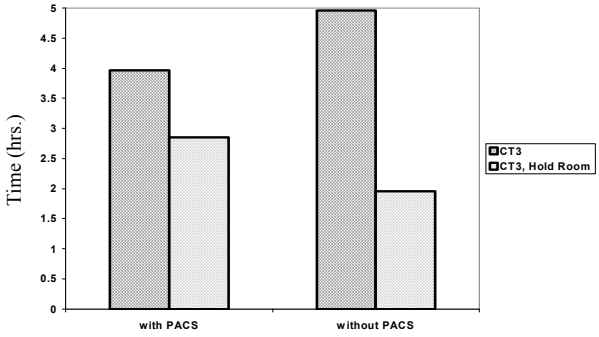

Figure 5(a): Effect of PACS on Report Generation Time

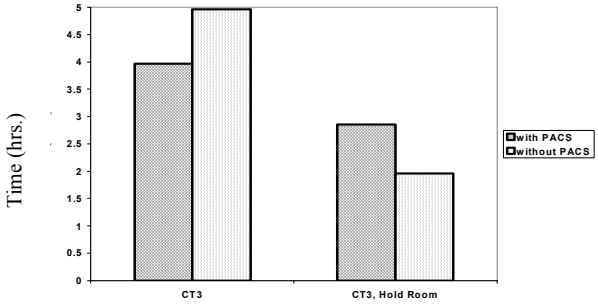

Figure 5(b): Effect of Hold Room on Report Generation Time

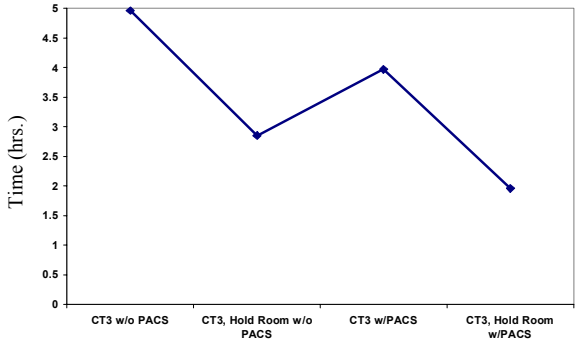

Figure 5(c): Report Generation Time per Patient in Scenario 2

6.3 Scenario 3: Increase the Number of Radiologists

In the existing setup, based on the observations from this study, only one designated radiologist reads the CT Scan images. With the digital image archiving system, multiple radiologists from diverse locations could concurrently observe images. A simulation study was conducted to understand the effects on throughput, waiting times and report generation with two radiologists assigned to the CT Scan area, especially with respect to patients from the emergency room. The ANOVA test results showed that the addition of a radiologist to the existing system would decrease the report

generation time. Figures 6(a), 6(b) and 6(c) show the report generation time per patient in hours for scenario 3.

It was found that adequate resources were available to add one radiologist to the system. Consequently, the addition of one radiologist was tested. It was observed that the report generation time could reduce by approximately 59% and an additional 40% patients could be examined.

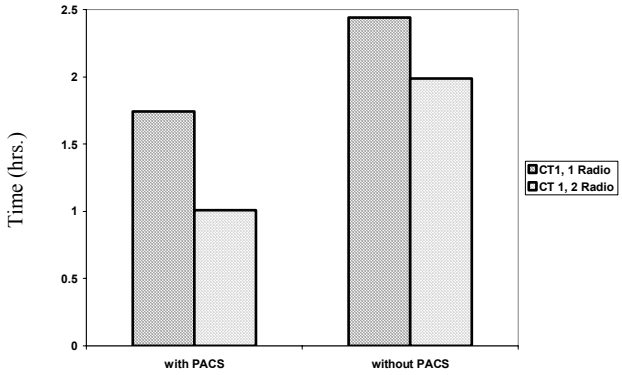

Figure 6(a): Effect of PACS on Report Generation Time

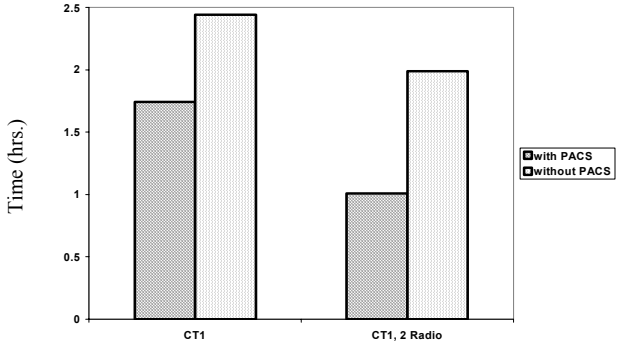

Figure 6(b): Effect of Hold Room on Report Generation Time

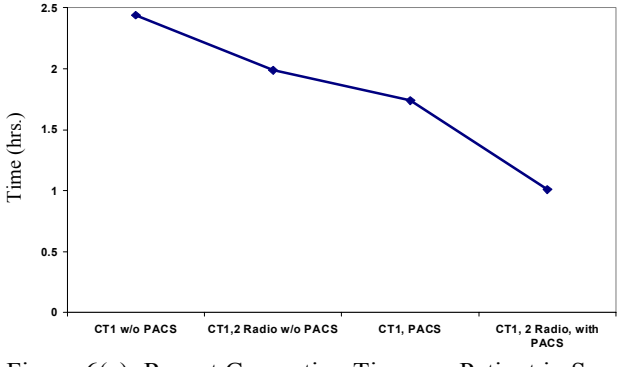

Figure 6(c): Report Generation Time per Patient in Scenario 3

The throughput was calculated based on the three scenarios mentioned above. Figure 7 shows the percentage increase in throughput associated with each scenario with respect to the baseline.

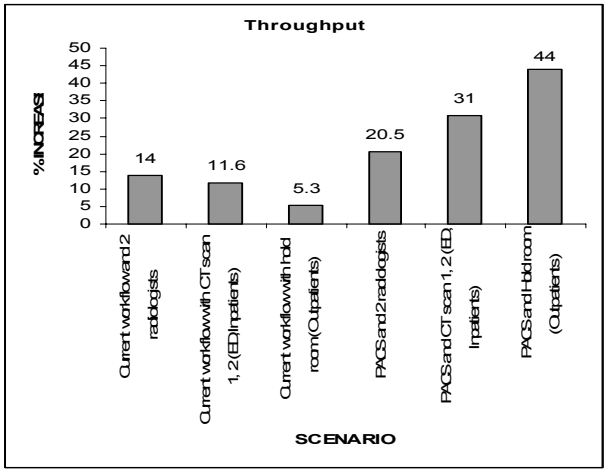

Figure 7: Change in Throughput

7 CONCLUSIONS AND FUTURE STUDIES

The results obtained from the simulation study conducted at the CT Scan area at Wilson Memorial Hospital have helped to quantify the benefits associated with the implementation of the digital image archiving system. These results were further verified by conducting statistical analysis. In addition, three different recommendations were provided to further enhance the performance of the CT Scan area. Metrics, such as throughput and report generation time, were used as the response variables to test the different scenarios. It was found that patient throughput would increase by 20% and the report generation time would decrease by more than 30% with the implementation of the digital image archiving system. Further, with the implementation of one or more additional recommendations, the patient throughput would increase by at least 30% over the existing system. The report generation times would also decrease by at least 45%.

The aforementioned results and recommendations will help during the implementation of the digital archiving system across other radiology services at Wilson Memorial and similar instances elsewhere.

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