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Film vs. digital - A Simulation of diagnostic imaging systems in healthcare

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ABSTRACT

Today, healthcare providers are faced with the decision of how to perform diagnostic imaging services with respect to continuing with traditional film-based imaging techniques or converting to digital imaging technology. This research focuses on the multifactor operational aspects of the diagnostic imaging system, and evaluates the effect that film or digital based imaging have on operational performance, productivity, and quality of patient care. That is, the time the patient spends in the system, the number of diagnostic imaging procedures performed per week and machine utilization. The goal of this research is to provide a quantitative analysis of film-based versus digital diagnostic imaging systems from an operational perspective in order to aid healthcare providers in their decisions with regard to diagnostic imaging technology. This involves using simulation to design an operationally efficient digital diagnostic imaging system, performing a quantitative comparison of film-based and the most efficient digital diagnostic imaging system, and conducting a case study of the Diagnostic Imaging Department at F.F. Thompson Hospital in Canandaigua, New York to validate experiments and to aid the hospital in reorganizing workflow as they switch from film to digital imaging. Based on the results of these experiments and case study, healthcare providers will be better able to decide upon an appropriate diagnostic imaging technology and system configuration that will attain high performance in terms of productivity and the quality of care provided to their patients.

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1. INTRODUCTION

Diagnostic Imaging is one of the principal functions of most healthcare facilities and is defined as the art of identifying a particular disease or characteristic by optically forming a duplicate, counterpart, or other representative reproduction of an object. Some of the modalities that you would typically find in a hospital or imaging facility include, Computed Tomography (CT), Radiology (X-Ray), Ultrasound, Nuclear Medicine, and Mammography.

The U.S. diagnostic imaging industry is a growing and viable business. In 2002, $9.616 billion in product revenue was generated, a compound annual growth rate of 9.8% from the $8.76 billion in sales recorded in 2001. According to Ridley (2003), the outlook for 2003 remains positive as well, with revenues projected to climb 9.3% to $10.511 billion. However, as with all segments of the healthcare industry, spending has increased dramatically over the last few decades. In 2000, the overall healthcare spending increased 7.4% and in 2001, this increased further by 8.7% (Price Waterhouse Coopers, 2003). This has forced healthcare providers to seek ways to cut costs and increase their profit margin in order to stay in business.

A study conducted by the American Hospital Association (AHA) indicates that outpatient volumes have increased by 150% since 1980 (American Hospital Association, 2001). As demand increases, hospitals are facing capacity constraints. Hospitals are also facing a critical shortage in healthcare professionals, which includes radiologists, technologists and other radiology staff members due to competition from health care employers, declining enrollment in health education programs, and an aging workforce. The AHA indicates that this shortage is expected to worsen over the next 20 years. This rising demand for health care services, including the rise in

demand for diagnostic imaging modalities, falling revenues and increasing costs, coupled with increased competition has forced organizations to face the challenge of becoming more efficient.

Film based diagnostic imaging has been around for over 100 years and much has been done to improve aspects of diagnostic imaging with the objective of providing safe, effective, timely and efficient service, which will in turn improve patient care and satisfaction (Parks, 2001). However, more hospitals have seen the development of efforts to improve aspects of diagnostic imaging outside the diagnostic realm in order to provide better service and, in turn, better patient care. As a result, many hospitals are moving from a film-based image management system to a digital (filmless) method of diagnostic imaging called Picture Archival and Communication System (PACS). PACS is an integrated system of digital products and technology allowing for the acquisition, storage, retrieval, and display of radiographic images (Bon Secours Health System, 2001).

PACS, which originally started in the 1980s has quickly taken hold of the medical field. Originally, PACS was implemented by large hospitals and academic centers (Ridley, 2001), but current trends indicate an expansion of the market. According to a study by Baccari (2002), the U.S. has a PACS market size of $297.1 million in 2001 and a penetration rate of 15-20%. The European digital image market is expected to reach around $688.2 million by 2004 with an annual rate of 25% within the next few years (See Figure 1). Apart from the aforementioned gains that hospitals see in acquiring this technology many also see this change as essential to staying in business (Templeton, 2003).

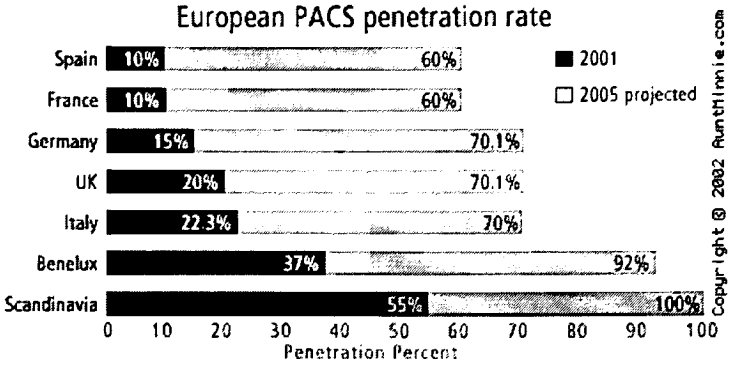


Figure 1 PACS European Market (Baccari, 2002)

PACS has been shown to provide the benefit of advanced communication standards, enhanced technology, decreased costs, a stronger competitive position, efficient workflows and a high quality of healthcare service (SCAR, 2002).

The gains in efficiency have allowed radiology departments to decrease backlog and open more time slots on patient schedules, which minimizes the chances that patients will choose to take their imaging business elsewhere. Waiting time for MRI appointments at the Toledo Hospital ran 21 to 30 days. Now, after the implementation of PACS, it is closer to 5 days. CT studies entailed a wait of nearly 2 weeks but now patients enjoy next-day appointments (Smith, 2003). Other specific successes with PACS implementation are given in Siegel (1995).

The aforementioned benefits are specific, but healthcare systems vary in their processes, structure and their outcomes. In addition, these benefits are by no means automatic and depend on successful implementation of PACS. This thesis will look at quantifying operational system performance more generally as would occur in typical system.

The transition from film to digital can be a complex one and so it is necessary to take a holistic approach in the implementation. As hospitals make this switch it is necessary to take into

consideration the workflow of their imaging department before implementation of a new digital system so that inefficiencies are not transferred (Reiner et al., 2003).

The thesis will also investigate the workflow of typical digital diagnostic system and try to optimize this system using industrial engineering techniques. Lean concepts, statistics and simulation analysis are some of the tools employed to investigate alternate configurations and determine the best configuration based on system performance.

2. PROBLEM STATEMENT

Today, healthcare providers are faced with the decision of how to perform diagnostic imagining services with respect to continuing with traditional film-based imaging techniques or converting to digital imaging technology. Adopting digital imaging technology affects workflow, roles, relationships, and the organization's culture in sometimes unexpected ways. The selection of film or digital imaging media affects much more than the image that is produced. The entire diagnostic imaging system is dependent on the media selected, including image quality, diagnostic capability, timeliness of image availability, patient flow, workflow, information flow, and image storage, retrieval, and viewing methods.

A large body of research exists on comparing the image quality produced by film and digital methods (Garmer et al., 2000). Image quality for making diagnoses is an important element of the media decision. This research however, focuses on the multifactor operational aspects of the system, and will evaluate the effect that film or digital based imaging will have on operational performance, productivity, and quality of patient care. That is, the time the patient spends in the system, the number of diagnostic imaging procedures performed per week, and machine utilization. The goal of this research is to provide a quantitative analysis of film-based versus digital diagnostic imaging systems from an operational perspective in order to aid healthcare providers in their decisions with regard to diagnostic imaging technology.

The objectives of this research are to:

- Design an operationally efficient digital diagnostic imaging system;
- Perform a quantitative comparison of film-based and the most efficient digital diagnostic imaging system, focusing on the operational aspects of the systems; and

- Conduct a case study of the Diagnostic Imaging Department at F.F. Thompson Hospital in Canandaigua, New York to validate experiments and to aid the hospital in reorganizing workflow as they switch from film to digital imaging.

The first objective entails designing an operationally efficient digital imaging system. This is achieved by applying lean techniques to a typical diagnostic imaging system to reduce waste. To compare design alternatives, a factorial simulation experiment is performed that includes the following factors: workflow alternatives and staffing levels.

To accomplish the second objective, a simulation experiment is conducted that quantitatively compares the operational performance of film-based imaging systems to the most efficient digital imaging systems deduced from the first objective. This experiment evaluates whether significant differences in productivity exist between the two systems under different patient loads using the levels for workflow and staffing levels obtained from meeting the first objective.

Finally, conducting a simulation case study of the Diagnostic Imaging Department at F.F. Thompson Hospital is conducted in order to evaluate the accuracy and validity of the results of the experiments conducted. Furthermore, a comparative workflow analysis for their proposed digital imaging system will be conducted.

Based on the results of these experiments and case study, healthcare providers will be better able to decide upon an appropriate and efficient diagnostic imaging technology and system configuration that will attain high performance in terms of productivity and the quality of care provided to their patients.

3. LITERATURE REVIEW

Healthcare services should not only be safe, effective and equitable, but also timely and efficient. Healthcare providers are constantly seeking ways of performing quality care at the lowest cost and advances are being made in the diagnostic imaging industry to meet these objectives. This literature review will compare the traditional film-based diagnostic imaging to digital imaging techniques with regards to image quality, costs, number of retakes, technological advances, information flow, and last but not least workflow. Simulation and its application in healthcare will also be discussed, along with other problem solving techniques that can be used to study healthcare systems.

3.1 Overview of the Diagnostic Imaging Process

Figure 2 outlines the generic steps that are performed during the radiographic diagnostic imaging process. There is first a reception area where all administrative needs are considered and notification to the department of patient arrival. After which retrieval of prior related examinations takes place. The patient then undergoes the diagnostic procedure after which the results are viewed by the radiologist and the exam is dictated. Transcription of the information then takes place and then the radiologist signs the report. The completed document is then sent for clinical reviewing and the patient information is archived for future reference.

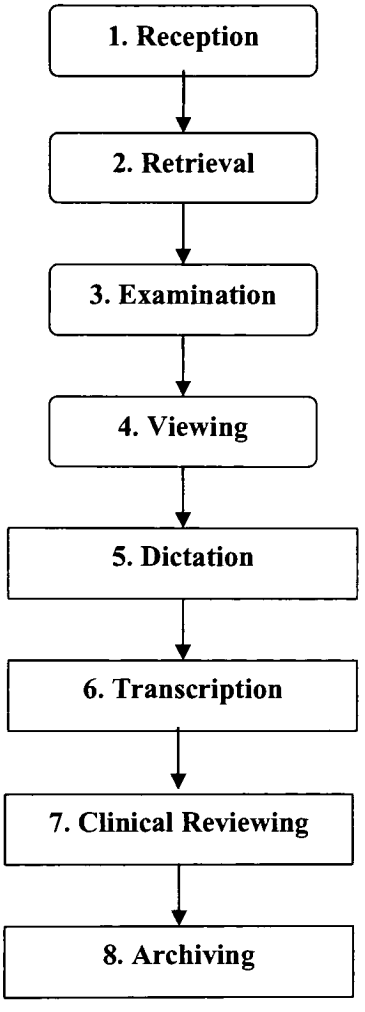


Figure 2 Generic Steps of the Diagnostic Imaging Process

Steps one through four of in Figure 2 are stages that change to with the implementation of PACS. Steps five through eight do not change with PACS implementation, but can also be automated with further integration of PACS with Radiology Information Systems (RIS) or Hospital Information Systems (HIS).

3.2 Traditional Film-Based versus Digital Diagnostic Imaging

Film based versus digital diagnostic imaging can be compared on many aspects including image quality, cost, the number of retakes, information flow, technical advances and workflow. The following sections compare film versus digital imaging based on these aspects.

3.2.1 Image Quality

Garmer et al. (2000) conducted a study that compares the diagnostic performance of flat-panel digital radiography to computed radiography and film-screen chest radiography on a chest x-ray. The digital form of imaging was found to be equivalent or superior to the other technologies for visualizing anatomic structures.

Another research study has found that more information is obtained with digital imaging of soft tissues on musculoskeletal radiographs (Wright, 2003). Digital also has the ability to be used in conjunction with pictures obtained with an optical camera to enhance the patients understanding of their treatment.

Siegel, (1995) further discusses that digital provides opportunities to view images in multiple windows at different levels if so desired. This result in finding additional clinically significant findings that would have otherwise been missed by film.

3.2.2 Cost

Pal (2001) discusses some of the costs associated with employing a digital mammography at M.D. Anderson Cancer Center in Houston. The initial capital outlay of the digital system was $450,000, $370,000 more than the purchase price of a film-based machine. The operating cost over a five-year period is $135,000 a year, compared to $24,000 for film-

based mammography. Maintenance costs for the digital system runs at $45,000 per year. Examination costs for the digital versus traditional system are detailed in the Table 1.

Table 1 Film vs. Digital Mammography Examination Costs (Pal, 2001)

Examination	**Film-based**	**Digital**
Screening	$160	$219
Unilateral Diagnostic Exam	$176	$253
Bilateral Exam	$213	$272

There are a number of cost savings that can be obtained when moving to a totally filmless environment. For example: no film costs, no processor maintenance, no film jacket purchase, no real estate costs for room to store films, no time spent searching for old films and no time spent filing films (Wright, 2003). The return on investment may take many years, due to the high outlay and operating costs. The literature suggests many of the benefits have not been quantified (e.g., it is believed that operating efficiencies make up for costs). There is also system cost savings especially in the rural areas where physician offices are scattered, time and transportation costs are reduced (Templeton, 2003).

3.2.3 Number of Retakes

With film-based imaging techniques, once the image is taken, it is permanent and no further adjustments can be made. A study conducted at Baltimore Veterans Affairs Medical Center (BVAMC), after PACS implementation retake rates dropped from 4% to less than 1% (Siegel, 1995). This is so as digital imaging system provides increased latitude (i.e. post

processing of the image, which decreases the number of re-takes necessary). This also provides the advantage of decreased radiation dose to the patient and personnel (The American Dental Hygienists' Association, 2003). If, for example, the image produced is too overexposed (too black), the digital radiography system can do a good job of clearing the image to see the information on the image so the exposure need not be repeated (Wright, 2003).

3.2.4 Information Flow

The flow of information in a film-based imaging system is focused on the print of the image taken. This print is physically stored, and the patient takes copies to the referring clinicians. In a digital system an archiving database like PACS is used for the archiving and retrieval of films images are electronically transmitted. There is no need to wait for film to be processed and then analyzed or delivered. So greater flexibility is achieved as, referring clinicians, and radiologists can log into the radiology server and look at radiographs even from their home, which is also translated into improved patient care especially where immediate decisions are critical (Batchelor, 2003). This system also reduces the incidence of lost films.

In a film-based imaging, radiologists have much dependence on film room personnel. In a digital system, the dependence lies on qualified Information Technology professionals (which traditionally were non-existent) at the facility to maintain and backup the system archives. This resource could be either in-house or out-sourced.

3.2.5 Technological Advances

According to a statement by Agfa CEO Bruce Gower (2001), there continues to be innovation and product development in support of film production and interpretation. The same is also true for digital imaging techniques. One problem that faces computer-based technology is

that they quickly become obsolete, which is a concern for many embarking on the technology. An issue that needs to be addressed is when does it become better to choose one technology over the next if you are a high-volume practice versus a private practice.

3.2.6 Workflow

In a process analysis completed at Baltimore Veterans Affairs Medical Center by Reiner et al. (2003), before PACS implementation there were 59 individual steps to perform a chest radiograph (Figure 3).

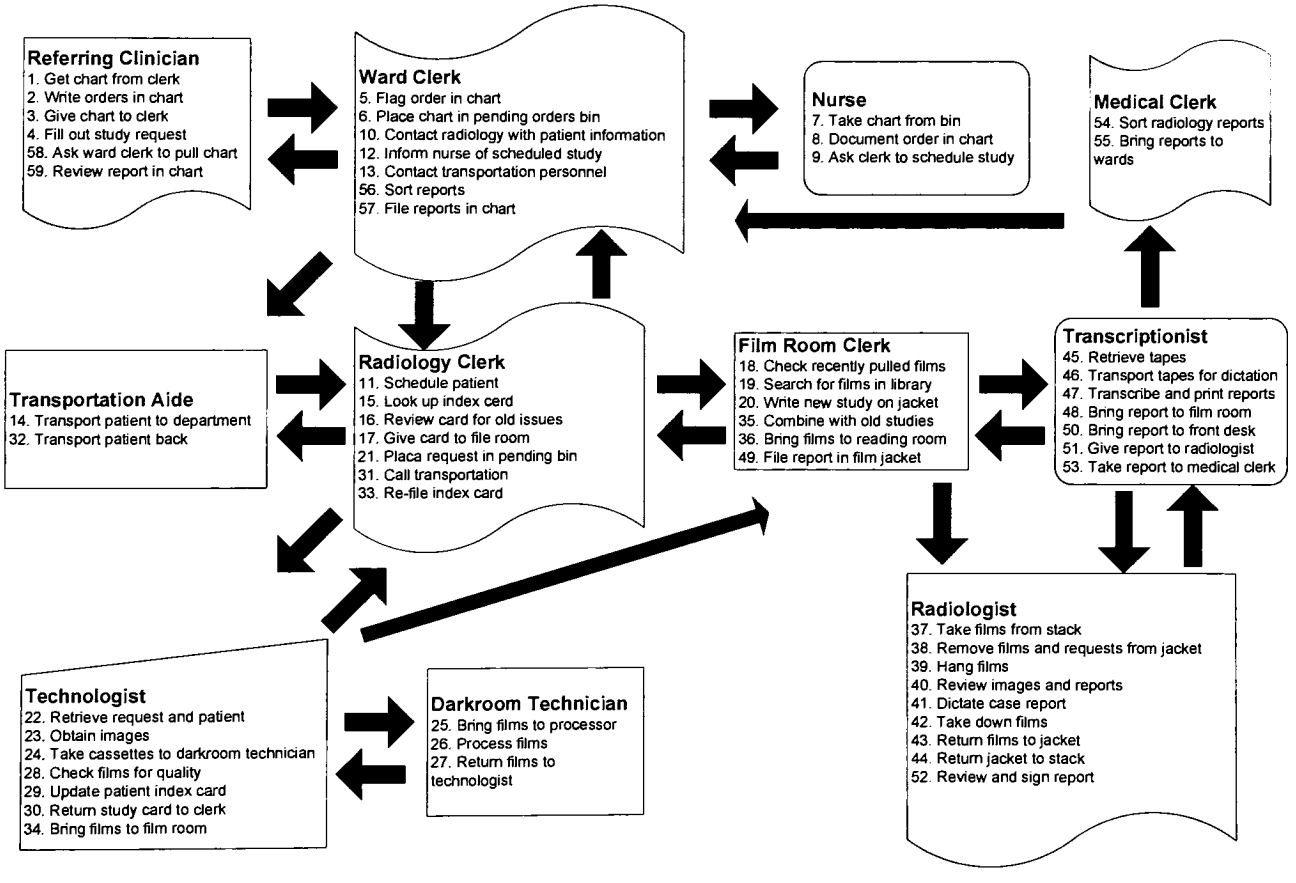


Figure 3 Film-Based Workflow for a Chest Radiograph (Reiner, 2003)

The transition to a filmless operation would have eliminated only 12 of these steps. However, by carefully studying the department's workflow process and integrating the Hospital Information System (HIS) with PACS, workflow steps was reduce to 9 for the same examination as shown in Figure 4.

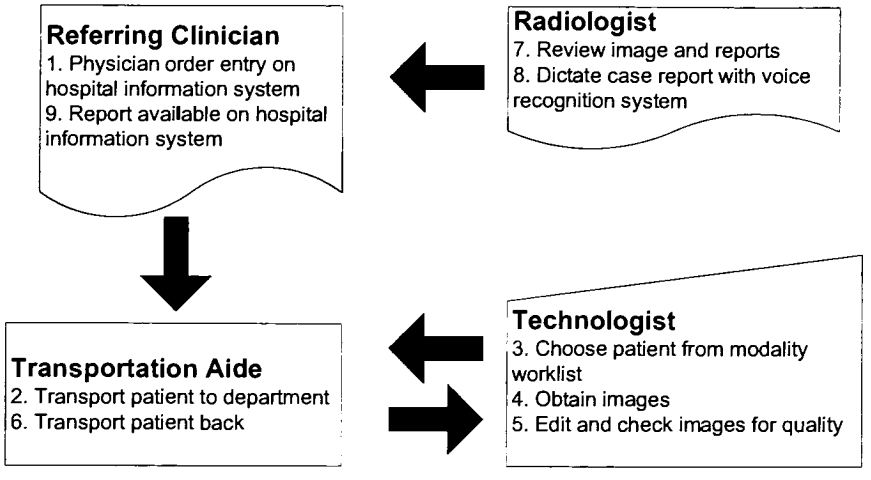


Figure 4 Digital Workflow for Chest Radiograph after PACS/HIS Implementation (Reiner, 2003)

From just analysis of the process and information flows of film versus digital (Figures 3 and 4) we can see that film is highly labor intensive. However although the digital flow shows less staff, additional staff may be received in the form of PACS administrators and technicians (Templeton, 2003). So the work may shift from one resource to the next.

Regardless of the modality, there are typical functions are executed in a diagnostic imaging process by various persons.

After a number of iterations, interviews and consultation with medical experts and journals a generic operational flow chart for both digital and film diagnostic imaging system were developed. These descriptions contain both the information and process flows that occur within the system and are highlighted in section 4.1.

3.3 Simulation and Healthcare

Operations research and management techniques have been applied to healthcare organizations to aid in restructuring or re-engineering operation systems. Methods such as motion-time method (MTM) studies, queuing methods and simulation have been employed to improve healthcare delivery (Su, 2003). We see however that both the MTM and queuing models have restrictions. The MTM model only explores a specific activity movement, and the queuing method targets the systems waiting behavior or waiting lines, and is based on theoretical assumptions. Both these methods fail to capture the interactions among subsystems that are characteristic of healthcare delivery.

Simulation is useful for modeling uncertainty, interactions and complexity all characteristics of the healthcare industry, and has proven to be useful in gaining the edge with modern trends. Simulation has successfully been applied as an analysis and decision making tool to a wide range of issues in the healthcare industry (Standridge, 1999). These include:

1. Design Problems;
2. Planning Problems; and
3. Operational Problems.

Design problems generally deal with system configuration issues and simulation tools are primarily used to evaluate candidate designs to aide in the design and selection process. Planning problems generally deal with how existing and proposed systems will be used. Operational problems relate to the actual use of the system (Pritsker, 1992).

Simulation also allows the analysis of various system alterations without the disturbance of the actual system and the experiment can be replicated as often as desired.

3.3.1. General Simulation Applications in Healthcare

Simulation has proven to be highly effective as hospitals seek to reduce costs and increase customer satisfaction amidst increasing financial pressure increases. Groothuis et al. (2002) use simulation techniques to assess the effects of relocating a hospital phlebotomy department. Simulation proved useful in assessing the consequences of the future changes in the location of the hospital department. The results of this study decreased the turn around time of the patients from 12 minutes to 8 minutes, enabling the department to cope with any increase in numbers of patients. Another study conducted by Pritsker et al. (1996) developed a simulation model that has successfully been used by the United Network for Organ Sharing to develop alternative organ allocation policies.

It can be deduced from these studies that simulation allows for the significant exploration of multiple options, without spending enormous amounts of money on staff, training, and equipment without risking possible degradation in the level of healthcare (Barnes et al., 1997). It allows for re-engineering of processes in line with clinical guidelines and, the management of the total organization with a view to a better performance for the individual patients as well as for the organization and its staff.

Success with simulation however, cannot be achieved without the involvement of healthcare professionals who are experienced in the management of the facility. Who through participation makes the model meaningful and develops a sense of ownership and acceptance of the model and the results.

Although simulation is a useful tool for healthcare applications, Lowery (1996) warns and discusses that there are concerns that frequently arise when clinicians and healthcare

managers review results of simulation models. These are (1) simulation does not provide the single best answer to the problem at hand; and (2) simulation models do not predict the future.

Unlike analytical models, simulation models do not automatically provide the single, optimal solution to the problem under investigation. Instead, simulation provides answers to "what-if" questions via a series of trial and error experiments; or the results of simulation experiments are analyzed using statistical techniques such as analysis of variance, to determine the relationships between independent and dependent variables of interest.

The other major "limitation" of simulation is its inability to predict the future. However, this characteristic is only considered a limitation if predictive powers are expected. Therefore, it is important that managers understand up front that simulation is actually a "what-if" tool. The values of input variables must be specified and often must be predicted. It must be noted that Simulation does not provide solutions. It only allows potential solutions to be relationally quantified.

3.4 Lean Techniques in Healthcare

Lean was developed and perfected by the manufacturing industry and is defined as a systematic approach that shortens customer's lead-time between order and delivery by eliminating all forms of waste. It provides a flexible production environment, with a faster response (cycle time), higher reliability (quality) and minimum waste (or non-value added task). It also provides the benefits of raising revenues, increasing margins and improves return on capital. Although developed for the manufacturing industry, the concept has many applications to other operations including the healthcare industry. The term Lean Healthcare has quickly grabbed hold of the medical industry as many seek apply lean concepts to their processes because of competitive pressure, cost pressures or for sheer survival.

Guiding principles of lean is total quality commitment, short cycle times and people empowerment. Therefore, in applying these principles we would be only doing things that add value. If a task is not value added, it is waste and should be eliminated from the system, which is one of the fundamental lean principles. Table 2 below gives examples of common wastes found in the healthcare industry. As in any industry, seven types of waste in healthcare describe all activity that adds cost but not value, and must be targeted for elimination and is the first focus of Lean Healthcare.

By applying quality to systems, 'mistakes' and errors are reduced, which reduces customer dissatisfaction and process time, which in turn reduces cost. Other fundamental principle of lean are removing or reducing overburden, inconsistencies or variations and responding to customer demand (pull system).

3.4.1 Applying Lean techniques to Diagnostic Imaging

Applied to diagnostic imaging, the lean approach focuses on optimizing time, and human and equipment resources; improving service delivery (for patients, staff, radiologists, referring physicians); reducing costs while enhancing revenue. Lean strategies using the DMAIC methodology (Define, Measure, Analyze, Improve and Control) eliminate non-value-added steps that cause delays, pinpoint root causes for defects and variability, and remove inefficiencies and redundancies that can undermine any organization's best efforts.

Today's imaging technologies provide greater speed and superior image quality. However, when workflow is laden with inefficiencies, the benefit to the organization and ultimately the patients may not be fully realized. To optimize performance, technology must not only be leading edge, it also must be appropriately aligned with the people and process steps involved in the delivery of safe and cost-effective patient care. Process improvement and

workflow adjustments using lean tools can have a measurable impact on cost and quality of services and on an organization's operational efficiency.

The financial benefits to the organization for improving operational efficiency are often significant. Table 3 illustrates the potential for various modalities:

Table 2 One More Patient per Day per Modality (Pexton, 2003)

Modality	**Additional Cases/Yr.**	**Revenue Impact****	**% Change in Volume**
CT (3 scanners)	750	$150,000	3.3
MR (1 scanner)	250	$100,000	5.5
Interventional	250	$250,000	10
Mammography (3 rooms)	750	$45,000	5
US (3 rooms)	750	$75,000	6.6

**Based on average Medicare reimbursement per modality

Table 3 Lean Healthcare /Lean Manufacturing Comparison (www.leanhealthcare.com)

The 7 Wastes- "Muda"	Definition	Healthcare	Manufacturing
Overproduction	Producing more than the customer needs right now	• Pills given early to suit staff schedules • Testing ahead of time to suit lab schedule • Treatments done to balance hospital staff or equipment workload	• Producing product to stock based on sales forecasts • Producing more to avoid set-ups • Batch process resulting in extra output
Transportation	Movement of product that does not add value	• Moving samples • Moving specimens • Moving patients for testing • Moving patients for treatment • Moving equipment	• Moving parts in and out of storage • Moving material from one workstation to another • Moving patients to and fro
Motion	Movement of people that does not add value	• Searching for patients • Searching for meds • Searching for charts • Gathering tools • Gathering supplies • Handling paperwork	• Searching for parts, tools, prints, etc. • Sorting through materials • Reaching for tools • Lifting boxes of parts
Waiting	Idle time created when material, information, people, or equipment is not ready	• Waiting for... • Bed assignments • Admission to Emergency Dept. • Testing & Treatment, Discharge • Patient lab test results	• Waiting for parts • Waiting for prints • Waiting for inspection • Waiting for information • Waiting for machine repair
Processing	Effort that adds no value from the customer's viewpoint	• Multiple bed moves • Retesting • Excessive paperwork • Unnecessary procedures • Multiple testing	• Multiple cleaning of parts • Paperwork • Over-tight tolerances • Awkward tool or part design
Inventory	More materials, parts, or products on hand than the customer needs right now	• Bed assignments • Pharmacy stock • Lab supplies • Samples • Specimens waiting analysis • Paperwork in process • Patients in beds	• Raw materials • Work in process • Finished goods • Consumable supplies
Defects	Work that contains errors, rework, mistakes or lacks something necessary	• Medication error • Wrong patient • Wrong procedure • Missing information • Redraws • Poor clinical outcomes	• Scrap • Rework • Defects • Correction • Field failure • Variation • Missing parts

4. DESIGN AND ANALYSIS METHODOLOGY

Although much work has been undertaken in modeling workflow and looking at the productivity of radiologists and/or technologists (Dackiewiez, 2000; Gay et al., 2003; Redfern, 1999; Reiner, 1998), the result of theses studies are empirical and specific to the facility where the study is conducted and look mostly on a one-factor view of system changes that occur. In this study, we take a holistic approach, finding an efficient typical diagnostic imaging system configuration relative to performance measures and to also see at what point can a provider decide to make a switch from film to digital.

Healthcare systems differ in their structure, processes and outcomes. The structure refers to the availability and organization of the wide range of physical and human resources. Outcomes refer to things such as customer satisfaction and on the quality of life. Processes of care are highly variable as these involve a diversity of patients whose needs are highly variable. In order to address that in building the model, a typical system is used. The focus being on the processes rather than structure, so the concentration is on large volume patient types with established care plans to generalize the model.

The system modeled in this experiment is an entire typical diagnostic imaging department and includes the interaction within the department, the resources (machines, technicians, radiologists and nurses), the information flow and workflow through each modality. The boundary of the system for analysis purposes considers the entire process from first patient contact to generation of the final report. There are three patient inputs to the system inpatient, outpatients and emergency patients.

Three experiments were conducted to meet the study's objectives. The first compares alternative configurations of a digital imaging system to find the best configuration of factors, which are workflow, and staffing levels of technologists and nurses. The second experiment takes the best configuration from experiment 1 and applies it to both a digital and a film based systems which each were subjected to two different number of modalities the system contains (we chose two and five modalities) and two levels of patient throughput, low and high. the third experiment is a case study where the current mixed film and digital based imaging operations and the future all digital operations of F.F. Thompson Hospital is modeled. The best configuration for a digital system from the first experiment is applied to the digital system and is compared to the current system. Apart from being fully digital the future operations at F.F. Thompson Hospital will have a much larger workspace which therefore increases travel times. The third experiment also is used to verify the meaningfulness of the second experiment.

In order for the experiments conducted to be informative, quantitative and meaningful performance measures were gathered on a five-day work-week basis and were collected as the overall system and per modality. Standard performance measures used in analyzing healthcare systems included throughput and cycle time or time in system (Weng, 1999). The performance measures used in the experiments conducted included:

- Patient throughput;
- Report throughput;
- Patient cycle time;
- Standard deviation of patient cycle time;
- Report cycle time;
- Standard deviation of report cycle time;

- Machine Utilization;
- Patient work in progress;
- Report work in progress; and
- Staff utilization of various personnel.

The discussion that follows further details the system modeled and how the problem is addressed.

4.1 System Description

Understanding and defining the system is the first step in conducting a systems analysis. In the previous chapter, the primary functions of a Diagnostic Imaging Department are shown in Figure 2. In this section a further breakdown or lower level detail and descriptions of these functions is given. After studying the system for a few months, a process and information flow was generated to ensure that a good enough understanding of the system is acquired to build the simulation model.

This description contains both the information and process flows that occur within the system. From these well-defined process and information flows along with well-defined boundaries, computer simulation models are constructed that are representative of the real world system.

A description of the case study at F.F. Thompson Hospital will also be discussed. Note however that the specific tasks are not the focus of the first two objectives of this study but rather general Diagnostic Imaging methods.

4.1.1 Typical Film - Based Imaging Process

In a typical flim-based diagnostic imaging system work follows the flow shown in Figure 5. A clinician orders the diagnostic exam, after which the radiology clerk schedules an exam and passes the information to the film librarian who at which time locates or creates the patients file. When the patient arrives he/she is registered and the requisition is printed and placed in the

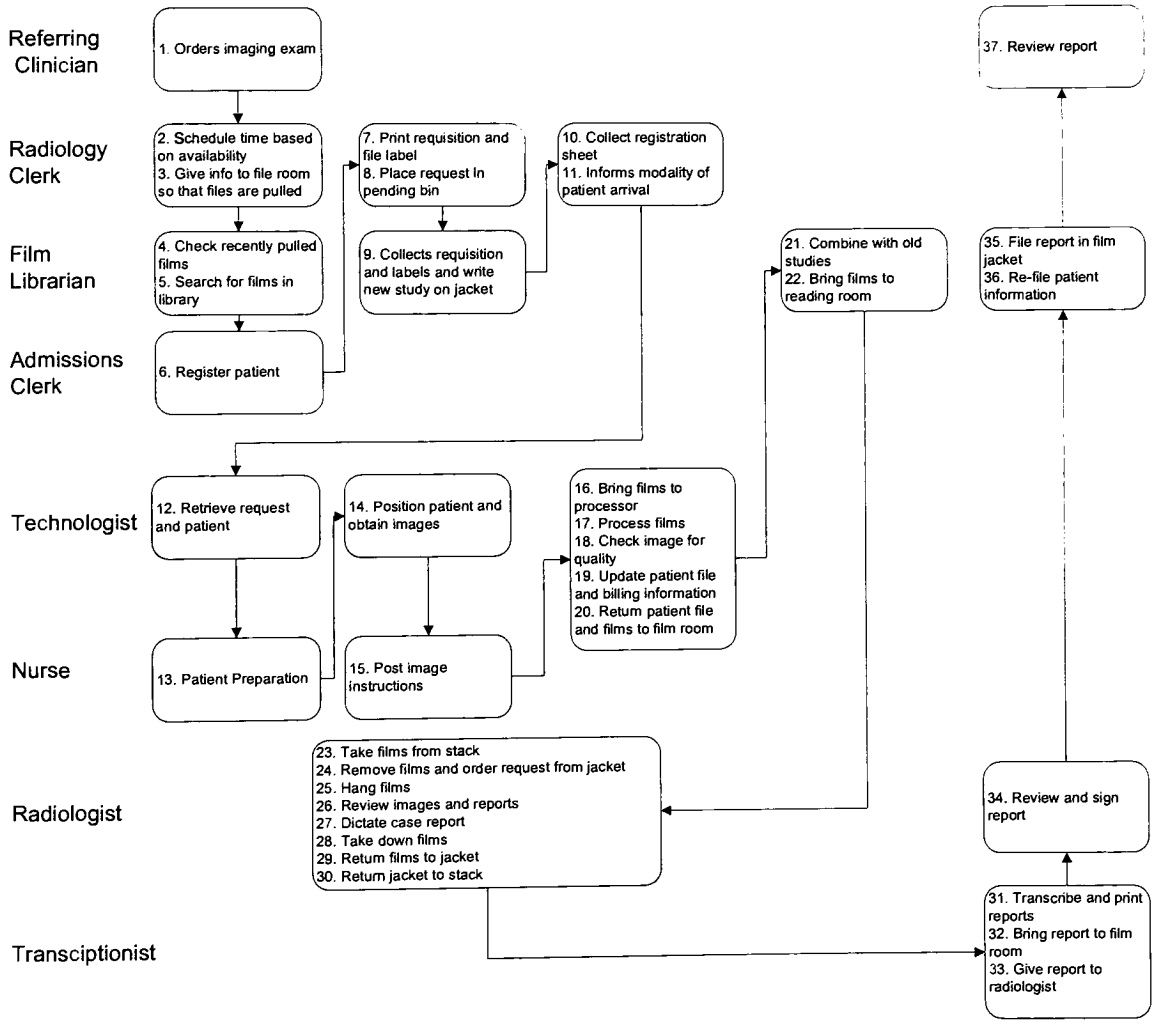


Figure 5 Typical Film Based Diagnostic Imaging Patient and Information Flow

pending bin. The film librarian collects this requisition and associated patient information and writes the study in the patient file. The radiology clerk collects the registration information and informs modality of patient arrival.

The technologist collects the requisition, retrieves the patient and escorts them to the modality. After preparation, the patient is positioned for image capture. After the image is taken the patient is given post image instructions.

The technologist then develops the films and checks the image for quality. If the quality is good, the patient is free to go. The technologist then updates the patient's file and returns the file along with the film to the film room where the film librarian combines the new images with old studies and brings the files to the radiologist.

The radiologist takes the file from the stack and removed films and order request from the jacket. The films are hung on the light box and the images are reviewed. The case report is then dictated and the films are taken down and returned to the file jacket and the file is put in a stack (which is later removed by the film librarian and re-filed).

The transcriptionist logs into a data bank, transcribes, and prints the dictated report. After which the reports are transferred to the radiologist and he/she reviews and signs the report. The film librarian puts a copy of this report in the patients file and then a copy is sent to the referring clinician for review.

4.1.2 Typical Digital - Based Imaging Process

In a typical digital diagnostic imaging system combined with RIS/HIS there is a reduction in the number of steps shown in Figure 6.

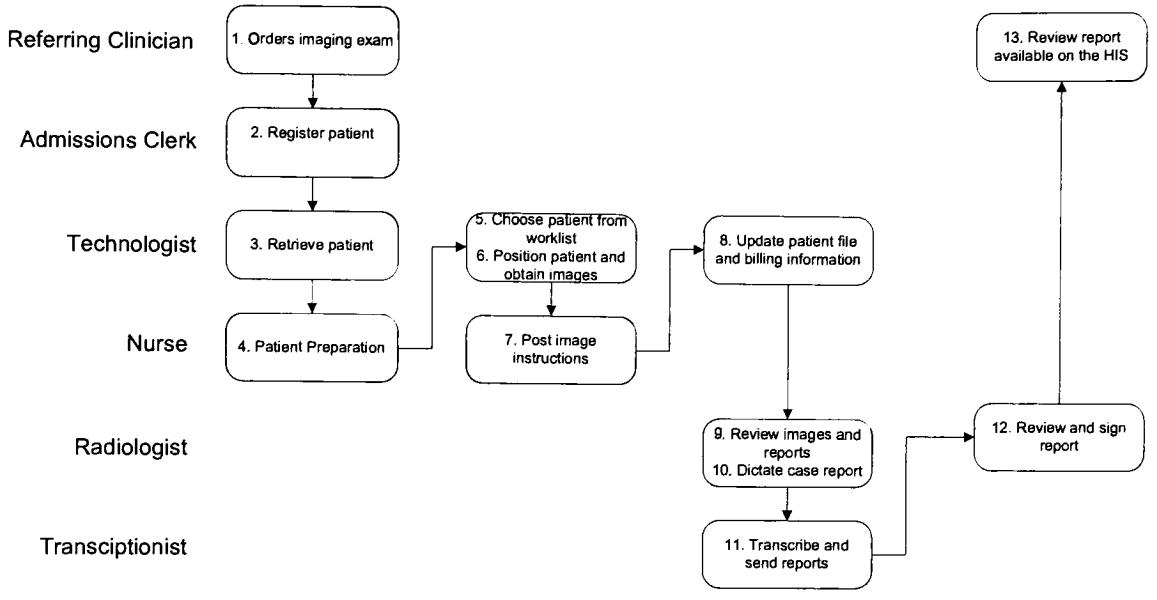


Figure 6 Typical Digital Based Diagnostic Imaging Patient and Information Flow

The process again is initiated with the referring clinician. All order information is stored electronically including previous exams conducted and a scheduled time is given. When the patient arrives, they are registered. After which the technologist retrieves the patient and then the nurse does any patient preparation necessary. All patient info is stored in a worklist, after image capture the digital information is stored. The nurse gives the patient any post image instruction and the patient leaves.

The technologist updates the patient electronic file and billing information. From his office, the radiologist review patient images and dictates the reports. The dictated report is transcribed and returned to the radiologist who reviews and signs the report. The referring clinician can then log into the RIS/HIS system to view the examination report.

As can be observed from the process and information flow charts of Figures 6 and 7 resource levels requirements is much less in the digital system. Roles such as the radiology clerk

and the film librarian are now non-existent. In addition it is also observed that the changes with employing digital technology occurs in the flow of information within the system.

Note also that some of the processes shown in the information and data flow diagram are lumped for the purpose of this study if they are tasks carried out by the same resource in consecutive steps.

4.1.3 Case Study System Process Description

A case study is conducted at F.F. Thompson Hospital in Canandaigua, New York, to apply the technology presented in this paper. This hospital is comprised of six corporations including F.F. Thompson Hospital, a 113-bed acute care facility that performs more than 54,000 radiological procedures a year.

Five different modalities make up the diagnostic imaging department at F.F. Thompson Hospital. These are Nuclear Medicine, Ultrasound, Mammography, Computed Tomography and Radiology (X-Ray). All modalities except mammography are currently undergoing changes to a fully digital picture archival and communication system. This will allow images to be distributed electronically and interpreted on computer workstations

Currently the modalities are in a transition stage and are partially digital, with a fair amount of filming still being done. The modalities are physically very close to each other and the support services surrounding are within close proximity so that travel times for both information and patient flow are short. This case study is a unique one as not only was the hospital moving to a digital system but also the diagnostic imaging department is undergoing physical reconstruction and will be three times its current size. In addition, there is expected acquisition of new machinery. The future system will therefore be fully digital, having more resources, therefore increased capacity and increased travel times (See Tables 4 and 5). In addition to the

resource increase in Table 4 there will be an additional registered nurse available bringing the total number to four. The travel times contained in Table 5 was derived by obtaining the distance that is traveled in the current system and that will be traveled in the future system from AUTOCAD drawings of the current and proposed layout. The product of these distances and the average walking rate of 3 feet/sec (which was derived from observation) resulted in the times displayed in Table 5.

With the aforementioned modifications to the system namely, workflow, architectural and layout, the changeover will be a complex one. Both the management and staff at F.F. Thompson Hospital are looking for ways to improve the system and being uncertain of what lies ahead, they would like to have a quantitative idea of the effect the changes will have on productivity. Simulation proves to be vital in helping this facility set proper staffing levels and reorganize their workflow to achieve maximum productivity.

Patient and information flows at F.F. Thompson Hospital's Diagnostic Imaging Department follow the typical flow discussed in the previous section.

Table 4 Current and Future Case Study Resource Levels

Modality	**Current**		**Future**	
	Technologist*	Machines	Technologist*	Machines
Nuclear Medicine	2.4	1	3.4	2
Computed Tomography	3.0	1	3.0	1
Mammography	3.5	2	3.5	2
Ultrasound	4.3	3	5.3	4
Radiology	8.5	4	8.5	5

* These are full time equivalent resource levels

Table 5 Estimated Current and Future Travel Times at F.F. Thompson Hospital

Transfers	Current		Future	
	Distance/ feet	Time/min	Distance / feet	Time/min
NM Tech retrieve patient and request	19.07	0.11	130.88	0.73
CT Tech retrieve patient and request	81.63	0.45	67.30	0.37
Mam Tech retrieve patient and request	21.70	0.12	51.70	0.29
US Tech retrieve patient and request	53.20	0.30	101.68	0.56
Rad Tech retrieve patient and request	62.34	0.35	123.34	0.69
To Admin	82.78	0.46	54.52	0.30
Admin to waiting room	52.14	0.29	177.98	0.99
Transfer prints from Rad to film room*	75.45	0.42	-	-
Transfer prints from US to film room*	66.31	0.37	-	-
Transfer prints from CT to film room*	94.74	0.53	-	-
Transfer prints from Mam to film room*	30.35	0.17	-	-
Transfer prints from NM to film room*	32.12	0.18	-	-
Route Films to Radiologist*	9.28	0.05	-	-

* These transfers would not be made in a fully digital system

4.2 Simulation Modeling

Simulation is defined as, "the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding behavior of a system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system." (Shannon, 1975)

In developing the simulation models for this study, the typical process and information flows shown in figures 5 and 6 were modified for each modality modeled in order to have a better and more accurate representation of the modalities under study. The variation to the typical for each department is discussed in sections 4.2.4 to section 4.2.8.

There are different patient classifications that visit a diagnostic imaging facility, In-Patients, Outpatients (which are either scheduled or unscheduled) and Emergency Patients (See Figure 7).

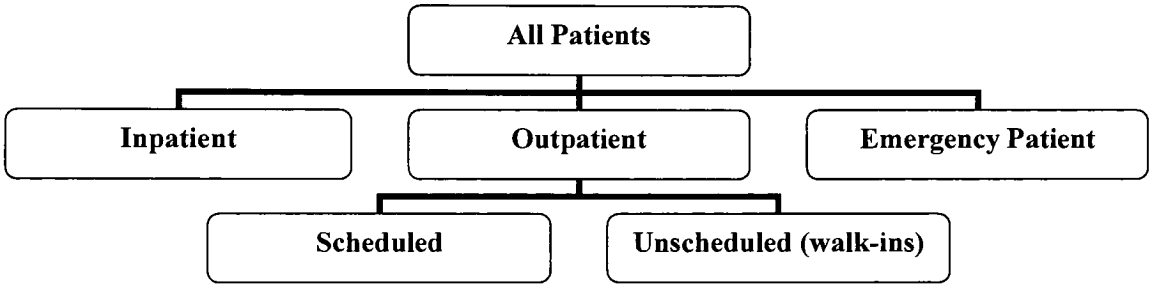


Figure 7 Patient Classifications

Inpatients are already registered, so when they need an exam done they go straight to the diagnostic imaging department. On the other hand, outpatients and emergency patient has to go through the registration process. Different proportions of these patient types were used in building the model and will be discussed in the preceding sections.

An emergency patient gets the highest priority during registration, in seizing a technologist and in getting their images read by the radiologist.

The simulation modeling software chosen for this project is ARENA, version 7.0 (Kelton, 2003). Arena, a user-friendly Windows based simulation software, has wide applications and is appropriate in handling the complexity if this system and its interactions. It has great input and output analyzing capabilities that fit input probability distributions based on

actual data and analyzes output data using statistical measures. Arena also has animation capabilities that provide visual representation of the system for those not familiar with the technicalities of the simulation language. In addition, animation is useful in the verification and validation process.

Dynamic, discrete, stochastic models were built using ARENA to meet the project objectives, as this generally provides more accurate and informative representation of the probabilistic nature of the healthcare system. The models created represents patient and information flow within a typical diagnostic imaging facility, as well as human and physical resources. The flows modeled start from first patient contact to generation of the final report and patient care and image quality was taken to into account during model building and analysis. So for all modalities if the image quality is inferior then it is retaken before the patient leaves the system.

A summary of the components of the simulation models in this thesis is shown in the Table 6 below. There are two entities modeled, patients and information and they were modeled in parallel. Entities cause changes in the state of the simulation.

Table 6 Modeling Components

Type of system:	Non-terminating
Entities:	Patient and information.
Resources:	Technologist, nurses, radiologist, admissions staff, film librarian, and radiology clerk.
Attributes:	Modality: is given a number 1 – 5 which represents each of the five modalities. TimeIn: Is the time the entity enters the system
Inputs:	Service times Interarrival times Percentages for the modality type Percentages for patient type
Outputs:	Various performance measures

Resources included in the model are also listed in Table 6. Attributes are characteristics given to the entity that are unique to that entity and are critical in understanding the performance and function of entities in the simulation.

4.2.1 Simulation Model Formulation for Experiment 1

The typical digital diagnostic imaging department is modeled as a patient-driven pull system where entity flow within a modality is generated by a demand downstream the process and the seizure of a technologist as a resource. Therefore, patient entities are created only when replacing another patient that has been processed, and a patient will not leave the waiting room until a technologist is seized to perform the examination or in other words, entity flow is generated by demand generated by downstream processes. By modeling the system as a pull system, an estimate of the maximum throughput capacity will be determined. It also overcomes the problem of scheduling and the variabilities associated. Therefore, the model is based on consumption rather than forecasting. The percentages of Outpatients/Emergency patients and Inpatients are set to 75% and 25% respectively. Five modalities were model these are using computed tomography, radiology, ultrasound, nuclear medicine, and mammography modalities.

Variables were set up in the model so that factors can be changed easily for the different configurations. These variables direct entities to different routes where they undergo various processes.

4.2.2 Simulation Model Formulation for Experiment 2

The models that were built to meet the second objective built as push system to see the systems behavior with variable inputs. The models are split into two categories a two-modality

configuration (using the radiology and ultrasound modalities) and a five-modality configuration (using computed tomography, radiology, ultrasound, nuclear medicine, and mammography modalities). A film and a digital model was built for each configuration.

The patient arrival rate for these models was determined by applying a pull system to the models in each configuration to determine a high and a low level of patient arrival that can be applied to both film and digital models (see section 4.3 for more details on levels). Percentages of which modality the patients go to were also based on the film pull system for each modality. For Radiology and Ultrasound in the two-modality configuration, the split was 55% and 45% respectively. In the five-modality configuration the percentage split for Nuclear Medicine, Mammography, Computed Tomography, Ultrasound and Radiology were 7%, 19%, 27%, 26% and 21% respectively. The percentages of Outpatients/Emergency patients and Inpatients are set to 75% and 25% respectively of the total inflow of patients.

4.2.3 Simulation Model Formulation for Case Study

This experiment was formulated differently from the theoretical models in experiments 1 and 2. In this experiment actual travel times, resources levels, and other specific attributes of F.F. Thompson Hospital are modeled. Some of these specific attributes are discusses below and in section 4.1.3.

Over a five-month period, the average actual arrival rate of patients into the diagnostic imaging department at F.F. Thompson Hospital followed an Exponential distribution with a mean of 4.02 minutes. The patient split over this five month period for the year 2004 is summarized in Table 7.

Table 7 Percentage of Case Study Patient Types

	Jan	Feb	Mar	Apr	May	Average
NM	4.16%	4.18%	4.24%	4.37%	4.23%	4.24 ± 0.07%
RAD	51.61%	50.38%	47.98%	46.70%	48.94%	49.12 ± 1.69%
CT	15.64%	16.06%	16.32%	15.30%	14.57%	15.58 ± 0.60%
US	14.49%	14.52%	15.12%	16.66%	16.29%	15.42 ± 0.88%
Mam	14.10%	14.86%	16.34%	16.97%	15.96%	15.65 ± 1.01%

For this experiment the percentages of Outpatients/Emergency patients and Inpatients of the current system is 87% and 13% respectively of the total inflow of patients.

The operations at FF. Thompson follow the diagram shown in Figure 2. All patients that enter the hospital are registered and can be categorized as Inpatients, Out Patients (which are either Scheduled or Walkins see Figure 7). Emergency patients are registered in the ER department, Inpatients are already registered, and all Out Patients that arrive and go to the admissions clerk where they are registered. They then go to the diagnostic department to the reception window, where the radiology clerk accepts their registration sheet, passes on information to the film librarian, and informs the modality of patient arrival.

As soon as a technologist is available the technologist comes, retrieves the patient from the waiting room (based on the FIFO queue discipline), and escorts them to the examination room. Emergency patients get the highest priority in this queue, jump to the front of the line, and gets service. Before the examination process begins the patient is prepared sometimes a nurse is required for this step. The exam is conducted and then the nurse and/or technologist give any post image instructions to the patient before the patient leaves.

The image taken is then processed if it is a film-based modality, and the processed films are then taken to the Radiologist for dictation. If a digital image taken, the image instantly enters a worklist for the radiologists to dictate. The dictated information is sent to the Transcriptionist

who then transcribes the dictated information into a final report and sends it back to the radiologist for review and signature. The information is now ready to be passed on to the referring physician.

4.2.4 Simulation model formulation Nuclear Medicine

In Nuclear medicine, the patients are not required to undress, so the time for the patient to undress is lower than the other departments. In addition, Nuclear Medicine Technologists are able to do their own patient preparation work and rarely requires the use of a nurse. Other processes occurring in nuclear medicine follow the typical diagnostic imaging process.

4.2.5 Simulation Model Formulation for Mammography

After the registration process, the patient has the option to see a breast health who teaches them about breast health, before their scheduled exam. On average 16% of the patients that enters this department see the breast health nurse. If they decide to go there or not, the next step is the obtaining of the image. There are three different categories of exams modeled in Mammography, mammograms, dexascans and mammography procedures. The percentages of total patients that receive these treatments are 90%, 8% and 2% respectively.

4.2.6 Simulation Model Formulation for Computed Tomography

In Computed Tomography, the flow follows the typical steps shown in Figure 6. There are two categories that were modeled for the images captured in this department, scans that take a maximum of 10 minutes and longer procedures, which include angiograms and biopsies that can take up to a maximum of 70 minutes duration. The percentages of total patients that take these exams are 98% and 2% respectively.

4.2.7 Simulation Model Formulation for Ultrasound

Ultrasound follows the typical steps and procedures. Approximately 4% of the procedures done in this department that require a nurse these can take up do 45 duration for image capture alone.

4.2.8 Simulation Model Formulation for Radiology

Approximately 3% of the patients entering the radiology department require a nurse during image capture. These procedures take up to 90 minutes in length.

4.3 Run Set up and Parameters

The model was run for one hundred replications, which is a sufficiently long time to reduce variance and gather useful information on the various performance measures. The warm up period was determined by using the graphs of patient and information flow shown in the Figure 8. This is necessary to get the system in steady state before statistics collection. With knowledge of the warm up period of 600 minutes the replication length was decided on based on the formula of 6 * warm up period. The replication length of 3,600 minutes less the warm up period of 600 minutes will be equivalent to a five day work week with each day 10 hours in length. The number of replications was adjusted for statistical validity.

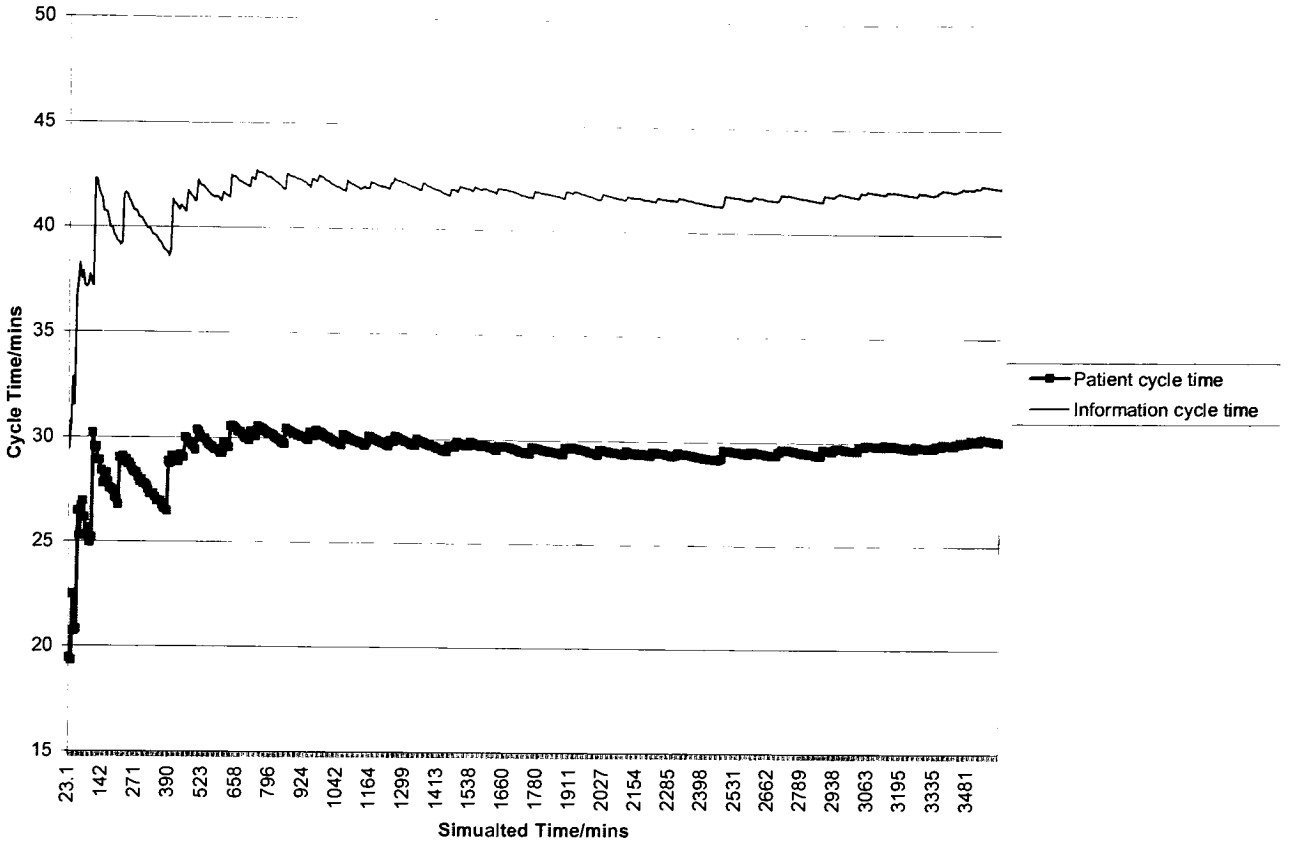


Figure 8 Warm-up Determination

The duration of a simulated day is 600 minutes (10 hours), from 7:30 am to 5:30 pm; this models the busiest period of the hospital with its maximum staff levels. Modeling the system in this way will allow us to determine system capacity performance under the busiest period and therefore the system will be able to function under less busy conditions.

4.4 Data Collection and Input Analysis

There was no historical data present at F.F. Thompson Hospital. As a result, hospital personnel most knowledgeable of the processes were interviewed and gave their best estimates of minimum and maximum parameters for the input data and were verified by actual

observations. Other information was gathered from the department's monthly reports and direct observations. A beta distribution was determined to be the best theoretical distribution to vary time for thee processes in this study (Table 8). It was selected as it provides variability and limits this variability to a particular range and is a more accurate estimation than the normal or triangular distributions (McGuire, 1994). As the estimated time given by the persons who perform the task on a daily basis are competent at what they do and will more than likely perform the task in a time closer to the minimum than the maximum time. Values for the various tasks and other modeling issues for both film and digital are discussed below.

Patients are categorized into five different categories one for each modality (Nuclear Medicine, Ultrasound, Radiology, Computed Tomography and Mammography) each having unique flows with appropriate treatment times and patterns. These flows were typical of the flows shown in figures 6 and 7 and were modified to better suit the modality under study. These unique flows are highlighted in the following sections.

Table 8 Model Process Time Inputs

Area	Process	Input Distribution/ mins.
Admissions	Register Patient	2+3*BETA(1.5,5)
Reception	Print requisition and file label place info in request bin	1+1*BETA(1.5,5)
Nuclear Medicine	Patient NM Preparation by tech	5+15*BETA(1.5,5)
	Obtain NM Images	60+120*BETA(1.5,5)
	Print images	5+5*BETA(1.5,5)
	Tech gives NM patient post image instruction	2+3*BETA(1.5,5)
	Update NM patient file	1+1*BETA(1.5,5)
	Nurse gives NM patient post image instruction	3+2*BETA(1.5,5)
	NM Patient prepares for departure	1
Mammography	Breast Exam by health nurse	15+5*BETA(1.5,5)
	Patient Undresses and prepares for exam	5+5*BETA(1.5,5)
	Obtain Mammogram Images	5+3*BETA(1.5,5)
	Obtain Mam Dexa Images	35+40*BETA(1.5,5)
	Obtain Mam procedures Images	60+120*BETA(1.5,5)
	Print images2	2+3*BETA(1.5,5)
	Tech gives Mam patient post image instruction	2+3*BETA(1.5,5)
	Nurse gives Mam patient post image instruction	3+2*BETA(1.5,5)
	Update Mam patient file	5+10*BETA(1.5,5)
	Mam Patient prepares for departure	5
Computed Tomography	Obtain CT Images	4+6*BETA(1.5,5)
	Patient CT Preparation by nurse	5+15*BETA(1.5,5)
	Nurse gives CT patient post image instruction	5+10*BETA(1.5,5)
	Update CT patient file	1+1*BETA(1.5,5)
	Obtain CT Biopsies Angio etc Images	64+6*BETA(1.5,5)
	Print images3	5+5*BETA(1.5,5)
	CT Patient prepares for departure	5
Radiology	Obtain Rad Images without nurse	5+15*BETA(1.5,5)
	Obtain Rad Images	45+45*BETA(1.5,5)
	Patient Rad Preparation by tech	2+3*BETA(1.5,5)
	Tech gives Rad patient post image instruction	2+3*BETA(1.5,5)
	Nurse gives Rad patient post image instruction	5+10*BETA(1.5,5)
	Print images5	5+5*BETA(1.5,5)
	Update Rad patient file	1+1*BETA(1.5,5)
	Rad Patient prepares for departure	5
Ultrasound	Patient US Preparation by tech	2+3*BETA(1.5,5)
	Obtain US Images	15+15*BETA(1.5,5)
	Obtain US Images2	30+15*BETA(1.5,5)
	Print images4	5+3*BETA(1.5,5)
	Update US patient file	1+1*BETA(1.5,5)
	Tech gives US patient post image instruction	2+3*BETA(1.5,5)
	Nurse gives US patient post image instruction	5+10*BETA(1.5,5)
	US Patient prepares for departure	5
Film Library	Combine with old studies	20+20*BETA(1.5,5)
Radiologists	Take prints from stack	0.5+1*BETA(1.5,5)
	Remove prints from jacket	0.5+1*BETA(1.5,5)
	Hang prints	0.5+1*BETA(1.5,5)
	Take down prints	0.5+0.75*BETA(1.5,5)
	Return prints to jacket	0.5+1*BETA(1.5,5)
	Return jacket to stack	0.5+0.75*BETA(1.5,5)
	Review images and reports	0.5+9.5*BETA(1.5,5)
	Dictate case report	0.5+1.5*BETA(1.5,5)
	Review and sign report	10+20*BETA(1.5,5)
Transcription	Transcribe and print reports	1+3*BETA(1.5,5)

4.5 Modeling Assumptions

According to Lowery (1998), any assumptions made should be clearly documented, "no matter how seemingly minor, so that your clients understand the model's limitations." These inputs will need to be as accurate as possible so that truthful model predictions can be made. Some of the assumptions made in building the simulation models include:

- The same level/capacity of resource is available throughout the simulation run.
- When an emergency patient arrives, the current patient in the system is finished and then the emergency patient is attended to next.
- Percentage retakes that occur in the film-diagnostic imaging system is 2%, which was given by the hospital as the typical amount.
- All transfers of information in a digital system are negligible and therefore the variable called Transfer Info Time is set to zero.
- Information flows model starts after the admissions process so all preparatory or priors that needs to be pulled are done before patient arrival.
- The time taken to print digital images unto films is approximately the same time it takes to develop the films.

4.6 Verification and Validation

Before any analysis can be performed the model has to be validated (the model operates as indented) and verified (the model is an accurate representation of the system).

Verification of the simulation model was done to determine whether that model performs as intended. One of the verification methods was achieved by using the debugging software available in Arena. Also all assumptions and data used was in the model was verified by experts

on the system and other simulation experts reviewed the models. Many hours were also spent watching patient and information flow through the simulation model ensuring that they were going to the right places and seizing the correct resources.

Validation of the model is also done to ensure that it accurately represents the system under study. This along with verification is an important step in the acceptance of the model. Using animation tools available in Arena, replication of runs, and also statistical analysis of output are methods used for the validation process. So in this model the patient throughput of each patient type was used to validate the model. Means of the actual system versus the simulated systems throughput per modality was compared statistically at the 95% confidence interval this is summarized in the Table 9.

Table 9 Model Verification

MEASURE	Actual patient throughput CI – 95%			Simulated patient throughput CI – 95%		
Computed Tomography	116.35	±	7.65	117.27	±	2.15
Nuclear Medicine	31.61	±	1.35	27.9	±	0.62
Mammography	116.89	±	9.88	116.89	±	2.33
Ultrasound	115.05	±	7.51	116.06	±	2.02
Radiology	366.41	±	14.02	366.69	±	3.37

The table above shows that the actual data lies within the 95% confidence interval that is generated by the simulations output. Therefore, we can conclude that the mean actual time lies within the confidence interval 95% of the time.

4.7 Design of Experiments

We seek to determine how changing factors and/or interaction of factors affect the various performance measures. The factors and levels chosen had to be general enough that they can be applied to most imaging departments or facilities. It must be noted however, that while the goal of the experiments is optimization, it cannot be approached from a pure engineering standpoint as patients are involved and their care should not be compromised. For the purposes of this study, workflow will be defined as the series or progress of tasks done within the diagnostic imaging department.

4.7.1 Lean Application in Experiment Set-up

The eliminate, simplify and automate a Lean rule was used to determine the levels for the workflow and staffing factors and levels. In addition, the levels for both technologist and nurses was done to reduce 'set-up' times between patients per study or in other words, changeover time. This can be further defined as, the time that elapses from the last patient to the next. This was found to be true when there were two technologists per machine in a modality.

Another example of using Lean concepts with the objective being to find ways to change the system to improve system performance is seen in workflow alternative 4. Automation is introduced which eliminates the need for a transcriptionist as with the introduction of automation the software translates the radiologists speech at dictation into a report. He checks the report at the end of his dictation and signs it. So the time and the extra resource that is normally needed for the transcription process is eliminated.

4.7.2 Experiment 1 – Experiment Set-Up and Analysis

Several factors affect the operational efficiency diagnostic systems. Some of the factors that would affect the system's performance and are considered in this study are workflow and staffing. For the purposes of this study, workflow will be defined as the series or progress of tasks done within the diagnostic imaging department. Staffing levels considered are that of nurses and technologists. Different levels of these factors are combined to establish the best alternative. The factors and levels are discussed in detail in the following paragraphs.

Table 10 Levels for Factor A – Workflow

Workflow Level #	Printing of images (incl. Filing)	Reading of digital images by radiologist	Outside transcription
1	√	-	√
2	√	√	√
3	-	√	√
4	-	√	-

In workflow alternative 1 the image is printed, and once printed the image is filed. A facility may still print the images from a digital system for many reasons but often it is done at the request of the referring clinician. The radiologist reads the printed copy of the image and sends it to the Transcriptionist to be transcribed. This alternative mimics the workflow in a film-based system with respects to hard copy management.

In workflow alternative 2 although the technologist prints the image, the radiologist reads the digital image.

In workflow alternative 3 no image is printed and the images are read digitally. In workflow 4 no image is printed, and therefore no need for filing and the radiologist reads the digital images. The transcription however in workflow 4 is done automatically at dictation using transcription software.

Table 11 Levels for Factors B and C – Staffing

STAFFING	LEVEL 1	LEVEL 2
Factor B – Number of Technologists	1	2
Factor C – Number of Nurses	1	2

There are 4 levels of factor A (Workflow), 2 levels of factor B (Technicians) and 2 levels of factor C (Nurses). The result was 16 different treatment combinations to determine the combination that gave the best result. For the purposes of this study, workflow will be defined as the series or progress of tasks done within the diagnostic imaging department.

Using the levels of the factors shown in tables 10 and 11 above a 3 Factor Experiment is conducted with a resulting 16 treatment combinations to determine statistical significance and to get information about single effects and the interaction effects of the factors under study.

Resources used in the models but were not varied are shown in the table 12 and their resource levels are set so that they are sufficient to handle the workload with no bottlenecking.

Table 12 Resource Allocations

RESOURCE	NUMBER IN SIMULATION MODEL
Admissions Clerk	5
Radiology Clerk	1
Radiologists	3
Film Room Clerk	1

Statistical analysis of model output was conducted to determine the significance of the single factors and the interaction of factors by analysis of variance techniques. Tukey pairwise comparison tests were also conducted on all significant factors. The Tukey test identifies statistically significant difference among a set of treatment combinations at the desired significance level. For the purposes of this study, this level of significance is 0.05.

The performance measures collected for this experiment are as follows and were collected for the overall system and for each modality. Patient cycle time, standard deviation of patient cycle time, information cycle time, standard deviation of information cycle time, patient throughput, report throughput and machine utilization.

4.7.3 Experiment 2 – Film vs. Digital Comparison

For the second experiment, the factor that will be considered is the number of diagnostic procedures performed per week. Two levels are chosen for this factor that would adequately cover the maximum and a low range of the number of procedures conducted in a typical diagnostic imaging facility having two or five imaging modalities. Film versus digital is compared at a particular throughput level.

To determine levels of throughput, the film models were built as pull systems to determine the high level throughput and these were split in half to determine the lower level of throughput. These is summarized in Table 13.

Table 13 Throughput Levels for Experiment 2

Throughput Level	Two modality configuration	Five modality configuration
Low	100	220
High	200	440

The patient input to both film and digital was set so that these throughput levels were achieved for both the film and digital for a particular configuration resulting in eight models. The means of the output of film and digital at a certain level were compared at a particular level using the Output Analyzer software in ARENA.

4.7.4 Experiment 3 – Case Study

The case study at F.F. Thompson Hospital will validate the experiments conducted. An application of the experiments is made to F.F. Thompson Hospital to aid in the implementation process of their digital system. This will be achieved by first looking at the current situation of the system and identify bottlenecks that exist. A simulation model is both of the current and future system is built and validated. These models are then compared based on the means of the output performance measures. By modeling the business, various alternatives for carrying out business processes and also opportunities for change will be identified (Groothius, 2002).

Since the patient and report throughput rate is determined by the patient arrival rate, more useful the performance measures were collected for this experiment i.e. the work in progress for both patient and information in addition to the other performance measures discussed in Experiment 1.

5. RESULTS AND DISCUSSION

After completing several runs of the models and collecting their output analysis was performed in order to convert the data gathered into useful information. Analysis was carried out as discussed in section 4.7 using various software including MINITAB, version 14.0. Which was used to do analysis of variance test to determine the significance of the factors under study at the 95% confidence interval level. Performance measures with a p -value smaller than 0.05 shows that the differences are significant. It was also used to carry out Tukey tests. Other software used includes Output Analyzer from ARENA and Microsoft EXCEL.

The information gathered for all the experiments and the case study using these various tools are summarized and discussed in the following sections.

5.1 Experiment 1

All of the 16 different treatment combinations were analyzed to determine the most efficient digital system. The results from the different alternatives are summarized in Table 14. Where factor A refers to workflow levels 1 through 4, factor B refers to the number of technologists and factor C refers to the number of nurses (See section 4.7.1). In Table 14 a summary of the mean overall system performance measures is shown. The averages and the 95% confidence interval is shown in the following tables.

Table 14 Overall Performance Measure Summary Statistics

Treatment			Overall Patient Cycle Time	Standard deviation of overall Patient Cycle Time	Overall Information Cycle Time	Standard deviation of Overall Information Cycle Time	Overall Patient Throughput	Overall Report Throughput	Overall Machine Utilization
A	B	C							
1	1	1	30.09 ± 0.12	21.71 ± 0.22	42.25 ± 0.10	22.83 ± 0.23	470.02 ± 1.49	470.08 ± 1.52	0.6658 ± 0.0013
2	1	1	30.08 ± 0.12	21.66 ± 0.21	38.11 ± 0.12	22.71 ± 0.21	469.63 ± 1.63	469.32 ± 1.57	0.6654 ± 0.0013
3	1	1	30.62 ± 0.11	20.93 ± 0.21	32.09 ± 0.10	21.40 ± 0.21	564.15 ± 1.81	560.70 ± 2.30	0.8128 ± 0.0008
4	1	1	30.59 ± 0.11	20.97 ± 0.18	30.11 ± 0.10	21.44 ± 0.18	562.67 ± 1.91	559.99 ± 2.18	0.8139 ± 0.0009
1	2	1	41.42 ± 0.20	37.23 ± 0.24	54.76 ± 0.17	37.49 ± 0.24	679.45 ± 2.79	672.58 ± 2.52	0.9803 ± 0.0006
2	2	1	41.76 ± 0.22	37.42 ± 0.25	50.46 ± 0.21	37.56 ± 0.26	674.81 ± 3.06	678.22 ± 2.74	0.9608 ± 0.0006
3	2	1	45.52 ± 0.21	37.69 ± 0.28	47.59 ± 0.19	37.66 ± 0.28	704.05 ± 3.02	703.29 ± 3.36	0.9904 ± 0.0004
4	2	1	41.64 ± 0.19	37.37 ± 0.30	50.39 ± 0.18	37.33 ± 0.31	676.30 ± 2.85	705.67 ± 3.38	0.9604 ± 0.0006
1	1	2	30.02 ± 0.12	21.65 ± 0.21	42.20 ± 0.11	22.76 ± 0.20	876.30 ± 2.65	471.13 ± 1.59	0.8646 ± 0.0013
2	1	2	30.07 ± 0.12	21.70 ± 0.20	38.03 ± 0.10	22.78 ± 0.20	470.44 ± 1.55	470.78 ± 1.58	0.6654 ± 0.0014
3	1	2	29.72 ± 0.11	20.38 ± 0.19	37.77 ± 0.10	21.34 ± 0.18	474.61 ± 1.51	603.50 ± 2.36	0.6624 ± 0.0013
4	1	2	29.12 ± 0.10	20.47 ± 0.22	28.16 ± 0.09	21.45 ± 0.22	603.73 ± 2.27	603.91 ± 2.23	0.8092 ± 0.0010
1	2	2	38.45 ± 0.19	35.73 ± 0.27	51.41 ± 0.17	36.65 ± 0.26	739.30 ± 3.19	739.49 ± 3.21	0.9605 ± 0.0006
2	2	2	38.52 ± 0.19	36.04 ± 0.27	46.70 ± 0.17	36.77 ± 0.27	738.16 ± 3.19	736.59 ± 3.29	0.9601 ± 0.0005
3	2	2	42.49 ± 0.20	35.68 ± 0.25	43.96 ± 0.18	36.22 ± 0.25	770.59 ± 3.57	769.81 ± 3.33	0.9903 ± 0.0004
4	2	2	42.39 ± 0.18	35.82 ± 0.26	41.93 ± 0.17	36.36 ± 0.26	772.37 ± 3.26	768.85 ± 3.39	0.9903 ± 0.0004

Tables 15 through to Table 19 that follows, summarizes the mean and their 95% interval after 100 replications for the individual modalities.

Table 15 Radiology Performance Measure Summary Statistics

Treatment			Radiology Patient Cycle Time	Standard deviation of Radiology Patient Cycle Time	Radiology Information Cycle Time	Standard deviation of Radiology Information Cycle Time	Radiology Patient Throughput	Radiology Report Throughput	Radiology Machine Utilization
A	B	C							
1	1	1	20.66 ± 3.76	9.66 ± 0.50	34.10 ± 0.15	8.75 ± 0.44	126.08 ± 0.74	126.14 ± 0.74	0.5347 ± 0.0028
2	1	1	20.55 ± 4.17	9.66 ± 0.49	29.74 ± 0.16	8.65 ± 0.43	126.48 ± 0.82	125.77 ± 0.83	0.5335 ± 0.0030
3	1	1	20.63 ± 6.49	9.47 ± 0.43	22.12 ± 0.13	8.48 ± 0.37	174.89 ± 1.27	175.44 ± 1.24	0.7423 ± 0.0019
4	1	1	20.63 ± 6.49	10.36 ± 0.49	20.64 ± 0.15	9.27 ± 0.43	174.89 ± 1.27	173.14 ± 1.47	0.7423 ± 0.0019
1	2	1	23.73 ± 9.50	13.30 ± 0.51	37.81 ± 0.22	12.66 ± 0.47	223.66 ± 1.86	221.90 ± 1.80	0.9484 ± 0.0010
2	2	1	23.76 ± 9.88	12.79 ± 0.51	32.73 ± 0.22	12.07 ± 0.48	223.33 ± 1.94	224.29 ± 1.80	0.9493 ± 0.0009
3	2	1	29.03 ± 10.05	13.12 ± 0.52	30.53 ± 0.22	12.37 ± 0.49	235.26 ± 1.97	235.51 ± 1.92	1.0000 ± 0.0000
4	2	1	24.02 ± 8.70	13.17 ± 0.59	28.93 ± 0.27	12.45 ± 0.55	221.35 ± 1.70	234.62 ± 2.36	0.9502 ± 0.0009
1	1	2	20.65 ± 7.88	9.70 ± 0.48	34.12 ± 0.14	8.78 ± 0.43	126.06 ± 0.73	126.03 ± 0.75	0.5347 ± 0.0027
2	1	2	20.74 ± 3.89	10.14 ± 0.61	29.87 ± 0.18	9.19 ± 0.54	125.73 ± 0.76	125.38 ± 0.90	0.5360 ± 0.0028
3	1	2	20.63 ± 3.92	9.85 ± 0.52	22.21 ± 0.16	8.88 ± 0.46	126.12 ± 0.77	174.24 ± 1.47	0.5344 ± 0.0028
4	1	2	20.75 ± 7.64	9.56 ± 0.40	20.47 ± 0.13	8.59 ± 0.34	174.06 ± 1.50	175.04 ± 1.28	0.7432 ± 0.0023
1	2	2	23.88 ± 10.34	13.15 ± 0.59	38.03 ± 0.26	12.55 ± 0.55	222.76 ± 2.03	222.77 ± 2.04	0.9498 ± 0.0010
2	2	2	23.78 ± 8.68	12.83 ± 0.52	32.85 ± 0.23	12.12 ± 0.49	223.35 ± 1.70	223.21 ± 1.88	0.9489 ± 0.0010
3	2	2	29.19 ± 11.19	12.65 ± 0.53	30.38 ± 0.23	11.94 ± 0.49	234.12 ± 2.19	236.88 ± 2.10	1.0000 ± 0.0000
4	2	2	28.81 ± 8.88	13.50 ± 0.50	29.11 ± 0.26	12.70 ± 0.47	237.13 ± 1.74	233.13 ± 2.23	1.0000 ± 0.0000

Table 16 Ultrasound Performance Measure Summary Statistics

Treatment			Ultrasound Patient Cycle Time	Standard deviation of Ultrasound Patient Cycle Time	Ultrasound Information Cycle Time	Standard deviation of Ultrasound Information Cycle Time	Ultrasound Patient Throughput	Ultrasound Report Throughput	Ultrasound Machine Utilization
A	B	C							
1	1	1	30.12 ± 0.11	5.61 ± 0.25	40.07 ± 0.10	4.95 ± 0.20	100.85 ± 0.31	100.88 ± 0.30	0.7439 ± 0.0009
2	1	1	30.14 ± 0.11	5.64 ± 0.24	35.68 ± 0.10	4.98 ± 0.19	100.75 ± 0.33	100.66 ± 0.34	0.7446 ± 0.0009
3	1	1	29.24 ± 0.06	5.70 ± 0.20	31.62 ± 0.11	4.91 ± 0.15	115.56 ± 0.28	112.70 ± 0.40	0.8299 ± 0.0005
4	1	1	29.24 ± 0.06	5.71 ± 0.23	29.85 ± 0.09	4.98 ± 0.18	115.56 ± 0.28	113.01 ± 0.37	0.8299 ± 0.0005
1	2	1	43.09 ± 0.11	7.46 ± 0.29	55.01 ± 0.16	7.05 ± 0.27	139.50 ± 0.35	135.37 ± 0.51	1.0000 ± 0.0000
2	2	1	44.77 ± 0.17	7.52 ± 0.26	50.26 ± 0.16	6.96 ± 0.23	135.05 ± 0.48	135.49 ± 0.49	1.0000 ± 0.0000
3	2	1	48.00 ± 0.18	7.40 ± 0.24	49.34 ± 0.15	6.83 ± 0.21	135.14 ± 0.51	135.51 ± 0.49	1.0000 ± 0.0000
4	2	1	43.13 ± 0.11	7.54 ± 0.25	47.66 ± 0.17	6.95 ± 0.23	139.49 ± 0.38	135.42 ± 0.52	1.0000 ± 0.0000
1	1	2	30.18 ± 0.12	5.87 ± 0.25	40.14 ± 0.11	5.14 ± 0.21	100.75 ± 0.36	100.74 ± 0.35	0.7444 ± 0.0010
2	1	2	30.18 ± 0.12	5.60 ± 0.23	35.68 ± 0.10	4.89 ± 0.19	100.79 ± 0.35	100.86 ± 0.33	0.7449 ± 0.0009
3	1	2	29.15 ± 0.07	5.58 ± 0.20	31.48 ± 0.09	4.83 ± 0.16	115.93 ± 0.32	113.16 ± 0.36	0.8290 ± 0.0005
4	1	2	30.14 ± 0.11	5.77 ± 0.22	29.88 ± 0.09	5.02 ± 0.19	112.91 ± 0.39	112.82 ± 0.41	0.8337 ± 0.0006
1	2	2	44.71 ± 0.19	7.50 ± 0.28	55.29 ± 0.17	7.13 ± 0.25	135.35 ± 0.54	135.44 ± 0.52	1.0000 ± 0.0000
2	2	2	44.66 ± 0.18	7.34 ± 0.22	50.23 ± 0.16	6.80 ± 0.21	135.50 ± 0.48	135.47 ± 0.48	1.0000 ± 0.0000
3	2	2	47.84 ± 0.19	7.33 ± 0.28	49.29 ± 0.17	6.80 ± 0.25	135.58 ± 0.53	135.62 ± 0.56	1.0000 ± 0.0000
4	2	2	47.83 ± 0.19	7.53 ± 0.25	47.71 ± 0.17	6.93 ± 0.23	135.51 ± 0.52	135.07 ± 0.53	1.0000 ± 0.0000

Table 17 Computed Tomography Performance Measure Summary Statistics

Treatment			Computed Tomography Patient Cycle Time	Standard deviation of Computed Tomography Patient Cycle Time	Computed Tomography Information Cycle Time	Standard deviation of Computed Tomography Information Cycle Time	Computed Tomography Patient Throughput	Computed Tomography Report Throughput	Computed Tomography Machine Utilization
A	B	C							
1	1	1	27.66 ± 0.16	8.55 ± 0.50	34.03 ± 0.15	8.61 ± 0.50	126.43 ± 0.82	126.43 ± 0.15	0.6468 ± 0.0023
2	1	1	27.94 ± 0.19	9.07 ± 0.54	29.82 ± 0.15	9.12 ± 0.53	125.11 ± 0.99	125.47 ± 0.82	0.6507 ± 0.0027
3	1	1	33.12 ± 0.17	9.03 ± 0.46	27.50 ± 0.15	9.06 ± 0.46	133.52 ± 0.94	133.60 ± 0.85	0.9230 ± 0.0006
4	1	1	27.99 ± 0.17	8.62 ± 0.58	25.72 ± 0.17	8.65 ± 0.57	124.64 ± 0.85	133.93 ± 1.01	0.9230 ± 0.0006
1	2	1	49.17 ± 0.36	13.09 ± 0.78	55.95 ± 0.32	13.20 ± 0.77	132.99 ± 1.04	132.64 ± 0.90	1.0000 ± 0.0000
2	2	1	48.87 ± 0.30	9.10 ± 0.45	51.12 ± 0.33	13.26 ± 0.76	133.59 ± 0.89	132.83 ± 0.95	1.0000 ± 0.0000
3	2	1	55.30 ± 0.30	12.90 ± 0.68	50.17 ± 0.30	12.93 ± 0.67	134.27 ± 0.88	132.96 ± 0.85	1.0000 ± 0.0000
4	2	1	49.00 ± 0.36	12.25 ± 0.76	48.08 ± 0.30	12.24 ± 0.75	133.31 ± 1.01	134.12 ± 0.89	1.0000 ± 0.0000
1	1	2	27.65 ± 0.17	9.32 ± 0.61	34.00 ± 0.17	9.37 ± 0.61	126.79 ± 0.87	126.84 ± 0.90	0.6460 ± 0.0023
2	1	2	27.51 ± 0.16	8.78 ± 0.56	29.43 ± 0.16	8.81 ± 0.55	127.39 ± 0.83	127.75 ± 0.80	0.6437 ± 0.0024
3	1	2	27.38 ± 0.15	9.10 ± 0.45	21.95 ± 0.13	9.08 ± 0.45	128.02 ± 0.82	177.05 ± 1.34	0.6418 ± 0.0023
4	1	2	27.49 ± 0.15	8.85 ± 0.48	20.20 ± 0.14	8.86 ± 0.48	177.66 ± 1.50	177.62 ± 1.44	0.8976 ± 0.0009
1	2	2	34.21 ± 0.23	12.23 ± 0.56	41.14 ± 0.22	12.41 ± 0.56	198.27 ± 1.46	198.29 ± 1.45	1.0000 ± 0.0000
2	2	2	34.47 ± 0.28	12.85 ± 0.66	36.49 ± 0.28	12.64 ± 0.65	196.83 ± 1.78	196.57 ± 1.73	1.0000 ± 0.0000
3	2	2	40.83 ± 0.26	13.28 ± 0.68	35.73 ± 0.30	13.27 ± 0.68	198.82 ± 1.64	195.64 ± 1.83	1.0000 ± 0.0000
4	2	2	40.92 ± 0.25	12.44 ± 0.66	33.63 ± 0.27	12.43 ± 0.65	198.08 ± 1.63	198.30 ± 1.71	1.0000 ± 0.0000

Table 18 Mammography Performance Measure Summary Statistics

Treatment			Mammography Patient Cycle Time	Standard deviation of Mammography Patient Cycle Time	Mammography Information Cycle Time	Standard deviation of Mammography Information Cycle Time	Mammography Patient Throughput	Mammography Report Throughput	Mammography Machine Utilization
A	B	C							
1	1	1	24.82 ± 0.43	16.21 ± 0.84	44.15 ± 0.41	16.08 ± 0.78	89.23 ± 1.06	89.26 ± 0.41	0.5037 ± 0.0058
2	1	1	24.61 ± 0.33	16.01 ± 0.73	39.33 ± 0.31	15.86 ± 0.68	89.67 ± 0.87	89.94 ± 0.31	0.5002 ± 0.0047
3	1	1	24.90 ± 0.35	16.39 ± 0.69	32.43 ± 0.32	16.17 ± 0.66	109.26 ± 1.28	109.59 ± 0.32	0.6179 ± 0.0046
4	1	1	24.90 ± 0.35	16.11 ± 0.60	30.55 ± 0.31	15.99 ± 0.58	109.26 ± 1.28	110.46 ± 0.31	0.6179 ± 0.0046
1	2	1	29.77 ± 0.47	22.47 ± 0.80	49.70 ± 0.46	22.34 ± 0.78	152.54 ± 1.82	151.77 ± 0.46	0.8529 ± 0.0026
2	2	1	29.89 ± 0.55	21.91 ± 0.80	44.47 ± 0.51	21.73 ± 0.78	152.28 ± 2.09	153.13 ± 0.51	0.8545 ± 0.0028
3	2	1	31.93 ± 0.56	23.28 ± 0.89	39.67 ± 0.51	23.13 ± 0.87	168.36 ± 2.41	168.80 ± 0.51	0.9522 ± 0.0019
4	2	1	30.00 ± 0.52	22.57 ± 0.83	37.57 ± 0.52	22.46 ± 0.82	151.69 ± 1.88	170.64 ± 0.52	0.8517 ± 0.0027
1	1	2	24.51 ± 0.36	15.50 ± 0.75	43.77 ± 0.35	15.39 ± 0.70	90.04 ± 0.93	90.00 ± 0.35	0.4993 ± 0.0051
2	1	2	24.78 ± 0.36	16.77 ± 0.91	39.67 ± 0.39	16.52 ± 0.87	89.16 ± 0.92	89.18 ± 0.39	0.5035 ± 0.0052
3	1	2	24.43 ± 0.36	16.39 ± 0.68	32.42 ± 0.31	16.21 ± 0.65	90.24 ± 0.94	109.74 ± 0.31	0.4977 ± 0.0053
4	1	2	24.71 ± 0.33	16.39 ± 0.79	30.86 ± 0.34	16.27 ± 0.74	109.87 ± 1.27	109.25 ± 0.34	0.6147 ± 0.0044
1	2	2	29.75 ± 0.46	21.98 ± 0.82	49.69 ± 0.45	21.94 ± 0.79	152.32 ± 1.84	152.35 ± 0.45	0.8525 ± 0.0026
2	2	2	29.95 ± 0.50	22.74 ± 0.92	45.04 ± 0.54	22.54 ± 0.90	151.86 ± 1.85	150.83 ± 0.54	0.8519 ± 0.0023
3	2	2	31.29 ± 0.50	22.59 ± 0.83	39.27 ± 0.51	22.47 ± 0.82	171.29 ± 2.36	170.87 ± 0.51	0.9516 ± 0.0019
4	2	2	31.35 ± 0.47	22.16 ± 0.73	37.25 ± 0.41	22.01 ± 0.71	170.99 ± 2.17	171.85 ± 0.41	0.9513 ± 0.0018

Table 19 Nuclear Medicine Performance Measure Summary Statistics

Treatment			Nuclear Medicine Patient Cycle Time	Standard deviation of Nuclear Medicine Patient Cycle Time	Nuclear Medicine Information Cycle Time	Standard deviation of Nuclear Medicine Information Cycle Time	Nuclear Medicine Patient Throughput	Nuclear Medicine Report Throughput	Nuclear Medicine Machine Utilization
A	B	C							
1	1	1	102.28 ± 0.88	22.48 ± 1.30	120.23 ± 0.90	22.63 ± 1.30	27.43 ± 0.24	27.37 ± 0.90	0.8988 ± 0.0009
2	1	1	101.55 ± 0.92	22.07 ± 1.17	115.25 ± 0.86	22.10 ± 1.16	27.62 ± 0.23	27.48 ± 0.86	0.8980 ± 0.0009
3	1	1	101.20 ± 0.68	22.25 ± 1.24	107.08 ± 0.81	22.28 ± 1.24	29.44 ± 0.21	29.37 ± 0.81	0.9565 ± 0.0003
4	1	1	101.20 ± 0.68	21.66 ± 1.08	105.48 ± 0.72	21.70 ± 1.08	29.44 ± 0.21	29.45 ± 0.72	0.9565 ± 0.0003
1	2	1	188.10 ± 1.61	29.65 ± 1.43	205.78 ± 1.56	29.79 ± 1.43	30.76 ± 0.27	30.90 ± 1.56	1.0000 ± 0.0000
2	2	1	189.48 ± 1.70	30.44 ± 1.35	203.13 ± 1.66	30.42 ± 1.36	30.56 ± 0.26	30.48 ± 1.66	1.0000 ± 0.0000
3	2	1	192.66 ± 1.44	30.18 ± 1.33	202.25 ± 1.59	30.28 ± 1.33	31.02 ± 0.25	30.51 ± 1.59	1.0000 ± 0.0000
4	2	1	190.03 ± 1.92	30.56 ± 1.71	198.53 ± 1.66	30.64 ± 1.70	30.66 ± 0.25	30.87 ± 1.66	1.0000 ± 0.0000
1	1	2	102.03 ± 0.73	22.00 ± 1.06	119.88 ± 0.71	22.14 ± 1.06	27.44 ± 0.21	27.52 ± 0.71	0.8988 ± 0.0009
2	1	2	102.24 ± 0.84	21.70 ± 1.07	114.76 ± 0.73	21.70 ± 1.07	27.37 ± 0.22	27.61 ± 0.73	0.8990 ± 0.0008
3	1	2	102.41 ± 0.83	22.12 ± 1.07	107.37 ± 0.76	22.13 ± 1.07	27.37 ± 0.22	29.31 ± 0.76	0.8993 ± 0.0009
4	1	2	102.22 ± 0.84	23.05 ± 1.19	106.48 ± 0.87	23.10 ± 1.19	29.23 ± 0.25	29.18 ± 0.87	0.9570 ± 0.0004
1	2	2	188.97 ± 1.68	30.71 ± 1.41	208.01 ± 1.69	30.77 ± 1.41	30.60 ± 0.27	30.64 ± 1.69	1.0000 ± 0.0000
2	2	2	188.96 ± 1.60	31.05 ± 1.55	203.28 ± 1.66	31.10 ± 1.55	30.62 ± 0.26	30.51 ± 1.66	1.0000 ± 0.0000
3	2	2	194.67 ± 1.51	29.96 ± 1.50	200.15 ± 1.58	29.99 ± 1.51	30.78 ± 0.25	30.80 ± 1.58	1.0000 ± 0.0000
4	2	2	195.90 ± 1.96	30.51 ± 1.71	200.32 ± 1.53	30.61 ± 1.71	30.63 ± 0.25	30.50 ± 1.53	1.0000 ± 0.0000

Analysis of Variance and Tukey Comparison tests was done on the overall (or system) performance measures (shown in the tables that follow) and for each modality (see Appendix A). The ANOVA test showed that all the factors and interaction of these factors for overall patient cycle time are significant (Table 20). The Tukey comparison test in Table 21 shows that treatment combination 412 is the best with regards to patient cycle time, combination 321 being the worst.

Table 20 Analysis Of Variance for Overall Patient Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	1121.00	1121.00	373.70	560.83	0.00
B	1	52769.20	52769.20	52769.20	79204.00	0.00
C	1	747.90	747.90	747.90	1122.57	0.00
A*B	3	1053.70	1053.70	351.20	527.17	0.00
A*C	3	145.90	145.90	48.60	73.01	0.00
B*C	1	228.10	228.10	228.10	342.43	0.00
A*B*C	3	480.60	480.60	160.20	240.47	0.00
Error	1584	1055.30	1055.30	0.70		
Total	1599	57601.80				

Table 21 Tukey Comparison of Overall Patient Cycle Time

A	B	C	Average
4	1	2	29.12
3	1	2	29.72
1	1	2	30.02
2	1	2	30.07
2	1	1	30.08
1	1	1	30.09
4	1	1	30.59
3	1	1	30.62
1	2	2	38.45
2	2	2	38.52
1	2	1	41.42
4	2	1	41.64
2	2	1	41.76
4	2	2	42.39
3	2	2	42.49
3	2	1	45.52

Table 22 Analysis Of Variance for Standard Deviation of Overall Patient Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	95.00	95.00	31.70	21.47	0.00
B	1.00	95356.80	95356.80	95356.80	64650.55	0.00
C	1.00	354.10	354.10	354.10	240.08	0.00
A*B	3.00	109.90	109.90	36.60	24.83	0.00
A*C	3.00	22.20	22.20	7.40	5.01	0.00
B*C	1.00	179.20	179.20	179.20	121.50	0.00
A*B*C	3.00	2.90	2.90	1.00	0.65	0.59
Error	1584.00	2336.30	2336.30	1.50		
Total	1599.00	98456.30				

Table 23 Tukey Comparison of Standard Deviation of Overall Patient Cycle Time

A	B	C	Average
3	1	2	20.38
4	1	2	20.47
3	1	1	20.93
4	1	1	20.97
1	1	2	21.65
2	1	1	21.66
2	1	2	21.70
1	1	1	21.71
3	2	2	35.68
1	2	2	35.73
4	2	2	35.82
2	2	2	36.04
1	2	1	37.23
4	2	1	37.37
2	2	1	37.42
3	2	1	37.69

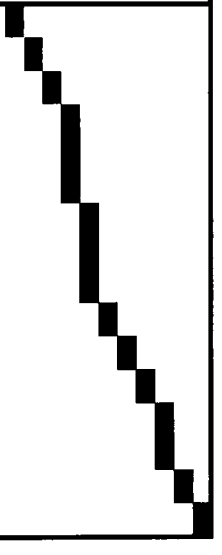
The single factor effect and the two factor effect are all significant for the overall standard deviation on patient cycle time, but the three way interaction of workflow (A), Technicians (B) and nurses (C) is not significant at the 95% confidence level (Table 22). The Tukey test shows that combinations 312, 412 ad 311 is the best alternative for this performance measure.

Table 24 Analysis Of Variance for Overall Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	22063.2	22063.2	7354.4	13172.2	0.00
B	1	60639.6	60639.6	60639.6	108609.0	0.00
C	1	1519.5	1519.5	1519.5	2721.5	0.00
A*B	3	2965.7	2965.7	988.6	1770.6	0.00
A*C	3	1956.3	1956.3	652.1	1167.9	0.00
B*C	1	3248.2	3248.2	3248.2	5817.8	0.00
A*B*C	3	588.2	588.2	196.1	351.1	0.00
Error	1584	884.4	884.4	0.6		
Total	1599	93865.1				

Table 25 Tukey Comparison of Overall Information Cycle Time

A	B	C	Average Time
4	1	2	28.16
4	1	1	30.11
3	1	1	32.09
3	1	2	37.77
2	1	2	38.03
2	1	1	38.11
4	2	2	41.93
1	1	2	42.20
1	1	1	42.25
3	2	2	43.96
2	2	2	46.70
3	2	1	47.59
4	2	1	50.39
2	2	1	50.46
1	2	2	51.41
1	2	1	54.76



ANOVA results for Information cycle time (Table 24) shows that all factors and their interaction affect the cycle time significantly and for the Tukey test treatment 412 comes out as being best.

Table 26 Analysis Of Variance for Standard Deviation of Overall Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	252.70	252.70	84.20	57.18	0.00
B	1	88990.40	88990.40	88990.40	60413.15	0.00
C	1	104.40	104.40	104.40	70.90	0.00
A*B	3	131.40	131.40	43.80	29.74	0.00
A*C	3	8.70	8.70	2.90	1.97	0.12
B*C	1	99.00	99.00	99.00	67.21	0.00
A*B*C	3	5.40	5.40	1.80	1.23	0.30
Error	1584	2333.30	2333.30	1.50		
Total	1599	91925.40				

Table 27 Tukey Comparison of Standard Deviation of Overall Information Cycle Time

A	B	C	Average
3	1	2	21.34
3	1	1	21.40
4	1	1	21.44
4	1	2	21.45
2	1	1	22.71
1	1	2	22.76
2	1	2	22.78
1	1	1	22.83
3	2	2	36.22
4	2	2	36.36
1	2	2	36.65
2	2	2	36.77
4	2	1	37.33
1	2	1	37.49
2	2	1	37.56
3	2	1	37.66

For the standard deviation of information cycle time the ANOVA results (Table 26) shows that all the single effects and interactions are significant with the exception of the A*C

and the A*B*C interaction. The Tukey tests reveal the top combinations for this performance measure is 312,311,411 and 412.

Table 28 Analysis Of Variance for Overall Patient Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	967740.00	967740.00	322580.00	1877.84	0.00
B	1	13386086.00	13386086.00	13386086.00	77924.73	0.00
C	1	1234432.00	1234432.00	1234432.00	7186.03	0.00
A*B	3	801920.00	801920.00	267307.00	1556.08	0.00
A*C	3	1122451.00	1122451.00	374150.00	2178.05	0.00
B*C	1	101124.00	101124.00	101124.00	588.68	0.00
A*B*C	3	1217378.00	1217378.00	405793.00	2362.25	0.00
Error	1584	272103.00	272103.00	172.00		
Total	1599	19103233.00				

Table 29 Tukey Comparison of Overall Patient Throughput

A	B	C	Average
4	2	2	772.37
3	2	2	770.59
1	2	2	739.30
2	2	2	738.16
3	2	1	704.05
1	2	1	679.45
4	2	1	676.30
1	1	2	676.30
2	2	1	674.81
4	1	2	603.73
3	1	1	564.15
4	1	1	562.67
3	1	2	474.61
2	1	2	470.44
1	1	1	470.02
2	1	1	469.63

All the single effects and interaction effects of the factor for patient throughput is significant. The Tukey test shows that treatment combinations 422 and 322 give the best output for patients. In comparing the results of patient throughput to patient cycle time, we see that there

is a tradeoff between throughput and cycle time. The best output for cycle time was as a result of using workflow number four, with 1 technologist and 2 nurses (treatment combination 412), by adding another technician the throughput increases but the cycle time decrease due to the fact that there is and increased work in progress with one machine. So in order to get increased throughput it comes at a cost both time and money (due to increased resources).

Table 30 Analysis Of Variance for Overall Report Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	2027295.00	2027295.00	675765.00	3757.28	0.00
B	1	15270315.00	15270315.00	15270315.00	84903.48	0.00
C	1	749134.00	749134.00	749134.00	4165.21	0.00
A*B	3	656382.00	656382.00	218794.00	1216.50	0.00
A*C	3	47436.00	47436.00	15812.00	87.92	0.00
B*C	1	175875.00	175875.00	175875.00	977.87	0.00
A*B*C	3	42662.00	42662.00	14221.00	79.07	0.00
Error	1584	284890.00	284890.00	180.00		
Total	1599	19253990.00				

Table 31 Tukey Comparison of Overall Report Throughput

A	B	C	Average
3	2	2	769.81
4	2	2	768.85
1	2	2	739.49
2	2	2	736.59
4	2	1	705.67
3	2	1	703.29
2	2	1	676.22
1	2	1	672.58
4	1	2	603.91
3	1	2	603.50
3	1	1	560.70
4	1	1	559.99
1	1	2	471.13
2	1	2	470.78
1	1	1	470.08
2	1	1	469.32

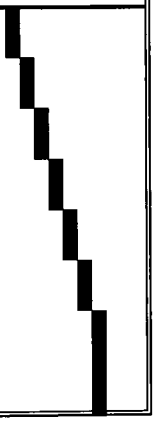
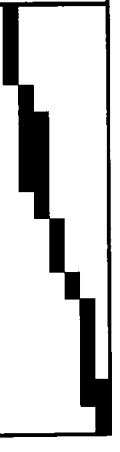


Table 32 Analysis Of Variance for Overall Machine Utilization

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.0	1.91	1.91	0.64	29467.67	0.00
B	1.0	25.35	25.35	25.35	1172640.12	0.00
C	1.0	0.10	0.10	0.10	4637.69	0.00
A*B	3.0	1.15	1.15	0.38	17759.47	0.00
A*C	3.0	0.48	0.48	0.16	7432.78	0.00
B*C	1.0	0.21	0.21	0.21	9934.04	0.00
A*B*C	3.0	0.38	0.38	0.13	5858.18	0.00
Error	1584.0	0.03	0.03	0.00		
Total	1599.0	29.62				

Table 33 Tukey Comparison of Overall Machine Utilization

A	B	C	Average
3	2	1	0.9904
3	2	2	0.9903
4	2	2	0.9903
2	2	1	0.9608
1	2	2	0.9605
4	2	1	0.9604
1	2	1	0.9603
2	2	2	0.9601
4	1	1	0.8139
3	1	1	0.8128
4	1	2	0.8092
1	1	1	0.6656
2	1	2	0.6654
2	1	1	0.6654
1	1	2	0.6646
3	1	2	0.6624



The comparison for the machine utilization follows that of the throughput performance measure. The greater the patient throughput the greater the machine utilization.

The ANOVA tables and the Tukey comparison tests for the performance measures, standard deviation on patient cycle time, information cycle time, standard deviation on

information cycle time, patient throughput, report throughput and machine utilization for each modality is detailed in Appendix A. For each modality the configuration is ranked either in category 1 (the best alternative) or category 2 (the second best alternatives) based on the individual Tukey tables. A summary of the Tukey test across modalities is shown in the Table 34.

Table 34 Tukey Comparison Results Ranking

Performance Measure	Overall		Radiology		Ultrasound	
	1	2	1	2	1	2
Patient Cycle Time	412	312/112/ 212/211/ 111	211	311/411	312/311/ 411/	111/211/ 412/112/ 212
Standard deviation of Patient Cycle Time	312/412/ 311	312/412/ 311/411	311	412/211/ 111/112/ 312/212/ 411	312/212/ 111/211/ 311/411/ 412/112	322/222/ 321/121/ 122/221/ 422/421
Information Cycle Time	412	411	412/411	311/312	411/412	312/311
Standard deviation of Information Cycle Time	312/311/ 411/412	211/112/ 212/111	311/412/ 211/111/ 112/312/ 212/411	322/221/ 222/321/ 421/122/ 121/422	312/212/ 311/111/ 411/211/ 412/112	222/322/ 321/422/ 421/221/ 121/122
Patient Throughput	422/322	122/222	422/321/ 322	121/222/ 221/122/ 421	121/421	322/422/ 222/122/ 321/221
Report Throughput	322/422	122/222	322/321/ 421/422	221/222/ 122/121	322/321/ 221/222/ 122/421/ 121/422	312/411/ 412/311
Machine Utilization	321/322/ 422	221/122/ 421/121	321/322/ 422	421/122/ 221/222/ 121	121/221/ 321/421/ 122/322/ 222/422	412

Table 34 (cont'd) Tukey Comparison Results Ranking continued

Performance Measure	Computed Tomography		Mammography		Nuclear Medicine	
	1	2	1	2	1	2
Patient Cycle Time	312/412/ 212/112/ 111/211	412/212/ 112/111/ 211/411	312/112/ 211/412/ 212/111/ 311/411	122/121/ 221/421/ 322/422/ 321	311/411/ 211/112/ 412/212/ 111/312	121/222/ 122/221/ 421
Standard deviation of Patient Cycle Time	111/411/ 212/412/ 311/211/ 221/312/ 112	122/421/ 422/222/ 321/121/ 322	112/211/ 411/111/ 412/312/ 311/212	221/122/ 422/121/ 421/322/ 222/321	411/212/ 112/211/ 312/311/ 111/412	121/322/ 321/221/ 422/421/ 122/222
Information Cycle Time	412	312	411/412	312/311	411/412/ 311/312	212/211
Standard deviation of Information Cycle Time	111/411/ 212/412/ 311/312/ 211/112	421/122/ 422/222/ 321/121/ 221/322	112/211/ 411/111/ 311/312/ 412/212	221/122/ 422/121/ 421/322/ 222/321	411/212/ 211/312/ 112/311/ 111/412	121/322/ 321/221/ 422/421/ 122/222
Patient Throughput	322/122/ 422/222	412	322/422/ 321	121/122/ 221/222/ 421	321/322/ 121/421/ 422/222/ 122/221	311/411/ 412
Report Throughput	422/122/ 222/322	412/312	422/322/ 421/321	221/122/ 121/222	121/421/ 322/122/ 321/222/ 422/221	411/311/ 312/412
Machine Utilization	121/221/ 321/421/ 322/422/ 122/222	311/411	321/322/ 422	221/121/ 122/222/ 421	121/221/ 321/421/ 122/222/ 322/422	412/311/ 411

The above summary chart shows that across modalities one technologist (Factor B) and two nurses results in the best cycle time (Factor C). On the other hand, having two technologists (Factor B) and two nurses (Factor C) results in very high throughput for both patient and information and a high utilization of machines. A trade-off exists between cycle time and throughput, a configuration that results in a high throughput results in a longer cycle time due to the increased work in progress. For example in configuration 412 Patient Cycle Time is 29.12 minutes and Patient Throughput 603.73 (See Table 14). For configuration 422 Patient Cycle

Time is 42.39 minutes (which is 46% greater than that of configuration 412) and Patient Throughput 772.37 patients per week (which is 28% greater than that of configuration 412).

Choosing the best alternative depend on if low cycle time is the aim or high throughput. One could argue that 422 would be a better alternative but the decision would have to be made from an economic standpoint regarding hiring an extra technologist versus having on average 162 patients more patients leaving per week (a 28% increase in throughput). Also with a high throughput and increased patient cycle time patient care and customer satisfaction will be compromised.

On the basis of patient care, workflow 4 (i.e. No printing of images, digital reading by radiologist and automatic transcription using software) with one technologist per machine and 2 nurses per modality is the best digital alternative. This is so as patients will be most happy if they can get individual attention and can get out of the system as quickly as possible.

5.2 Experiment 2

A comparison of the outputs film versus digital system subject to different modality configuration at different patient throughput levels was analyzed to determine if would make sense operationally for a facility with these configurations choose to employ digital or to stay with their current film based system.

Film versus digital is compared by varying the number of modalities and the patient load, which resulted in eight single factor experiments. The results of the overall system performance measures for these experiments is summarized in Table 35. Summaries of the performance measures for individual modalities are shown in Appendix B.

Table 35 Overall Summary of Performance Measures for Experiment 2

	Two modalities with low throughput		Two modalities with high throughput		Five modalities with low throughput		Five modalities with high throughput	
Performance Measure	Film	Digital	Film	Digital	Film	Digital	Film	Digital
Patient Cycle Time	39.90 ± 1.09	31.80 ± 0.66	160.00 ± 13.60	55.60 ± 2.63	54.60 ± 1.47	44.00 ± 0.91	246.00 ± 10.30	30.80 ± 0.15
Standard deviation of Patient Cycle Time	22.80 ± 1.30	16.10 ± 1.00	99.20 ± 8.99	40.70 ± 3.35	47.10 ± 2.82	40.90 ± 2.64	212.00 ± 10.60	22.10 ± 0.28
Information Cycle Time	60.30 ± 1.08	34.40 ± 0.66	180.00 ± 13.50	58.20 ± 2.62	74.10 ± 1.48	46.30 ± 0.93	265.00 ± 10.30	30.10 ± 0.16
Standard Deviation of Information Cycle Time	22.20 ± 1.31	15.70 ± 1.00	98.70 ± 6.97	40.50 ± 3.35	48.20 ± 2.82	42.20 ± 2.65	211.00 ± 10.50	23.20 ± 0.28
Machine Utilization	0.29 ± 0.01	0.56 ± 0.01	1.10 ± 0.01	1.12 ± 0.02	0.33 ± 0.01	0.33 ± 0.01	0.59 ± 0.00	0.63 ± 0.01
Technician Utilization	0.48 ± 0.01	0.71 ± 0.02	1.85 ± 0.02	1.41 ± 0.02	0.51 ± 0.01	0.40 ± 0.01	0.93 ± 0.01	0.77 ± 0.01
Patient WIP	1.35 ± 0.06	1.06 ± 0.04	11.10 ± 1.08	3.72 ± 0.24	4.00 ± 0.14	3.23 ± 0.09	38.70 ± 1.88	18.80 ± 1.17
Report WIP	1.88 ± 0.06	1.06 ± 0.04	12.10 ± 1.09	3.70 ± 0.24	5.17 ± 0.15	3.19 ± 0.09	40.90 ± 1.88	18.70 ± 1.17

In the following tables 36 and 37 shows the results of the mean comparisons for film versus digital at the low and high level with two and five modalities systems based on the overall performance measures to see if there is a difference or not at the 5% level between these means.

Table 36 Comparison of Means for Overall Performance Measures with two Modalities and a Patient Throughput of 100

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	8.2	6.1	1.2	32.2	56.8	100	
				26.6	45.8	100	No
Std Deviation of Patient Cycle Time	6.7	8.0	1.6	13.5	44.5	100	
				8.2	39.8	100	No
Report Cycle Time	25.9	6.1	1.2	53.0	77.2	100	
				29.4	48.3	100	No
Std Deviation of Report Cycle Time	6.5	8.1	1.6	12.8	43.4	100	
				8.4	39.5	100	No
Patient WIP	0.3	0.3	0.1	0.8	2.2	100	
				0.8	1.7	100	No
Report WIP	0.8	0.4	0.1	1.3	2.8	100	
				0.75	1.67	100	No
Machine Utilization	-0.3	0.1	0.0	0.2	0.4	100	
				0.4	0.7	100	No
Technologist Utilization	-0.2	0.1	0.0	0.4	0.6	100	
				0.6	0.9	100	No
Patient Throughput	1.1	13.9	2.8	78.0	124.0	100	
				75.0	126.0	100	Yes
Reports Throughput	1.2	14.0	2.8	77.0	123.0	100	
				75.0	126.0	100	Yes

Table 37 Comparison of Means for Overall Performance Measures with two Modalities and a Patient Throughput of 200

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	105.0	66.9	13.7	69.7	415.0	100	
				33.9	122.0	100	No
Std Deviation of Patient Cycle Time	58.6	46.0	9.1	41.4	252.0	100	
				15.4	139.0	100	No
Report Cycle Time	122.0	66.5	13.6	90.6	435.0	100	
				36.6	124.0	100	No
Std Deviation of Report Cycle Time	56.2	46.0	9.1	40.7	254.0	100	
				15.0	136.0	100	No
Patient WIP	7.4	5.5	1.1	3.9	33.0	100	
				1.6	10.3	100	No
Report WIP	6.4	5.5	1.1	4.6	34.1	100	
				1.62	10.3	100	No
Machine Utilization	0.0	0.1	0.0	0.9	1.2	100	
				0.9	1.3	100	Yes
Technologist Utilization	0.4	0.1	0.0	1.5	2.0	100	
				1.1	1.7	100	No
Patient Throughput	-3.6	16.9	3.4	167.0	213.0	100	
				162.0	231.0	100	No
Reports Throughput	-3.6	16.9	3.4	166.0	212.0	100	
				162.0	231.0	100	No

In Table 36 the results from comparing film versus digital with two modalities at the throughput level of 100 patients is summarized. We see from the table that eight of the ten performance measures analyzed showed a difference between means of film and digital systems. The difference in the two systems was found in the performance measures, patient cycle time, report cycle time, standard deviation of patient cycle time, standard deviation of report cycle time, patient and report work in progress and, machine and technologist utilization. In table 37 the results from comparing film versus digital with two modalities having 200 patients is summarized. We see that of the 10 performance measures, 9 showed a difference in means. Also the means difference is higher for the two modality system with a high patient load. For example the performance measure of patient cycle time saw a mean difference of 8.2 minutes between film and digital system with a low patient load of 100 but saw a mean difference of 105.0 minutes with the higher patient load of 200.

From the two-modality systems summarized in table 36 and 37, we see that for a two-modality system it would be beneficial from an operational perspective to employ digital technology if there is a high patient load.

Table 38 and 39 shows the comparison of film versus digital at low and high patient load respectively.

Table 38 Comparison of Means for Overall Performance Measures with Five Modalities and a Patient Throughput Of 220

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	10.5	8.8	1.7	42.3	89.8	100	
				36.1	82.3	100	No
Patient Time in System	8.2	20.0	4.0	25.6	101.0	100	
				20.5	92.5	100	No
Report Cycle Time	27.8	8.8	1.8	81.8	110.0	100	
				38.6	85.2	100	Yes
Std Deviation of Report Cycle Time	8.0	20.0	4.0	28.8	103.0	100	
				21.8	93.8	100	No
Patient WIP	0.8	0.8	0.2	2.7	8.9	100	
				2.5	5.3	100	No
Report WIP	2.0	0.9	0.2	3.8	8.1	100	
				2.39	5.27	100	No
Machine Utilization	0.0	0.0	0.0	0.3	0.4	100	
				0.3	0.4	100	Yes
Technologist Utilization	0.1	0.1	0.0	0.4	0.6	100	
				0.3	0.5	100	No
Patient Throughput	0.0	20.5	4.1	184.0	287.0	100	
				185.0	279.0	100	Yes
Reports Throughput	0.0	20.4	4.1	185.0	286.0	100	
				185.0	278.0	100	Yes

Table 39 Comparison of Means for Overall Performance Measures with Five Modalities and a Patient Throughput Of 440

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	215.0	52.2	10.4	139.0	383.0	100	
				28.9	32.9	100	No
Std Deviation of Patient Cycle Time	190.0	53.3	10.6	99.9	344.0	100	
				18.1	25.6	100	No
Report Cycle Time	234.0	52.1	10.3	159.0	402.0	100	
				27.6	32.2	100	No
Std Deviation of Report Cycle Time	188.0	53.1	10.5	99.1	340.0	100	
				19.0	26.6	100	No
Patient WIP	19.9	11.1	2.2	22.0	65.2	100	
				8.1	35.3	100	No
Report WIP	22.1	11.1	2.2	24.1	67.4	100	
				7.97	35.2	100	No
Machine Utilization	-0.0466 0	0.0	0.0	0.5	0.6	100	
				0.6	0.7	100	No
Technologist Utilization	0.153 0	0.0	0.0	0.9	1.0	100	
				0.7	0.8	100	No
Patient Throughput	-28.3	21.8	4.3	374.0	438.0	100	
				372.0	481.0	100	No
Reports Throughput	-28.5	21.9	4.3	372.0	440.0	100	
				371.0	481.0	100	No

The comparisons shows that the high patient load system has great different between film and digital system. For example for the performance measure patient cycle time there is a mean difference if 10.5 minutes for the low level and a mean difference of 215.0 minutes for the high level. Similar comparisons between performance measures show that digital has greater benefits for the high modality system in both the two and five modality facilities.

In comparing 2 and 5 modality system at the high level it can be seen that the differences in means is greater for the five-modality configuration than the one with two modalities. Therefore, a five-modality system would have greater benefits or have greater economies of scale to go to a digital system than a 2-modality system.

5.3 Experiment 3 - Case Study

The summary of the overall system performance for the current and future systems at F.F. Thompson Hospital is shown in Tables 40 and 41.

Table 40 Output Summary of Current F.F. Thompson Hospital Operations/ Week

Performance Measure	Total	Radiology	Ultrasound	Computed Tomography	Mamography	Nuclear Medicine
Patient Cycle Time	43.100 ± 1.60	21.900 ± 0.112	31.500 ± 0.123	45.300 ± 1.870	30.800 ± 0.649	400.000 ± 36.800
Standard deviation of Patient Cycle Time	81.700 ± 7.62	9.850 ± 0.288	6.270 ± 0.217	24.900 ± 2.330	18.600 ± 0.913	172.000 ± 15.600
Information Cycle Time	61.300 ± 1.59	41.900 ± 0.190	47.800 ± 0.208	51.600 ± 1.900	56.200 ± 0.699	421.000 ± 36.500
Standard Deviation of Information Cycle Time	81.800 ± 7.54	10.300 ± 0.296	7.410 ± 0.272	25.600 ± 2.300	19.400 ± 0.874	172.000 ± 15.500
Machine Utilization	0.921 ± 0.008	0.389 ± 0.005	0.287 ± 0.005	0.603 ± 0.013	0.328 ± 0.008	0.929 ± 0.017
Technician Utilization	1.650 ± 0.018	0.343 ± 0.004	0.268 ± 0.005	0.373 ± 0.015	0.373 ± 0.008	0.729 ± 0.022
Patient WIP	11.300 ± 0.58	2.600 ± 0.033	1.200 ± 0.021	1.750 ± 0.090	1.190 ± 0.036	4.580 ± 0.555
Report WIP	15.500 ± 0.59	4.850 ± 0.065	1.770 ± 0.033	1.930 ± 0.093	2.120 ± 0.050	4.790 ± 0.557

Table 41 Summary of Future F.F. Thompson Hospital Operations/Week

Performance Measure	Total	Radiology	Ultrasound	Computed Tomography	Mamography	Nuclear Medicine
Patient Cycle Time	31.800 ± 0.35	21.400 ± 0.095	30.600 ± 0.106	43.900 ± 1.610	29.800 ± 0.484	121.000 ± 2.970
Standard deviation of Patient Cycle Time	26.300 ± 0.899	9.780 ± 0.271	5.510 ± 0.206	23.700 ± 1.920	18.600 ± 0.682	38.200 ± 2.960
Information Cycle Time	35.000 ± 0.35	24.500 ± 0.085	33.700 ± 0.103	39.900 ± 1.610	39.200 ± 0.481	128.000 ± 2.970
Standard Deviation of Information Cycle Time	26.400 ± 0.90	8.850 ± 0.235	5.000 ± 0.165	23.700 ± 1.920	18.500 ± 0.653	38.300 ± 2.950
Machine Utilization	0.941 ± 0.01	0.314 ± 0.004	0.213 ± 0.004	0.601 ± 0.012	0.337 ± 0.007	0.504 ± 0.020
Technician Utilization	1.320 ± 0.017	0.252 ± 0.003	0.194 ± 0.004	0.369 ± 0.014	0.318 ± 0.006	0.349 ± 0.017
Patient WIP	8.000 ± 0.12	2.840 ± 0.029	1.180 ± 0.024	1.720 ± 0.075	1.190 ± 0.027	1.270 ± 0.074
Report WIP	7.980 ± 0.12	2.620 ± 0.028	1.180 ± 0.024	1.440 ± 0.072	1.430 ± 0.030	1.310 ± 0.076

A comparison of the means at the 5% level between current and future systems is shown below in table 42, which shows that for all the overall systems performance measures there is a significant difference between film and digital. Means comparisons per modality is detailed in Appendix C and shows a similar trend. Further computations on experiment 3 are shown in Table 43, which shows the percentage improvement in the future all digital system.

Table 42 Overall Performance Measure Comparison of Means Current vs. Future System at F.F. Thompson Hospital

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	11.3	8.0	1.6	30.3	72.6	100	
				28.9	37.4	100	No
Std Deviation of Patient Cycle Time	55.4	37.9	7.5	24.0	217.0	100	
				18.8	39.6	100	No
Report Cycle Time	26.3	7.9	1.6	47.8	89.6	100	
				32.0	40.4	100	No
Std Deviation of Report Cycle Time	55.4	37.4	7.4	24.8	210.0	100	
				18.8	39.8	100	No
Patient WIP	3.3	2.8	0.6	7.1	21.9	100	
				6.7	9.5	100	No
Report WIP	7.5	2.9	0.6	10.8	26.3	100	
				6.7	9.5	100	No
Machine Utilization	0.0	0.1	0.0	0.8	1.1	100	
				0.8	1.1	100	No
Technologist Utilization	0.3	0.1	0.0	1.4	1.9	100	
				1.1	1.5	100	No

Table 43 Percent Improvements for Overall System Performance Measures Current vs. Future

Performance Measure	Current			Future			Percent Improvement
Patient Cycle Time	43.100	±	1.600	31.800	±	0.348	26.2%
Standard deviation of Patient Cycle Time	81.700	±	7.620	26.300	±	0.899	67.8%
Information Cycle Time	61.300	±	1.590	35.000	±	0.348	42.9%
Standard Deviation of Information Cycle Time	81.800	±	7.540	26.400	±	0.900	67.7%
Machine Utilization	0.921	±	0.008	0.941	±	0.010	-2.2%
Technician Utilization	1.650	±	0.018	1.320	±	0.017	20.0%
Patient WIP	11.300	±	0.579	8.000	±	0.120	29.2%
Report WIP	15.500	±	0.592	7.980	±	0.120	48.5%

As can be seen in the Table 43, great gains will be obtained from the future system in all areas studied, but especially in the information cycle time and the report work in progress. This is so as a Picture Archival and Communication System impacts information flow more than the patient flow as can be seen from the flow charts discussed in earlier chapters. Overall information cycle time is reduced by 42.9% and the report work in progress decreases by 48.5%. Overall patient cycle time and patient work in progress shows a decrease of 26.2% and 29.2% respectively. These advantages with proper marketing and resource planning great gains both operational and monetary can be derived.

6. RECOMMENDATIONS AND CONCLUSIONS

This chapter contains the conclusions, recommendations and future work suggested based on the research and the results from this study.

6.1 Conclusions from This Research

The following summarizes the conclusions made from the research and experiments conducted.

From the configurations studied in the first experiment, it can be concluded that in a fully digital system having a workflow number four (which is no prints, digital reading by technologists and using voice recognition software for transcription), with 1 technologist and 2 nurses (treatment combination 412) is the best overall configuration.

The second experiment showed that the greater the number of modalities and the higher the patient volumes the more feasible it is to make a switch to digital and reap added benefits. Also from the second experiment it was also determined that regardless of the number of modalities if a facility has patient volumes near maximum capacity, then it would be operationally feasible to switch a digital system.

The third experiment looked at the current operations at F.F. Thompson Hospital, a five-modality system operating under high volumes, and also the future digital system that is planned. This third experiment validated the second experiment, where it is operationally beneficial for a five-modality system operating under high volumes to employ digital technology. Also from the results from the third experiment it can be deduced that by employing digital technology into the future system at F.F. Thompson Hospital greatly improves report work-in-progress and cycle time. Which is very important for a diagnostic imaging facility as this is how they get reimbursed for services rendered.

6.2 Recommendations for F.F. Thompson Hospital

- Eliminate need for transcription by employing voice recognition software being aware that installation of PACS can produce shifts in work from one group of personnel to another instead of from personnel to PACS (Horii, 1999).
- Inform workers of the changes that will occur in the total information and process flow, and how they are affected by the changes.
- Get Physician buy-in – marketing strategies so that they can increase patient loads and make the most of time saved with digital technology.
- Reducing movement of people that does not add value i.e. searching for patients.
- Find the balance between patient output and radiologists for reading so that information can be available in less than 24 hours.

6.3 Future Research

One area of future research on this topic is looking at scheduling issues such as batching or grouping similar studies and their effect on film and digital systems (Pennisi, 2002). Another way to expand on this topic is also to quantify monetarily the cost differences between film and digital based systems, and the gains achieved from the operational improvement of digital technology. And still a further area of expanding the research is looking at the formulation of strategies to minimize the transition period when a facility switches from film to digital.

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APPENDIX A

The following contains Analysis of Variance Tables and Tukey Comparison tests for performance measures from experiment 1. Factor A represents workflow, Factor B represents the number of technologists and Factor C represents the number of nurses (see Section 4.7.2 for more information).

Table A.1.a Analysis of Variance for overall patient cycle time

A	B	C	Average
3	1	2	20.38
4	1	2	20.47
3	1	1	20.93
4	1	1	20.97
1	1	2	21.65
2	1	1	21.66
2	1	2	21.70
1	1	1	21.71
3	2	2	35.68
1	2	2	35.73
4	2	2	35.82
2	2	2	36.04
1	2	1	37.23
4	2	1	37.37
2	2	1	37.42
3	2	1	37.69

Table A.1.b Tukey comparison of overall patient cycle time

A	B	C	Average
4	1	2	29.12
3	1	2	29.72
1	1	2	30.02
2	1	2	30.07
2	1	1	30.08
1	1	1	30.09
4	1	1	30.59
3	1	1	30.62
1	2	2	38.45
2	2	2	38.52
1	2	1	41.42
4	2	1	41.64
2	2	1	41.76
4	2	2	42.39
3	2	2	42.49
3	2	1	45.52

Table A.2.a – Analysis of Variance for standard deviation of overall patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	95.00	95.00	31.70	21.47	0.00
B	1.00	95356.80	95356.80	95358.80	64650.55	0.00
C	1.00	354.10	354.10	354.10	240.08	0.00
A*B	3.00	109.90	109.90	36.60	24.83	0.00
A*C	3.00	22.20	22.20	7.40	5.01	0.00
B*C	1.00	179.20	179.20	179.20	121.50	0.00
A*B*C	3.00	2.90	2.90	1.00	0.65	0.59
Error	1584.00	2336.30	2336.30	1.50		
Total	1599.00	98456.30				

Table A.2.b – Tukey comparison of standard deviation of overall patient cycle time

Table A.3.a Analysis of Variance for Radiology patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	1936.90	1936.90	645.60	597.57	0.00
B	1.00	10470.80	10470.80	10470.80	9691.45	0.00
C	1.00	183.10	183.10	183.10	169.52	0.00
A*B	3.00	1949.50	1949.50	649.80	601.47	0.00
A*C	3.00	420.80	420.80	140.30	129.83	0.00
B*C	1.00	144.80	144.80	144.80	134.06	0.00
A*B*C	3.00	401.20	401.20	133.70	123.77	0.00
Error	1584.00	1711.40	1711.40	1.10		
Total	1599.00	17218.50				

Table A.3.b Tukey comparison of Radiology patient cycle time

A	B	C	Average
2	1	1	20.55
3	1	1	20.63
4	1	1	20.63
3	1	2	20.63
1	1	2	20.65
1	1	1	20.66
2	1	2	20.74
4	1	2	20.75
1	2	1	23.73
2	2	1	23.76
2	2	2	23.78
1	2	2	23.88
4	2	1	24.02
4	2	2	28.81
3	2	1	29.03
3	2	2	29.19

Table A.4.a – Analysis of Variance for standard deviation of Radiology patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	31.23	31.23	10.41	1.51	0.21
B	1.00	4257.56	4257.56	4257.56	616.36	0.00
C	1.00	0.12	0.12	0.12	0.02	0.90
A*B	3.00	21.51	21.51	7.17	1.04	0.38
A*C	3.00	13.00	13.00	4.33	0.63	0.60
B*C	1.00	0.73	0.73	0.73	0.11	0.75
A*B*C	3.00	54.60	54.60	18.20	2.63	0.05
Error	1584.00	10941.69	10941.69	6.91		
Total	1599.00	15320.44				

Table A.4.b – Tukey comparison of standard deviation of Radiology patient cycle time

A	B	C	Average
3	1	1	9.47
4	1	2	9.56
2	1	1	9.66
1	1	1	9.66
1	1	2	9.70
3	1	2	9.85
2	1	2	10.14
4	1	1	10.36
3	2	2	12.65
2	2	1	12.79
2	2	2	12.83
3	2	1	13.12
1	2	2	13.15
4	2	1	13.17
1	2	1	13.30
4	2	2	13.50

Table A.5.a Analysis of Variance for Ultrasound patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	505.50	505.50	168.50	343.72	0.00
B	1.00	98701.60	98701.60	98701.60	201333.91	0.00
C	1.00	303.00	303.00	303.00	618.08	0.00
A*B	3.00	1431.10	1431.10	477.00	973.04	0.00
A*C	3.00	556.30	556.30	185.40	378.24	0.00
B*C	1.00	165.30	165.30	165.30	337.12	0.00
A*B*C	3.00	259.20	259.20	86.40	178.21	0.00
Error	1584.00	776.50	776.50	0.50		
Total	1599.00	102698.50				

Table A.5.b Tukey comparison of Ultrasound patient cycle time

A	B	C	Average
3	1	2	29.15
3	1	1	29.24
4	1	1	29.24
1	1	1	30.12
2	1	1	30.14
4	1	2	30.14
1	1	2	30.18
2	1	2	30.18
1	2	1	43.09
4	2	1	43.13
2	2	2	44.66
1	2	2	44.71
2	2	1	44.77
4	2	2	47.83
3	2	2	47.84
3	2	1	48.00

Table A.6.a – Analysis of Variance for standard deviation of Ultrasound patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	5.01	5.01	1.67	1.07	0.36
B	1.00	1247.65	1247.65	1247.65	798.48	0.00
C	1.00	0.03	0.03	0.03	0.02	0.88
A*B	3.00	0.51	0.51	0.17	0.11	0.96
A*C	3.00	4.65	4.65	1.55	0.99	0.40
B*C	1.00	0.86	0.86	0.86	0.55	0.46
A*B*C	3.00	0.99	0.99	0.33	0.21	0.89
Error	1584.00	2475.06	2475.06	1.56		
Total	1599.00	3734.77				

Table A.6.b – Tukey comparison of standard deviation of Ultrasound patient cycle time

A	B	C	Average
3	1	2	5.58
2	1	2	5.60
1	1	1	5.61
2	1	1	5.64
3	1	1	5.70
4	1	1	5.71
4	1	2	5.77
1	1	2	5.87
3	2	2	7.33
2	2	2	7.34
3	2	1	7.40
1	2	1	7.46
1	2	2	7.50
2	2	1	7.52
4	2	2	7.53
4	2	1	7.54

Table A.7.a Analysis of Variance for Computed Tomography patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	5352.20	5352.20	1784.10	1196.30	0.00
B	1.00	99281.00	99281.00	99281.00	66572.65	0.00
C	1.00	21465.70	21465.70	21465.70	14393.81	0.00
A*B	3.00	1265.30	1265.30	421.80	282.83	0.00
A*C	3.00	1700.00	1700.00	566.70	379.97	0.00
B*C	1.00	12782.50	12782.50	12782.50	8571.26	0.00
A*B*C	3.00	1020.60	1020.80	340.20	228.13	0.00
Error	1584.00	2362.20	2362.20	1.50		
Total	1599.00	145229.80				

Table A.7.b Tukey comparison of Computed Tomography patient cycle time

A	B	C	Average
3	1	2	27.38
4	1	2	27.49
2	1	2	27.51
1	1	2	27.65
1	1	1	27.66
2	1	1	27.94
4	1	1	27.99
3	1	1	33.12
1	2	2	34.21
2	2	2	34.47
3	2	2	40.83
4	2	2	40.92
2	2	1	48.87
4	2	1	49.00
1	2	1	49.17
3	2	1	55.30

Table A.8.a – Analysis of Variance for standard deviation of Computed Tomography patient cycle

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	276.62	276.62	92.21	9.97	0.00
B	1.00	4485.23	4485.23	4485.23	484.78	0.00
C	1.00	111.78	111.78	111.78	12.08	0.00
A*B	3.00	236.66	236.66	78.89	8.53	0.00
A*C	3.00	197.11	197.11	65.70	7.10	0.00
B*C	1.00	45.26	45.26	45.26	4.89	0.03
A*B*C	3.00	431.11	431.11	143.70	15.53	0.00
Error	1584.00	14655.33	14655.33	9.25		
Total	1599.00	20439.10				

Table A.8.b – Tukey comparison of standard deviation of Computed Tomography patient cycle time

A	B	C	Average
1	1	1	8.55
4	1	1	8.62
2	1	2	8.78
4	1	2	8.85
3	1	1	9.03
2	1	1	9.07
2	2	1	9.10
3	1	2	9.10
1	1	2	9.32
1	2	2	12.23
4	2	1	12.25
4	2	2	12.44
2	2	2	12.85
3	2	1	12.90
1	2	1	13.09
3	2	2	13.28

Table A.9.a Analysis of Variance for Mammography patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	217.63	217.63	72.54	14.46	0.00
B	1.00	13368.65	13368.65	13368.65	2672.37	0.00
C	1.00	0.03	0.03	0.03	0.01	0.94
A*B	3.00	214.13	214.13	71.38	14.25	0.00
A*C	3.00	68.70	68.70	22.90	4.57	0.00
B*C	1.00	14.68	14.68	14.68	2.93	0.09
A*B*C	3.00	46.16	46.16	16.06	3.21	0.02
Error	1584.00	7935.68	7935.68	5.01		
Total	1599.00	21867.85				

Table A.9.b Tukey comparison of Mammography patient cycle time

A	B	C	Average
3	1	2	24.43
1	1	2	24.51
2	1	1	24.61
4	1	2	24.71
2	1	2	24.78
1	1	1	24.82
3	1	1	24.90
4	1	1	24.90
1	2	2	29.75
1	2	1	29.77
2	2	1	29.89
2	2	2	29.95
4	2	1	30.00
3	2	2	31.29
4	2	2	31.35
3	2	1	31.93

Table A.10.a – Analysis of Variance for standard deviation of Mammography patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	77.50	77.50	25.80	1.58	0.19
B	1.00	15597.00	15597.00	15597.00	953.65	0.00
C	1.00	1.20	1.20	1.20	0.07	0.79
A*B	3.00	22.00	22.00	7.30	0.45	0.72
A*C	3.00	109.90	109.90	36.60	2.24	0.08
B*C	1.00	7.30	7.30	7.30	0.45	0.51
A*B*C	3.00	17.70	17.70	5.90	0.36	0.78
Error	1584.00	25908.60	25908.60	16.40		
Total	1599.00	41739.10				

Table A.10.b – Tukey comparison of standard deviation of Mammography patient cycle time

A	B	C	Average
1	1	2	15.50
2	1	1	16.01
4	1	1	16.11
1	1	1	16.21
4	1	2	16.39
3	1	2	16.39
3	1	1	16.39
2	1	2	16.77
2	2	1	21.91
1	2	2	21.98
4	2	2	22.16
1	2	1	22.47
4	2	1	22.57
3	2	2	22.59
2	2	2	22.74
3	2	1	23.28

Table A.11.a Analysis of Variance for Nuclear Medicine patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	1781.00	1781.00	594.00	13.05	0.00
B	1.00	3182858.00	3182858.00	3182858.00	69986.70	0.00
C	1.00	744.00	744.00	744.00	16.36	0.00
A*B	3.00	2278.00	2278.00	759.00	16.70	0.00
A*C	3.00	712.00	712.00	237.00	5.22	0.00
B*C	1.00	192.00	192.00	192.00	4.23	0.04
A*B*C	3.00	479.00	479.00	160.00	3.51	0.02
Error	1584.00	72037.00	72037.00	45.00		
Total	1599.00	3261082.00				

Table A.11.b Tukey comparison of Nuclear Medicine patient cycle time

A	B	C	Average
3	1	1	101.20
4	1	1	101.20
2	1	1	101.55
1	1	2	102.03
4	1	2	102.22
2	1	2	102.24
1	1	1	102.28
3	1	2	102.41
1	2	1	188.10
2	2	2	188.96
1	2	2	188.97
2	2	1	189.48
4	2	1	190.03
3	2	1	192.66
3	2	2	194.67
4	2	2	195.90

Table A.12.a – Analysis of Variance for standard deviation of Nuclear Medicine patient cycle time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	22.90	22.90	7.60	0.16	0.92
B	1.00	26991.50	26991.50	26991.50	577.36	0.00
C	1.00	20.60	20.60	20.60	0.44	0.51
A*B	3.00	59.40	59.40	19.80	0.42	0.74
A*C	3.00	36.70	36.70	12.20	0.26	0.85
B*C	1.00	6.30	6.30	6.30	0.13	0.71
A*B*C	3.00	128.30	128.30	42.80	0.91	0.43
Error	1584.00	74051.50	74051.50	46.70		
Total	1599.00	101317.20				

Table A.12.b – Tukey comparison of standard deviation of Nuclear Medicine patient cycle time

A	B	C	Average
4	1	1	21.66
2	1	2	21.70
1	1	2	22.00
2	1	1	22.07
3	1	2	22.12
3	1	1	22.25
1	1	1	22.48
4	1	2	23.05
1	2	1	29.65
3	2	2	29.96
3	2	1	30.18
2	2	1	30.44
4	2	2	30.51
4	2	1	30.56
1	2	2	30.71
2	2	2	31.05

Table A.13.a Analysis Of Variance for Overall Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	22063.20	22063.20	7354.40	13172.17	0.00
B	1.00	60639.60	60639.60	60639.60	108609.04	0.00
C	1.00	1519.50	1519.50	1519.50	2721.45	0.00
A*B	3.00	2965.70	2965.70	988.60	1770.57	0.00
A*C	3.00	1956.30	1956.30	652.10	1167.93	0.00
B*C	1.00	3248.20	3248.20	3248.20	5817.77	0.00
A*B*C	3.00	588.20	588.20	196.10	351.14	0.00
Error	1584.00	884.40	884.40	0.60		
Total	1599.00	93865.10				

Table A.13.b Tukey Comparison of Overall Information Cycle Time

A	B	C	Average
4	1	2	28.16
4	1	1	30.11
3	1	1	32.09
3	1	2	37.77
2	1	2	38.03
2	1	1	38.11
4	2	2	41.93
1	1	2	42.20
1	1	1	42.25
3	2	2	43.96
2	2	2	46.70
3	2	1	47.59
4	2	1	50.39
2	2	1	50.46
1	2	2	51.41
1	2	1	54.76

Table A.14.a – Analysis Of Variance for Standard Deviation of Overall Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	252.70	252.70	84.20	57.18	0.00
B	1.00	88990.40	88990.40	88990.40	60413.15	0.00
C	1.00	104.40	104.40	104.40	70.90	0.00
A*B	3.00	131.40	131.40	43.80	29.74	0.00
A*C	3.00	8.70	8.70	2.90	1.97	0.12
B*C	1.00	99.00	99.00	99.00	67.21	0.00
A*B*C	3.00	5.40	5.40	1.80	1.23	0.30
Error	1584.00	2333.30	2333.30	1.50		
Total	1599.00	91925.40				

Table A.14.b – Tukey Comparison of Standard Deviation of Overall Information Cycle Time

A	B	C	Average
3	1	2	21.34
3	1	1	21.40
4	1	1	21.44
4	1	2	21.45
2	1	1	22.71
1	1	2	22.76
2	1	2	22.78
1	1	1	22.83
3	2	2	36.22
4	2	2	36.36
1	2	2	36.65
2	2	2	36.77
4	2	1	37.33
1	2	1	37.49
2	2	1	37.56
3	2	1	37.66

Table A.15.a Analysis Of Variance for Radiology Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	31209.80	31209.80	10403.30	10035.95	0.00
B	1.00	13859.30	13859.30	13859.30	13369.98	0.00
C	1.00	1.20	1.20	1.20	1.20	0.27
A*B	3.00	2513.90	2513.90	838.00	808.39	0.00
A*C	3.00	2.10	2.10	0.70	0.67	0.57
B*C	1.00	0.50	0.50	0.50	0.52	0.47
A*B*C	3.00	5.10	5.10	1.70	1.64	0.18
Error	1584.00	1642.00	1642.00	1.00		
Total	1599.00	49233.90				

Table A.15.b Tukey Comparison of Radiology Information Cycle Time

A	B	C	Average
4	1	2	20.47
4	1	1	20.64
3	1	1	22.12
3	1	2	22.21
4	2	1	28.93
4	2	2	29.11
2	1	1	29.74
2	1	2	29.87
3	2	2	30.38
3	2	1	30.53
2	2	1	32.73
2	2	2	32.85
1	1	1	34.10
1	1	2	34.12
1	2	1	37.81
1	2	2	38.03

Table A.14.a – Analysis Of Variance for Standard Deviation of Radiology Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	28.16	28.16	9.39	1.65	0.18
B	1.00	4996.90	4996.90	4996.90	876.53	0.00
C	1.00	0.01	0.01	0.01	0.00	0.96
A*B	3.00	24.12	24.12	8.04	1.41	0.24
A*C	3.00	13.00	13.00	4.33	0.76	0.52
B*C	1.00	1.76	1.76	1.76	0.31	0.58
A*B*C	3.00	43.78	43.78	14.59	2.56	0.05
Error	1584.00	9030.06	9030.06	5.70		
Total	1599.00	14137.79				

Table A.14.b – Tukey Comparison of Standard Deviation of Radiology Information Cycle Time

A	B	C	Average
3	1	1	8.48
4	1	2	8.59
2	1	1	8.65
1	1	1	8.75
1	1	2	8.78
3	1	2	8.88
2	1	2	9.19
4	1	1	9.27
3	2	2	11.94
2	2	1	12.07
2	2	2	12.12
3	2	1	12.37
4	2	1	12.45
1	2	2	12.55
1	2	1	12.66
4	2	2	12.70

Table A.17.a Analysis Of Variance for Ultrasound Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	17882.40	17862.40	5954.10	12346.87	0.00
B	1.00	108282.10	108262.10	108282.10	220352.29	0.00
C	1.00	0.30	0.30	0.30	0.55	0.46
A*B	3.00	900.80	900.80	300.30	822.84	0.00
A*C	3.00	4.10	4.10	1.40	2.80	0.04
B*C	1.00	0.80	0.60	0.60	1.16	0.28
A*B*C	3.00	0.80	0.80	0.30	0.53	0.68
Error	1584.00	783.90	783.90	0.50		
Total	1599.00	125794.80				

Table A.17.b Tukey Comparison of Ultrasound Information Cycle Time

A	B	C	Average
4	1	1	29.85
4	1	2	29.88
3	1	2	31.48
3	1	1	31.62
2	1	2	35.68
2	1	1	35.68
1	1	1	40.07
1	1	2	40.14
4	2	1	47.66
4	2	2	47.71
3	2	2	49.29
3	2	1	49.34
2	2	2	50.23
2	2	1	50.26
1	2	1	55.01
1	2	2	55.29

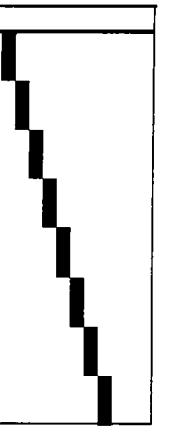

Table A.18.a – Analysis Of Variance for Standard Deviation of Ultrasound Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	10.85	10.85	3.62	3.11	0.03
B	1.00	1546.57	1546.57	1548.57	1331.78	0.00
C	1.00	0.04	0.04	0.04	0.04	0.85
A*B	3.00	0.80	0.80	0.27	0.23	0.88
A*C	3.00	3.48	3.48	1.18	1.00	0.39
B*C	1.00	0.25	0.25	0.25	0.21	0.65
A*B*C	3.00	0.31	0.31	0.10	0.09	0.97
Error	1584.00	1839.50	1839.50	1.18		
Total	1599.00	3401.81				

Table A.18.b – Tukey Comparison of Standard Deviation of Ultrasound Information Cycle Time

A	B	C	Average
3	1	2	4.83
2	1	2	4.89
3	1	1	4.91
1	1	1	4.95
4	1	1	4.98
2	1	1	4.98
4	1	2	5.02
1	1	2	5.14
2	2	2	6.80
3	2	2	6.80
3	2	1	6.83
4	2	2	6.93
4	2	1	6.95
2	2	1	6.96
1	2	1	7.05
1	2	2	7.13

Table A.19.a Analysis Of Variance for Computed Tomography Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	19924.00	19924.00	6641.00	4753.09	0.00
B	1.00	105069.00	105069.00	105069.00	75197.57	0.00
C	1.00	30474.00	30474.00	30474.00	21810.23	0.00
A*B	3.00	1382.00	1382.00	461.00	329.75	0.00
A*C	3.00	640.00	640.00	213.00	152.73	0.00
B*C	1.00	13716.00	13716.00	13716.00	9816.81	0.00
A*B*C	3.00	784.00	784.00	261.00	187.07	0.00
Error	1584.00	2213.00	2213.00	1.00		
Total	1599.00	174203.00				

Table A.19.b Tukey Comparison of Computed Tomography Information Cycle Time

A	B	C	Average
4	1	2	20.20
3	1	2	21.95
4	1	1	25.72
3	1	1	27.50
2	1	2	29.43
2	1	1	29.82
4	2	2	33.63
1	1	2	34.00
1	1	1	34.03
3	2	2	35.73
2	2	2	36.49
1	2	2	41.14
4	2	1	48.08
3	2	1	50.17
2	2	1	51.12
1	2	1	55.95

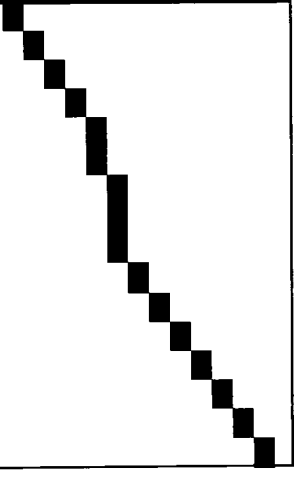

Table A.20.a – Analysis Of Variance for Standard Deviation of Computed Tomography Information

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	67.81	67.81	22.60	2.33	0.07
B	1.00	6006.77	6006.77	6006.77	620.17	0.00
C	1.00	0.00	0.00	0.00	0.00	1.00
A*B	3.00	15.42	15.42	5.14	0.53	0.66
A*C	3.00	20.84	20.84	6.95	0.72	0.54
B*C	1.00	11.55	11.55	11.55	1.19	0.28
A*B*C	3.00	51.09	51.09	17.03	1.76	0.15
Error	1584.00	15342.17	15342.17	9.69		
Total	1599.00	21515.64				

Table A.20.b – Tukey Comparison of Standard Deviation of Computed Tomography Information Cycle Time

A	B	C	Average
1	1	1	8.61
4	1	1	8.65
2	1	2	8.81
4	1	2	8.86
3	1	1	9.06
3	1	2	9.08
2	1	1	9.12
1	1	2	9.37
4	2	1	12.24
1	2	2	12.41
4	2	2	12.43
2	2	2	12.84
3	2	1	12.93
1	2	1	13.20
2	2	1	13.26
3	2	2	13.27

Table A.21.a Analysis Of Variance for Mammography Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	41032.90	41032.90	13677.80	2916.27	0.00
B	1.00	15295.10	15295.10	15295.10	3261.14	0.00
C	1.00	0.10	0.10	0.10	0.01	0.90
A*B	3.00	207.60	207.60	69.20	14.75	0.00
A*C	3.00	28.50	26.50	9.50	2.02	0.11
B*C	1.00	1.00	1.00	1.00	0.21	0.65
A*B*C	3.00	17.50	17.50	5.80	1.25	0.29
Error	1584.00	7429.10	7429.10	4.70		
Total	1599.00	64011.70				

Table A.21.b Tukey Comparison of Mammography Information Cycle Time

A	B	C	Average
4	1	1	30.55
4	1	2	30.86
3	1	2	32.42
3	1	1	32.43
4	2	2	37.25
4	2	1	37.57
3	2	2	39.27
2	1	1	39.33
3	2	1	39.67
2	1	2	39.67
1	1	2	43.77
1	1	1	44.15
2	2	1	44.47
2	2	2	45.04
1	2	2	49.69
1	2	1	49.70

Table A.22.a – Analysis Of Variance for Standard Deviation of Mammography Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	63.30	63.30	21.10	1.39	0.24
B	1.00	15701.60	15701.60	15701.60	1035.15	0.00
C	1.00	1.10	1.10	1.10	0.07	0.79
A*B	3.00	26.70	26.70	8.90	0.59	0.62
A*C	3.00	93.50	93.50	31.20	2.05	0.10
B*C	1.00	6.20	6.20	6.20	0.41	0.52
A*B*C	3.00	21.70	21.70	7.20	0.48	0.70
Error	1584.00	24026.70	24026.70	15.20		
Total	1599.00	39940.70				

Table A.22.b – Tukey Comparison of Standard Deviation of Mammography Information Cycle Time

A	B	C	Average
1	1	2	15.39
2	1	1	15.86
4	1	1	15.99
1	1	1	16.08
3	1	1	16.17
3	1	2	16.21
4	1	2	16.27
2	1	2	16.52
2	2	1	21.73
1	2	2	21.94
4	2	2	22.01
1	2	1	22.34
4	2	1	22.46
3	2	2	22.47
2	2	2	22.54
3	2	1	23.13

Table A.23.a Analysis Of Variance for Nuclear Medicine Information Cycle Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	28832.00	28832.00	9611.00	227.36	0.00
B	1.00	3284566.00	3284566.00	3284566.00	77704.28	0.00
C	1.00	39.00	39.00	39.00	0.93	0.34
A*B	3.00	3935.00	3935.00	1312.00	31.03	0.00
A*C	3.00	328.00	328.00	109.00	2.59	0.05
B*C	1.00	17.00	17.00	17.00	0.40	0.53
A*B*C	3.00	320.00	320.00	107.00	2.52	0.06
Error	1584.00	66956.00	66956.00	42.00		
Total	1599.00	3384993.00				

Table A.23.b Tukey Comparison of Nuclear Medicine Information Cycle Time

A	B	C	Average
4	1	1	105.48
4	1	2	106.48
3	1	1	107.08
3	1	2	107.37
2	1	2	114.76
2	1	1	115.25
1	1	2	119.88
1	1	1	120.23
4	2	1	198.53
3	2	2	200.15
4	2	2	200.32
3	2	1	202.25
2	2	1	203.13
2	2	2	203.28
1	2	1	205.78
1	2	2	208.01

Table A.24.a – Analysis Of Variance for Standard Deviation of Nuclear Medicine Information Cycle

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	24.10	24.10	8.00	0.17	0.92
B	1.00	27076.00	27076.00	27076.00	580.42	0.00
C	1.00	18.20	18.20	18.20	0.39	0.53
A*B	3.00	59.30	59.30	19.80	0.42	0.74
A*C	3.00	41.50	41.50	13.80	0.30	0.83
B*C	1.00	6.00	6.00	6.00	0.13	0.72
A*B*C	3.00	128.60	128.60	42.90	0.92	0.43
Error	1584.00	73891.60	73891.60	46.60		
Total	1599.00	101245.30				

Table A.24.b – Tukey Comparison of Standard Deviation of Nuclear Medicine Information Cycle Time

A	B	C	Average
4	1	1	21.70
2	1	2	21.70
2	1	1	22.10
3	1	2	22.13
1	1	2	22.14
3	1	1	22.28
1	1	1	22.63
4	1	2	23.10
1	2	1	29.79
3	2	2	29.99
3	2	1	30.28
2	2	1	30.42
4	2	2	30.61
4	2	1	30.64
1	2	2	30.77
2	2	2	31.10

Table A.25.a Analysis Of Variance for Overall Patient Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	967740.00	967740.00	322580.00	1877.84	0.00
B	1.00	13386086.00	13386086.00	13386086.00	77924.73	0.00
C	1.00	1234432.00	1234432.00	1234432.00	7186.03	0.00
A*B	3.00	801920.00	801920.00	267307.00	1556.08	0.00
A*C	3.00	1122451.00	1122451.00	374150.00	2178.05	0.00
B*C	1.00	101124.00	101124.00	101124.00	588.68	0.00
A*B*C	3.00	1217378.00	1217378.00	405793.00	2362.25	0.00
Error	1584.00	272103.00	272103.00	172.00		
Total	1599.00	19103233.00				

Table A.25.b Tukey Comparison of Overall Patient Throughput

A	B	C	Average
4	2	2	772.37
3	2	2	770.59
1	2	2	739.3
2	2	2	738.16
3	2	1	704.05
1	2	1	679.45
4	2	1	676.3
1	1	2	676.3
2	2	1	674.81
4	1	2	603.73
3	1	1	564.15
4	1	1	562.67
3	1	2	474.61
2	1	2	470.44
1	1	1	470.02
2	1	1	469.63

Table A.26.a Analysis Of Variance for Radiology Patient Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	1671725.00	1671725.00	557242.00	8761.47	0.00
B	1.00	646537.00	646537.00	646537.00	10165.45	0.00
C	1.00	594480.00	594480.00	594480.00	9346.96	0.00
A*B	3.00	1875624.00	1875624.00	625208.00	9830.10	0.00
A*C	3.00	2433517.00	2433517.00	811172.00	12754.01	0.00
B*C	1.00	493120.00	493120.00	493120.00	7753.29	0.00
A*B*C	3.00	2561678.00	2561678.00	853893.00	13425.70	0.00
Error	1584.00	100745.00	100745.00	84.00		
Total	1599.00	10377423.00				

Table A.26.b Tukey Comparison of Radiology Patient Throughput

A	B	C	Average
4	2	2	237.13
3	2	1	235.26
3	2	2	234.12
1	2	1	223.66
2	2	2	223.35
2	2	1	223.33
1	2	2	222.76
4	2	1	221.35
3	1	1	174.89
4	1	1	174.89
4	1	2	174.06
2	1	1	126.48
3	1	2	126.12
1	1	1	126.08
1	1	2	126.06
2	1	2	125.73

Table A.27.a Analysis Of Variance for Ultrasound Patient Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	20664.00	20664.00	6888.00	1567.88	0.00
B	1.00	324957.00	324957.00	324957.00	73969.55	0.00
C	1.00	574.00	574.00	574.00	130.57	0.00
A*B	3.00	20842.00	20842.00	6947.00	1581.44	0.00
A*C	3.00	999.00	999.00	333.00	75.82	0.00
B*C	1.00	150.00	150.00	150.00	34.16	0.00
A*B*C	3.00	309.00	309.00	103.00	23.41	0.00
Error	1584.00	6959.00	6959.00	4.00		
Total	1599.00	375453.00				

Table A.27.b Tukey Comparison of Ultrasound Patient Throughput

A	B	C	Average
1	2	1	139.5
4	2	1	139.49
3	2	2	135.58
4	2	2	135.51
2	2	2	135.5
1	2	2	135.35
3	2	1	135.14
2	2	1	135.05
3	1	2	115.93
3	1	1	115.56
4	1	1	115.56
4	1	2	112.91
1	1	1	100.85
2	1	2	100.79
2	1	1	100.75
1	1	2	100.75

Table A.28.a Analysis of Variance for Computed Tomography Patient Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	42645.00	42645.00	14215.00	398.09	0.00
B	1.00	410661.00	410661.00	410661.00	11508.65	0.00
C	1.00	592130.00	592130.00	592130.00	16582.50	0.00
A*B	3.00	42014.00	42014.00	14005.00	392.20	0.00
A*C	3.00	55785.00	55785.00	18588.00	520.58	0.00
B*C	1.00	270068.00	270068.00	270068.00	7563.77	0.00
A*B*C	3.00	54425.00	54425.00	18142.00	508.06	0.00
Error	1584.00	56562.00	56562.00	36.00		
Total	1599.00	1524510.00				

Table A.28.b Tukey Comparison of Computed Tomography Patient Throughput

A	B	C	Average
3	2	2	198.82
1	2	2	198.27
4	2	2	198.08
2	2	2	196.83
4	1	2	177.66
3	2	1	134.27
2	2	1	133.59
3	1	1	133.52
4	2	1	133.31
1	2	1	132.99
3	1	2	128.02
2	1	2	127.39
1	1	2	126.79
1	1	1	126.43
2	1	1	125.11
4	1	1	124.84

Table A.29.a Analysis of Variance for Mammography Patient Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	81131.00	81131.00	27044.00	382.44	0.00
B	1.00	1528932.00	1528932.00	1528932.00	21621.55	0.00
C	1.00	76.00	76.00	76.00	1.07	0.30
A*B	3.00	17069.00	17069.00	5690.00	80.48	0.00
A*C	3.00	16337.00	16337.00	5448.00	77.01	0.00
B*C	1.00	9851.00	9851.00	9851.00	139.30	0.00
A*B*C	3.00	10954.00	10954.00	3651.00	51.64	0.00
Error	1584.00	112010.00	112010.00	71.00		
Total	1599.00	1776360.00				

Table A.29.b Tukey Comparison of Mammography Patient Throughput

A	B	C	Average
3	2	2	171.29
4	2	2	170.99
3	2	1	168.36
1	2	1	152.54
1	2	2	152.32
2	2	1	152.28
2	2	2	151.86
4	2	1	151.69
4	1	2	109.87
3	1	1	109.26
4	1	1	109.26
3	1	2	90.24
1	1	2	90.04
2	1	1	89.67
1	1	1	89.23
2	1	2	89.16

Table A.30.a Analysis of Variance for Nuclear Medicine Patient Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	260.76	260.76	86.92	57.52	0.00
B	1.00	2573.03	2573.03	2573.03	1702.72	0.00
C	1.00	52.20	52.20	52.20	34.54	0.00
A*B	3.00	231.99	231.99	77.33	51.17	0.00
A*C	3.00	84.11	84.11	28.04	16.55	0.00
B*C	1.00	26.69	26.69	26.69	19.12	0.00
A*B*C	3.00	56.77	56.77	19.59	12.96	0.00
Error	1584.00	2393.63	2393.63	1.51		
Total	1599.00	5663.37				

Table A.30.b Tukey Comparison of Nuclear Medicine Patient Throughput

A	B	C	Average
3	2	1	31.02
3	2	2	30.78
1	2	1	30.76
4	2	1	30.66
4	2	2	30.63
2	2	2	30.62
1	2	2	30.6
2	2	1	30.56
3	1	1	29.44
4	1	1	29.44
4	1	2	29.23
2	1	1	27.62
1	1	2	27.44
1	1	1	27.43
2	1	2	27.37
3	1	2	27.37

Table A.31.a Analysis Of Variance for Overall Report Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	2027295.00	2027295.00	675765.00	3757.26	0.00
B	1.00	15270315.00	15270315.00	15270315.00	84903.46	0.00
C	1.00	749134.00	749134.00	749134.00	4165.21	0.00
A*B	3.00	656362.00	656362.00	218794.00	1216.50	0.00
A*C	3.00	47436.00	47436.00	15812.00	67.92	0.00
B*C	1.00	175675.00	175675.00	175675.00	977.67	0.00
A*B*C	3.00	42662.00	42662.00	14221.00	79.07	0.00
Error	1584.00	284690.00	284690.00	160.00		
Total	1599.00	19253990.00				

Table A.31.b Tukey Comparison of Overall Report Throughput

A	B	C	Average
3	2	2	769.61
4	2	2	766.65
1	2	2	739.49
2	2	2	736.59
4	2	1	705.67
3	2	1	703.29
2	2	1	676.22
1	2	1	672.56
4	1	2	603.91
3	1	2	603.50
3	1	1	560.70
4	1	1	559.99
1	1	2	471.13
2	1	2	470.76
1	1	1	470.06
2	1	1	469.32

Table A.31.a Analysis Of Variance for Radiology Report Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	388082.00	388082.00	122894.00	1753.79	0.00
B	1.00	2489532.00	2489532.00	2489532.00	35585.51	0.00
C	1.00	0.00	0.00	0.00	0.00	0.97
A*B	3.00	134578.00	134578.00	44859.00	641.21	0.00
A*C	3.00	73.00	73.00	24.00	0.35	0.79
B*C	1.00	2.00	2.00	2.00	0.03	0.87
A*B*C	3.00	487.00	487.00	162.00	2.32	0.07
Error	1564.00	110815.00	110815.00	70.00		
Total	1599.00	3103568.00				

Table A.31.b Tukey Comparison of Radiology Report Throughput

A	B	C	Average
3	2	2	236.88
3	2	1	235.51
4	2	1	234.62
4	2	2	233.13
2	2	1	224.29
2	2	2	223.21
1	2	2	222.77
1	2	1	221.9
3	1	1	175.44
4	1	2	175.04
3	1	2	174.24
4	1	1	173.14
1	1	1	126.14
1	1	2	126.03
2	1	1	125.77
2	1	2	125.38

Table A.32.a Analysis Of Variance for Ultrasound Report Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	14647.00	14647.00	4882.00	983.10	0.00
B	1.00	326498.00	326498.00	326498.00	64407.18	0.00
C	1.00	0.00	0.00	0.00	0.02	0.88
A*B	3.00	14828.00	14828.00	4943.00	975.08	0.00
A*C	3.00	18.00	18.00	5.00	1.07	0.38
B*C	1.00	2.00	2.00	2.00	0.33	0.58
A*B*C	3.00	4.00	4.00	1.00	0.28	0.64
Error	1564.00	8030.00	8030.00	5.00		
Total	1599.00	364025.00				

Table A.32.b Tukey Comparison of Ultrasound Report Throughput

A	B	C	Average
3	2	2	135.62
3	2	1	135.51
2	2	1	135.49
2	2	2	135.47
1	2	2	135.44
4	2	1	135.42
1	2	1	135.37
4	2	2	135.07
3	1	2	113.16
4	1	1	113.01
4	1	2	112.82
3	1	1	112.70
1	1	1	100.88
2	1	2	100.86
1	1	2	100.74
2	1	1	100.66

Table A.33.a Analysis Of Variance for Computed Tomography Report Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	84991.00	84991.00	28330.00	757.78	0.00
B	1.00	231987.00	231987.00	231987.00	6205.21	0.00
C	1.00	748571.00	748571.00	748571.00	20022.87	0.00
A*B	3.00	82819.00	82819.00	27606.00	738.42	0.00
A*C	3.00	41981.00	41981.00	13994.00	374.30	0.00
B*C	1.00	173098.00	173098.00	173098.00	4630.04	0.00
A*B*C	3.00	47483.00	47483.00	15828.00	423.36	0.00
Error	1584.00	59219.00	59219.00	37.00		
Total	1599.00	1470148.00				

Table A.33.b Tukey Comparison of Computed Tomography Report Throughput

A	B	C	Average
4	2	2	198.30
1	2	2	198.29
2	2	2	196.57
3	2	2	195.64
4	1	2	177.62
3	1	2	177.05
4	2	1	134.12
4	1	1	133.93
3	1	1	133.60
3	2	1	132.96
2	2	1	132.83
1	2	1	132.64
2	1	2	127.75
1	1	2	126.84
1	1	1	126.43
2	1	1	125.47

Table A.34.a Analysis Of Variance for Mammography Report Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	149782.00	149782.00	49927.00	679.26	0.00
B	1.00	1517947.00	1517947.00	1517947.00	20651.70	0.00
C	1.00	1.00	1.00	1.00	0.02	0.89
A*B	3.00	345.00	345.00	115.00	1.56	0.20
A*C	3.00	399.00	399.00	133.00	1.81	0.14
B*C	1.00	44.00	44.00	44.00	0.59	0.44
A*B*C	3.00	255.00	255.00	85.00	1.16	0.33
Error	1584.00	116428.00	116428.00	74.00		
Total	1599.00	1785201.00				

Table A.34.b Tukey Comparison of Mammography Report Throughput

A	B	C	Average
4	2	2	171.85
3	2	2	170.87
4	2	1	170.64
3	2	1	168.80
2	2	1	153.13
1	2	2	152.35
1	2	1	151.77
2	2	2	150.83
4	1	1	110.46
3	1	2	109.74
3	1	1	109.59
4	1	2	109.25
1	1	2	90.00
2	1	1	89.94
1	1	1	89.26
2	1	2	89.18

Table A.35.a Analysis Of Variance for Nuclear Medicine Report Throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	351.22	351.22	117.07	72.20	0.00
B	1.00	2007.04	2007.04	2007.04	1237.74	0.00
C	1.00	0.81	0.81	0.81	0.50	0.48
A*B	3.00	329.38	329.38	109.79	67.71	0.00
A*C	3.00	11.69	11.69	3.90	2.40	0.07
B*C	1.00	0.42	0.42	0.42	0.26	0.61
A*B*C	3.00	7.34	7.34	2.45	1.51	0.21
Error	1584.00	2568.52	2568.52	1.62		
Total	1599.00	5276.44				

Table A.35.b Tukey Comparison of Nuclear Medicine Report Throughput

A	B	C	Average
1	2	1	30.90
4	2	1	30.87
3	2	2	30.80
1	2	2	30.64
3	2	1	30.51
2	2	2	30.51
4	2	2	30.50
2	2	1	30.48
4	1	1	29.45
3	1	1	29.37
3	1	2	29.31
4	1	2	29.18
2	1	2	27.61
1	1	2	27.52
2	1	1	27.48
1	1	1	27.37

Table A.36.a Analysis Of Variance for Overall Machine Utilization

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	1.91	1.91	0.64	29467.67	0.00
B	1.00	25.35	25.35	25.35	1172640.12	0.00
C	1.00	0.10	0.10	0.10	4637.69	0.00
A*B	3.00	1.15	1.15	0.38	17759.47	0.00
A*C	3.00	0.48	0.48	0.16	7432.78	0.00
B*C	1.00	0.21	0.21	0.21	9934.04	0.00
A*B*C	3.00	0.38	0.38	0.13	5858.18	0.00
Error	1584.00	0.03	0.03	0.00		
Total	1599.00	29.62				

Table A.36.b Tukey Comparison of Overall Machine Utilization

A	B	C	Average
3	2	1	0.99
3	2	2	0.99
4	2	2	0.99
2	2	1	0.96
1	2	2	0.96
4	2	1	0.96
1	2	1	0.96
2	2	2	0.96
4	1	1	0.81
3	1	1	0.81
4	1	2	0.81
1	1	1	0.67
2	1	2	0.67
2	1	1	0.67
1	1	2	0.66
3	1	2	0.66

Table A.37.a Analysis Of Variance for Radiology Machine Utilization

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	4.09	4.09	1.36	14714.02	0.00
B	1.00	50.61	50.61	50.61	546008.53	0.00
C	1.00	0.15	0.15	0.15	1592.25	0.00
A*B	3.00	2.21	2.21	0.74	7964.97	0.00
A*C	3.00	1.00	1.00	0.33	3589.27	0.00
B*C	1.00	0.41	0.41	0.41	4400.04	0.00
A*B*C	3.00	0.73	0.73	0.24	2638.32	0.00
Error	1584.00	0.15	0.15	0.00		
Total	1599.00	59.34				

Table A.37.b Tukey Comparison of Radiology Machine Utilization

A	B	C	Average
3	2	1	1.00
3	2	2	1.00
4	2	2	1.00
4	2	1	0.95
1	2	2	0.95
2	2	1	0.95
2	2	2	0.95
1	2	1	0.95
4	1	2	0.74
3	1	1	0.74
4	1	1	0.74
2	1	2	0.54
1	1	2	0.53
1	1	1	0.53
3	1	2	0.53
2	1	1	0.53

Table A.38.a Analysis Of Variance for Ultrasound Machine Utilization

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	0.74	0.74	0.25	34426.17	0.00
B	1.00	18.06	18.06	18.06	2508847.13	0.00
C	1.00	0.00	0.00	0.00	11.31	0.00
A*B	3.00	0.74	0.74	0.25	34426.17	0.00
A*C	3.00	0.00	0.00	0.00	14.02	0.00
B*C	1.00	0.00	0.00	0.00	11.31	0.00
A*B*C	3.00	0.00	0.00	0.00	14.02	0.00
Error	1584.00	0.01	0.01	0.00		
Total	1599.00	19.56				

Table A.38.b Tukey Comparison of Ultrasound Machine Utilization

A	B	C	Average
1	2	1	1.00
2	2	1	1.00
3	2	1	1.00
4	2	1	1.00
1	2	2	1.00
2	2	2	1.00
3	2	2	1.00
4	2	2	1.00
4	1	2	0.83
3	1	1	0.83
4	1	1	0.83
3	1	2	0.83
2	1	2	0.74
2	1	1	0.74
1	1	2	0.74
1	1	1	0.74

Table A.39.a Analysis Of Variance for Computed Tomography Machine Utilization

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	4.80	4.80	1.60	32532.42	0.00
B	1.00	25.69	25.69	25.69	522398.24	0.00
C	1.00	0.62	0.62	0.62	12570.95	0.00
A*B	3.00	4.80	4.80	1.60	32521.49	0.00
A*C	3.00	1.38	1.38	0.46	9326.79	0.00
B*C	1.00	0.62	0.62	0.62	12558.02	0.00
A*B*C	3.00	1.38	1.38	0.46	9330.85	0.00
Error	1584.00	0.08	0.08	0.00		
Total	1599.00	39.36				

Table A.39.b Tukey Comparison of Computed Tomography Machine Utilization

A	B	C	Average
1	2	1	1.00
2	2	1	1.00
3	2	1	1.00
4	2	1	1.00
3	2	2	1.00
4	2	2	1.00
1	2	2	1.00
2	2	2	1.00
3	1	1	0.92
4	1	1	0.92
4	1	2	0.90
2	1	1	0.65
1	1	1	0.65
1	1	2	0.65
2	1	2	0.64
3	1	2	0.64

Table A.40.a Analysis Of Variance for Mammography Machine Utilization

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	2.54	2.54	0.85	2133.74	0.00
B	1.00	47.74	47.74	47.74	120510.14	0.00
C	1.00	0.01	0.01	0.01	12.72	0.00
A*B	3.00	0.61	0.61	0.20	509.96	0.00
A*C	3.00	0.59	0.59	0.20	498.49	0.00
B*C	1.00	0.30	0.30	0.30	765.71	0.00
A*B*C	3.00	0.32	0.32	0.11	268.91	0.00
Error	1584.00	0.63	0.63	0.00		
Total	1599.00	52.73				

Table A.40.b Tukey Comparison of Mammography Machine Utilization

A	B	C	Average
3	2	1	0.95
3	2	2	0.95
4	2	2	0.95
2	2	1	0.65
1	2	1	0.85
1	2	2	0.85
2	2	2	0.85
4	2	1	0.85
3	1	1	0.62
4	1	1	0.62
4	1	2	0.61
1	1	1	0.50
2	1	2	0.50
2	1	1	0.50
1	1	2	0.50
3	1	2	0.50

Table A.41.a Analysis Of Variance for Nuclear Medicine Machine Utilization

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3.00	0.23	0.23	0.08	11709.64	0.00
B	1.00	2.53	2.53	2.53	382021.41	0.00
C	1.00	0.02	0.02	0.02	2934.45	0.00
A*B	3.00	0.23	0.23	0.08	11709.64	0.00
A*C	3.00	0.06	0.06	0.02	3135.68	0.00
B*C	1.00	0.02	0.02	0.02	2934.45	0.00
A*B*C	3.00	0.06	0.06	0.02	3135.68	0.00
Error	1584.00	0.01	0.01	0.00		
Total	1599.00	3.17				

Table A.41.b Tukey Comparison of Nuclear Medicine Machine Utilization

A	B	C	Average
1	2	1	1.00
2	2	1	1.00
3	2	1	1.00
4	2	1	1.00
1	2	2	1.00
2	2	2	1.00
3	2	2	1.00
4	2	2	1.00
4	1	2	0.96
3	1	1	0.96
4	1	1	0.96
3	1	2	0.90
2	1	2	0.90
1	1	1	0.90
1	1	2	0.90
2	1	1	0.90

APPENDIX B

This contains summary charts for experiments 2, and includes all summary charts overall and per modality and the means comparison charts for each experiment.

Table B.1 Overall Summary of Performance Measures for Experiment 2

	Two modalities with low throughput		Two modalities with high throughput		Five modalities with low throughput		Five modalities with high throughput	
Performance Measure	Film	Digital	Film	Digital	Film	Digital	Film	Digital
Patient Cycle Time	39.90 ± 1.09	31.80 ± 0.66	160.00 ± 13.60	55.60 ± 2.63	54.60 ± 1.47	44.00 ± 0.91	246.00 ± 10.30	30.80 ± 0.15
Standard deviation of Patient Cycle Time	22.80 ± 1.30	16.10 ± 1.00	99.20 ± 8.99	40.70 ± 3.35	47.10 ± 2.82	40.90 ± 2.64	212.00 ± 10.60	22.10 ± 0.28
Information Cycle Time	80.30 ± 1.06	34.40 ± 0.66	160.00 ± 13.50	58.20 ± 2.62	74.10 ± 1.48	46.30 ± 0.93	265.00 ± 10.30	30.10 ± 0.16
Standard Deviation of Information Cycle Time	22.20 ± 1.31	15.70 ± 1.00	98.70 ± 8.97	40.50 ± 3.35	46.20 ± 2.82	42.20 ± 2.65	211.00 ± 10.50	23.20 ± 0.28
Machine Utilization	0.29 ± 0.01	0.56 ± 0.01	1.10 ± 0.01	1.12 ± 0.02	0.33 ± 0.01	0.33 ± 0.01	0.59 ± 0.00	0.63 ± 0.01
Technician Utilization	0.46 ± 0.01	0.71 ± 0.02	1.85 ± 0.02	1.41 ± 0.02	0.51 ± 0.01	0.40 ± 0.01	0.93 ± 0.01	0.77 ± 0.01
Patient WIP	1.35 ± 0.06	1.06 ± 0.04	11.10 ± 1.08	3.72 ± 0.24	4.00 ± 0.14	3.23 ± 0.09	38.70 ± 1.88	18.80 ± 1.17
Report WIP	1.88 ± 0.06	1.06 ± 0.04	12.10 ± 1.09	3.70 ± 0.24	5.17 ± 0.15	3.19 ± 0.09	40.90 ± 1.88	18.70 ± 1.17

Table B.2 Summary of Overall Performance Measures for a film system with two Modalities and a Patient Throughput of 100

Performance Measure	Total	Radiology	Ultrasound
Patient Cycle Time	39.90 ± 1.09	35.30 ± 1.51	45.10 ± 1.29
Standard deviation of Patient Cycle Time	22.80 ± 1.30	21.90 ± 1.69	20.30 ± 1.50
Information Cycle Time	60.30 ± 1.08	57.20 ± 1.49	63.60 ± 1.30
Standard Deviation of Information Cycle Time	22.20 ± 1.31	21.50 ± 1.66	20.20 ± 1.49
Machine Utilization	0.29 ± 0.01	0.24 ± 0.01	0.33 ± 0.01
Technician Utilization	0.48 ± 0.01	0.48 ± 0.01	0.48 ± 0.02
Patient WIP	1.35 ± 0.06	0.67 ± 0.04	0.69 ± 0.04
Report WIP	1.88 ± 0.06	0.99 ± 0.05	0.89 ± 0.04

Table B.3 Summary of Overall Performance Measures for a digital system with two Modalities and a Patient Throughput of 100

Performance Measure	Total	Radiology	Ultrasound
Patient Cycle Time	31.80 ± 0.66	25.10 ± 0.63	39.60 ± 1.13
Standard deviation of Patient Cycle Time	16.10 ± 1.00	12.10 ± 1.15	15.10 ± 1.28
Information Cycle Time	34.40 ± 0.66	27.90 ± 0.61	42.10 ± 1.12
Standard Deviation of Information Cycle Time	15.70 ± 1.00	11.60 ± 1.08	15.00 ± 1.27
Machine Utilization	0.56 ± 0.01	0.23 ± 0.01	0.33 ± 0.01
Technician Utilization	0.71 ± 0.02	0.31 ± 0.01	0.40 ± 0.01
Patient WIP	1.06 ± 0.04	0.46 ± 0.02	0.60 ± 0.03
Report WIP	1.06 ± 0.04	0.46 ± 0.02	0.60 ± 0.03

Table B.4 Summary of Overall Performance Measures for a film system with two Modalities and a Patient Throughput of 200

Performance Measure	Total	Radiology	Ultrasound
Patient Cycle Time	160.00 ± 13.60	146.00 ± 18.80	174.00 ± 17.50
Standard deviation of Patient Cycle Time	99.20 ± 8.99	77.30 ± 8.32	82.60 ± 6.72
Information Cycle Time	180.00 ± 13.50	168.00 ± 18.60	192.00 ± 17.40
Standard Deviation of Information Cycle Time	98.70 ± 8.97	77.10 ± 8.32	82.60 ± 6.71
Machine Utilization	1.10 ± 0.01	0.45 ± 0.01	0.65 ± 0.01
Technician Utilization	1.85 ± 0.02	0.92 ± 0.01	0.93 ± 0.01
Patient WIP	11.10 ± 1.08	5.63 ± 0.83	5.45 ± 0.63
Report WIP	12.10 ± 1.09	6.25 ± 0.84	5.85 ± 0.63

Table B.5 Summary of Overall Performance Measures for a digital system with two Modalities and a Patient Throughput

Performance Measure	Total	Radiology	Ultrasound
Patient Cycle Time	55.60 ± 2.63	38.40 ± 2.01	75.60 ± 5.11
Standard deviation of Patient Cycle Time	40.70 ± 3.35	25.20 ± 2.36	41.60 ± 3.97
Information Cycle Time	58.20 ± 2.62	41.10 ± 2.00	78.30 ± 5.11
Standard Deviation of Information Cycle Time	40.50 ± 3.35	24.90 ± 2.35	41.60 ± 3.97
Machine Utilization	1.12 ± 0.02	0.46 ± 0.01	0.66 ± 0.01
Technician Utilization	1.41 ± 0.02	0.62 ± 0.01	0.79 ± 0.02
Patient WIP	3.72 ± 0.24	1.42 ± 0.10	2.30 ± 0.21
Report WIP	3.70 ± 0.24	1.41 ± 0.10	2.29 ± 0.21

Table B.6 Summary of Overall Performance Measures for a film system with five Modalities and a Patient Throughput of 220

Performance Measure	Total	Radiology	Ultrasound	Computed Tomography	Mamography	Nuclear Medicine
Patient Cycle Time	54.60 ± 1.47	32.00 ± 1.35	58.20 ± 3.05	42.90 ± 1.56	50.00 ± 2.82	159.00 ± 9.16
Standard deviation of Patient Cycle Time	47.10 ± 2.82	18.50 ± 1.61	32.10 ± 3.03	21.80 ± 1.85	34.10 ± 2.80	88.80 ± 6.18
Information Cycle Time	74.10 ± 1.48	53.00 ± 1.35	75.60 ± 3.04	56.70 ± 1.57	76.70 ± 2.83	184.00 ± 9.09
Standard Deviation of Information Cycle Time	48.20 ± 2.82	18.10 ± 1.59	32.00 ± 3.04	21.70 ± 1.84	34.00 ± 2.77	68.90 ± 8.12
Machine Utilization	0.33 ± 0.01	0.20 ± 0.01	0.43 ± 0.01	0.30 ± 0.01	0.24 ± 0.01	0.48 ± 0.02
Technician Utilization	0.51 ± 0.01	0.40 ± 0.01	0.61 ± 0.02	0.50 ± 0.01	0.50 ± 0.02	0.55 ± 0.03
Patient WIP	4.00 ± 0.14	0.50 ± 0.03	1.14 ± 0.08	0.85 ± 0.04	0.71 ± 0.05	0.81 ± 0.08
Report WIP	5.17 ± 0.15	0.77 ± 0.04	1.41 ± 0.09	1.05 ± 0.05	1.03 ± 0.06	0.92 ± 0.08

Table B.7 Summary of Overall Performance Measures for a digital system with five Modalities and a Patient Throughput of 220

Performance Measure	Total		Radiology		Ultrasound		Computed Tomography		Mamography		Nuclear Medicine	
Patient Cycle Time	44.00 ±	0.91	25.00 ±	0.67	44.10 ±	1.31	33.60 ±	0.79	38.50 ±	1.48	153.00 ±	7.63
Standard deviation of Patient Cycle Time	40.90 ±	2.64	12.50 ±	1.13	19.30 ±	1.39	14.20 ±	1.32	25.00 ±	1.72	67.20 ±	6.79
Information Cycle Time	46.30 ±	0.93	27.70 ±	0.64	46.70 ±	1.30	29.20 ±	0.78	47.50 ±	1.47	160.00 ±	7.60
Standard Deviation of Information Cycle Time	42.20 ±	2.65	12.00 ±	1.02	19.10 ±	1.38	14.30 ±	1.29	24.90 ±	1.70	67.30 ±	6.79
Machine Utilization	0.33 ±	0.01	0.20 ±	0.01	0.42 ±	0.01	0.31 ±	0.01	0.23 ±	0.01	0.49 ±	0.02
Technician Utilization	0.40 ±	0.01	0.26 ±	0.01	0.51 ±	0.01	0.34 ±	0.01	0.38 ±	0.01	0.51 ±	0.03
Patient WIP	3.23 ±	0.09	0.39 ±	0.02	0.85 ±	0.04	0.67 ±	0.02	0.54 ±	0.03	0.79 ±	0.07
Report WIP	3.19 ±	0.09	0.38 ±	0.02	0.85 ±	0.04	0.52 ±	0.02	0.63 ±	0.03	0.81 ±	0.07

Table B.8 Summary of Overall Performance Measures for film system with five Modalities and a Patient Throughput of 440

Performance Measure	Total		Radiology		Ultrasound		Computed Tomography		Mamography		Nuclear Medicine	
Patient Cycle Time	246.00 ±	10.30	77.30 ±	6.40	415.00 ±	32.20	216.00 ±	23.30	187.00 ±	19.00	521.00 ±	41.20
Standard deviation of Patient Cycle Time	212.00 ±	10.60	48.80 ±	4.13	170.00 ±	14.40	92.50 ±	9.02	96.60 ±	7.75	213.00 ±	17.00
Information Cycle Time	265.00 ±	10.30	98.20 ±	6.33	430.00 ±	32.00	229.00 ±	23.30	213.00 ±	18.90	541.00 ±	40.40
Standard Deviation of Information Cycle Time	211.00 ±	10.50	48.70 ±	4.12	170.00 ±	14.50	92.40 ±	9.01	96.60 ±	7.79	214.00 ±	17.10
Machine Utilization	0.59 ±	0.00	0.40 ±	0.01	0.89 ±	0.00	0.57 ±	0.01	0.43 ±	0.01	0.85 ±	0.01
Technician Utilization	0.93 ±	0.01	0.81 ±	0.02	0.99 ±	0.00	0.96 ±	0.01	0.92 ±	0.01	0.96 ±	0.01
Patient WIP	38.70 ±	1.88	2.46 ±	0.24	16.30 ±	1.44	8.86 ±	1.09	5.30 ±	0.59	5.79 ±	0.57
Report WIP	40.90 ±	1.88	3.00 ±	0.24	16.70 ±	1.44	9.25 ±	1.10	5.90 ±	0.59	5.98 ±	0.57

Table B.9 Summary of Overall Performance Measures for digital system with five Modalities and a Patient Throughput of 440

Performance Measure	Total		Radiology		Ultrasound		Computed Tomography		Mamography		Nuclear Medicine	
Patient Cycle Time	30.80 ±	0.15	20.70 ±	0.22	30.10 ±	0.12	42.90 ±	1.56	24.40 ±	0.35	102.00 ±	0.90
Standard deviation of Patient Cycle Time	22.10 ±	0.28	9.63 ±	0.63	5.80 ±	0.24	8.90 ±	0.61	15.80 ±	0.77	22.20 ±	1.30
Information Cycle Time	30.10 ±	0.16	20.50 ±	0.19	29.80 ±	0.10	20.30 ±	0.18	30.40 ±	0.34	106.00 ±	0.91
Standard Deviation of Information Cycle Time	23.20 ±	0.28	8.65 ±	0.54	4.87 ±	0.19	8.88 ±	0.60	15.80 ±	0.74	22.30 ±	1.30
Machine Utilization	0.63 ±	0.01	0.40 ±	0.01	0.80 ±	0.01	0.61 ±	0.01	0.46 ±	0.01	0.90 ±	0.02
Technician Utilization	0.77 ±	0.01	0.54 ±	0.01	0.96 ±	0.01	0.88 ±	0.01	0.75 ±	0.02	0.94 ±	0.02
Patient WIP	18.80 ±	1.17	1.04 ±	0.05	8.49 ±	1.01	2.01 ±	0.11	2.19 ±	0.20	5.08 ±	0.56
Report WIP	18.70 ±	1.17	1.04 ±	0.05	8.48 ±	1.01	1.72 ±	0.11	2.35 ±	0.20	5.12 ±	0.57

The following are the results of the mean comparisons of film versus digital for experiment 2.

Table B.10 Comparison of Means for Overall Performance Measures with two Modalities and a Patient Throughput of 100

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	6.2	6.1	1.2	32.2	56.8	100	
				26.6	45.6	100	No
Std Deviation of Patient Cycle Time	6.7	8.0	1.6	13.5	44.5	100	
				6.2	39.6	100	No
Report Cycle Time	25.9	6.1	1.2	53.0	77.2	100	
				29.4	48.3	100	No
Std Deviation of Report Cycle Time	6.5	8.1	1.6	12.6	43.4	100	
				6.4	39.5	100	No
Patient WIP	0.3	0.3	0.1	0.6	2.2	100	
				0.6	1.7	100	No
Report WIP	0.8	0.4	0.1	1.3	2.6	100	
				0.75	1.67	100	No
Machine Utilization	-0.3	0.1	0.0	0.2	0.4	100	
				0.4	0.7	100	No
Technologist Utilization	-0.2	0.1	0.0	0.4	0.6	100	
				0.6	0.9	100	No
Patient Throughput	1.1	13.9	2.6	76.0	124.0	100	
				75.0	126.0	100	Yes
Reports Throughput	1.2	14.0	2.6	77.0	123.0	100	
				75.0	126.0	100	Yes

Table B.11 Comparison of Means for Radiology Performance Measures with two Modalities and a Patient Throughput of 100

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	10.2	8.3	1.7	24.9	63.6	100	
				19.7	38.0	100	No
Std Deviation of Patient Cycle Time	9.8	10.1	2.0	9.9	52.0	100	
				3.7	46.1	100	No
Report Cycle Time	29.4	8.2	1.6	46.8	85.3	100	
				22.4	40.8	100	No
Std Deviation of Report Cycle Time	9.9	9.9	2.0	10.0	52.0	100	
				3.9	45.7	100	No
Patient WIP	0.2	0.2	0.0	0.4	1.6	100	
				0.3	0.8	100	No
Report WIP	0.5	0.3	0.1	0.6	2.0	100	
				0.257	0.752	100	No
Machine Utilization	0.0	0.1	0.0	0.2	0.3	100	
				0.1	0.3	100	No
Technologist Utilization	0.2	0.1	0.0	0.3	0.6	100	
				0.2	0.4	100	No
Patient Throughput	1.1	10.8	2.2	40.0	73.0	100	
				33.0	71.0	100	Yes
Reports Throughput	1.1	10.9	2.2	39.0	72.0	100	
				33.0	71.0	100	Yes

Table B.12 Comparison of Means for Ultrasound Performance Measures with two Modalities and a Patient Throughput of 100

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	5.8	8.8	1.7	34.2	77.9	100	
				31.3	65.8	100	No
Std Deviation of Patient Cycle Time	5.1	10.5	2.1	7.5	51.3	100	
				8.7	53.7	100	No
Report Cycle Time	21.4	8.7	1.7	53.4	96.8	100	
				34.2	68.5	100	No
Std Deviation of Report Cycle Time	5.2	10.4	2.1	8.3	51.1	100	
				6.9	53.1	100	No
Patient WIP	0.1	0.2	0.0	0.3	1.4	100	
				0.4	1.2	100	No
Report WIP	0.3	0.2	0.0	0.5	1.7	100	
				0.374	1.18	100	No
Machine Utilization	0.0	0.1	0.0	0.2	0.5	100	
				0.2	0.5	100	Yes
Technologist Utilization	0.1	0.1	0.0	0.3	0.7	100	
				0.3	0.6	100	No
Patient Throughput	0.1	8.9	1.8	28.0	65.0	100	
				31.0	84.0	100	Yes
Reports Throughput	0.1	9.0	1.8	28.0	64.0	100	
				31.0	83.0	100	Yes

Table B.13 Comparison of Means for Overall Performance Measures with two Modalities and a Patient Throughput of 200

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	105.0	68.8	13.7	68.7	415.0	100	
				33.8	122.0	100	No
Std Deviation of Patient Cycle Time	58.6	46.0	8.1	41.4	252.0	100	
				15.4	138.0	100	No
Report Cycle Time	122.0	68.5	13.6	80.8	435.0	100	
				36.6	124.0	100	No
Std Deviation of Report Cycle Time	58.2	46.0	8.1	40.7	254.0	100	
				15.0	136.0	100	No
Patient WIP	7.4	5.5	1.1	3.8	33.0	100	
				1.8	10.3	100	No
Report WIP	8.4	5.5	1.1	4.8	34.1	100	
				1.82	10.3	100	No
Machine Utilization	0.0	0.1	0.0	0.8	1.2	100	
				0.8	1.3	100	Yes
Technologist Utilization	0.4	0.1	0.0	1.5	2.0	100	
				1.1	1.7	100	No
Patient Throughput	-3.6	16.8	3.4	167.0	213.0	100	
				162.0	231.0	100	No
Reports Throughput	-3.8	16.8	3.4	168.0	212.0	100	
				162.0	231.0	100	No

Table B.14 Comparison of Means for Radiology Performance Measures with two Modalities and a Patient Throughput of 200

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	108.0	94.4	18.7	46.8	588.0	100	
				25.0	99.4	100	No
Std Deviation of Patient Cycle Time	52.1	42.6	8.5	24.8	220.0	100	
				8.3	81.7	100	No
Report Cycle Time	127.0	83.6	18.6	68.7	611.0	100	
				27.8	102.0	100	No
Std Deviation of Report Cycle Time	52.2	42.6	8.5	23.8	217.0	100	
				8.5	81.3	100	No
Patient WIP	4.2	4.2	0.8	1.6	26.4	100	
				0.7	4.3	100	No
Report WIP	4.8	4.2	0.8	2.2	27.1	100	
				0.706	4.24	100	No
Machine Utilization	0.0	0.1	0.0	0.3	0.5	100	
				0.3	0.6	100	Yes
Technologist Utilization	0.3	0.1	0.0	0.7	1.0	100	
				0.5	0.8	100	No
Patient Throughput	-2.6	13.0	2.6	90.0	120.0	100	
				81.0	138.0	100	No
Reports Throughput	-2.7	13.1	2.6	88.0	120.0	100	
				81.0	138.0	100	No

Table B.15 Comparison of Means for Ultrasound Performance Measures with two Modalities and a Patient Throughput of 200

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	98.2	90.3	17.9	57.8	487.0	100	
				40.1	220.0	100	No
Std Deviation of Patient Cycle Time	40.9	35.8	7.1	25.7	194.0	100	
				12.9	150.0	100	No
Report Cycle Time	114.0	90.0	17.9	78.0	505.0	100	
				42.9	222.0	100	No
Std Deviation of Report Cycle Time	41.0	35.8	7.1	25.8	193.0	100	
				12.9	150.0	100	No
Patient WIP	3.2	3.3	0.6	1.8	15.7	100	
				0.9	8.9	100	No
Report WIP	3.8	3.3	0.7	1.9	18.2	100	
				0.888	8.93	100	Yes
Machine Utilization	0.0	0.1	0.0	0.5	0.7	100	
				0.5	0.8	100	No
Technologist Utilization	0.1	0.1	0.0	0.8	1.0	100	
				0.8	1.0	100	Yes
Patient Throughput	-1.0	9.7	1.9	70.0	88.0	100	
				85.0	109.0	100	Yes
Reports Throughput	-1.1	9.8	1.9	71.0	97.0	100	
				85.0	109.0	100	Yes

Table B.16 Comparison of Means for Overall Performance Measures with Five Modalities and a Patient Throughput Of 220

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	10.5	8.8	1.7	42.3	89.6	100	
				36.1	62.3	100	No
Patient Time in System	8.2	20.0	4.0	25.6	101.0	100	
				20.5	92.5	100	No
Report Cycle Time	27.8	8.8	1.8	81.8	110.0	100	
				36.6	65.2	100	Yes
Std Deviation of Report Cycle Time	6.0	20.0	4.0	26.6	103.0	100	
				21.8	93.8	100	No
Patient WIP	0.8	0.8	0.2	2.7	6.9	100	
				2.5	5.3	100	No
Report WIP	2.0	0.9	0.2	3.8	8.1	100	
				2.39	5.27	100	No
Machine Utilization	0.0	0.0	0.0	0.3	0.4	100	
				0.3	0.4	100	Yes
Technologist Utilization	0.1	0.1	0.0	0.4	0.6	100	
				0.3	0.5	100	No
Patient Throughput	0.0	20.5	4.1	184.0	267.0	100	
				185.0	279.0	100	Yes
Reports Throughput	0.0	20.4	4.1	185.0	266.0	100	
				185.0	278.0	100	Yes

Table B.17 Comparison of Means for Radiology Performance Measures with Five Modalities and a Patient Throughput Of 220

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	7.0	6.8	1.4	23.8	73.9	100	
				19.9	37.9	100	No
Patient Time in System	6.0	8.7	1.7	7.5	59.3	100	
				2.9	29.3	100	No
Report Cycle Time	25.3	6.8	1.4	44.3	94.9	100	
				22.8	39.8	100	No
Std Deviation of Report Cycle Time	6.1	8.5	1.7	7.2	58.6	100	
				3.9	28.5	100	No
Patient WIP	0.1	0.2	0.0	0.3	1.5	100	
				0.2	0.7	100	No
Report WIP	0.4	0.2	0.0	0.4	1.8	100	
				0.228	0.649	100	No
Machine Utilization	0.0	0.0	0.0	0.1	0.3	100	
				0.1	0.3	100	Yes
Technologist Utilization	0.1	0.1	0.0	0.3	0.8	100	
				0.2	0.4	100	No
Patient Throughput	0.2	9.7	1.9	30.0	64.0	100	
				31.0	64.0	100	Yes
Reports Throughput	0.2	9.8	1.9	31.0	64.0	100	
				31.0	64.0	100	Yes

Table B.18 Comparison of Means for Ultrasound Performance Measures with Five Modalities and a Patient Throughput Of 220

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	14.1	17.3	3.4	38.5	154.0	100	
				34.6	71.0	100	No
Patient Time in System	12.8	17.5	3.5	11.4	115.0	100	
				9.4	46.8	100	No
Report Cycle Time	29.0	17.1	3.4	55.8	172.0	100	
				37.4	72.9	100	No
Std Deviation of Report Cycle Time	12.9	17.5	3.5	10.9	115.0	100	
				8.6	47.1	100	No
Patient WIP	0.3	0.5	0.1	0.5	3.5	100	
				0.5	1.8	100	No
Report WIP	0.6	0.5	0.1	0.6	3.8	100	
				0.501	1.59	100	No
Machine Utilization	0.0	0.1	0.0	0.2	0.8	100	
				0.3	0.5	100	Yes
Technologist Utilization	0.1	0.1	0.0	0.3	0.8	100	
				0.4	0.6	100	No
Patient Throughput	0.7	10.6	2.1	34.0	75.0	100	
				42.0	73.0	100	Yes
Reports Throughput	0.7	10.6	2.1	34.0	75.0	100	
				42.0	73.0	100	Yes

Table B.19 Comparison of Means for Computed Tomography Performance Measures with Five Modalities and a Patient Throughput Of 220

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	9.2	8.2	1.6	30.7	85.0	100	
				27.4	53.1	100	No
Patient Time in System	7.4	10.0	2.0	7.2	59.8	100	
				3.5	39.3	100	No
Report Cycle Time	27.5	8.3	1.7	44.7	99.1	100	
				22.6	47.6	100	No
Std Deviation of Report Cycle Time	7.4	10.0	2.0	7.2	59.7	100	
				3.7	36.2	100	No
Patient WIP	0.2	0.3	0.1	0.5	1.8	100	
				0.4	1.0	100	No
Report WIP	0.5	0.3	0.1	0.6	2.0	100	
				0.304	0.875	100	No
Machine Utilization	0.0	0.1	0.0	0.2	0.4	100	
				0.2	0.4	100	Yes
Technologist Utilization	0.2	0.1	0.0	0.4	0.7	100	
				0.2	0.5	100	No
Patient Throughput	-0.4	11.8	2.3	45.0	85.0	100	
				45.0	77.0	100	Yes
Reports Throughput	-0.4	11.7	2.3	45.0	85.0	100	
				44.0	77.0	100	Yes

Table B.20 Comparison of Means for Mammography Performance Measures with Five Modalities and a Patient Throughput Of 220

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	11.4	16.3	3.2	31.7	98.2	100	
				28.2	65.8	100	No
Patient Time in System	9.0	16.1	3.2	12.4	78.9	100	
				11.5	53.0	100	No
Report Cycle Time	29.2	16.3	3.2	58.5	125.0	100	
				37.3	74.2	100	No
Std Deviation of Report Cycle Time	9.1	15.9	3.2	13.2	79.6	100	
				11.4	52.9	100	No
Patient WIP	0.2	0.3	0.1	0.3	1.8	100	
				0.3	1.1	100	No
Report WIP	0.4	0.3	0.1	0.5	2.2	100	
				0.352	1.17	100	No
Machine Utilization	0.0	0.1	0.0	0.1	0.4	100	
				0.1	0.4	100	Yes
Technologist Utilization	0.1	0.1	0.0	0.3	0.7	100	
				0.2	0.5	100	No
Patient Throughput	-0.4	8.4	1.7	25.0	61.0	100	
				25.0	59.0	100	Yes
Reports Throughput	-0.3	8.3	1.7	26.0	60.0	100	
				25.0	59.0	100	Yes

Table B.21 Comparison of Means for Nuclear Medicine Performance Measures with Five Modalities and a Patient Throughput Of 220

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	6.3	60.1	11.9	103.0	356.0	100	
				92.0	294.0	100	Yes
Patient Time in System	1.6	48.2	9.6	17.8	150.0	100	
				14.6	163.0	100	Yes
Report Cycle Time	24.7	59.6	11.8	128.0	380.0	100	
				99.5	301.0	100	No
Std Deviation of Report Cycle Time	1.6	48.1	9.5	17.3	151.0	100	
				15.1	164.0	100	Yes
Patient WIP	0.0	0.5	0.1	0.3	2.3	100	
				0.3	2.8	100	Yes
Report WIP	0.1	0.5	0.1	0.4	2.5	100	
				0.267	2.58	100	No
Machine Utilization	0.0	0.2	0.0	0.2	0.7	100	
				0.2	0.8	100	Yes
Technologist Utilization	0.0	0.2	0.0	0.3	0.8	100	
				0.3	0.9	100	No
Patient Throughput	-0.1	4.5	0.9	8.0	22.0	100	
				7.0	26.0	100	Yes
Reports Throughput	-0.1	4.6	0.9	8.0	22.0	100	
				7.0	26.0	100	Yes

Table B.22 Comparison of Means for Overall Performance Measures with Five Modalities and a Patient Throughput Of 440

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	215.0	52.2	10.4	139.0	383.0	100	
				28.9	32.9	100	No
Std Deviation of Patient Cycle Time	190.0	53.3	10.6	99.9	344.0	100	
				18.1	25.6	100	No
Report Cycle Time	234.0	52.1	10.3	159.0	402.0	100	
				27.6	32.2	100	No
Std Deviation of Report Cycle Time	188.0	53.1	10.5	99.1	340.0	100	
				19.0	26.6	100	No
Patient WIP	19.9	11.1	2.2	22.0	65.2	100	
				8.1	35.3	100	No
Report WIP	22.1	11.1	2.2	24.1	67.4	100	
				7.97	35.2	100	No
Machine Utilization	-0.0466 0	0.0	0.0	0.5	0.6	100	
				0.6	0.7	100	No
Technologist Utilization	0.153 0	0.0	0.0	0.9	1.0	100	
				0.7	0.8	100	No
Patient Throughput	-28.3	21.8	4.3	374.0	438.0	100	
				372.0	481.0	100	No
Reports Throughput	-28.5	21.9	4.3	372.0	440.0	100	
				371.0	481.0	100	No

Table B.23 Comparison of Means for Radiology Performance Measures with Five Modalities and a Patient Throughput Of 440

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	56.5	32.2	6.4	34.8	233.0	100	
				18.8	25.1	100	No
Std Deviation of Patient Cycle Time	39.2	21.2	4.2	16.4	132.0	100	
				2.4	18.1	100	No
Report Cycle Time	77.6	31.8	6.3	55.5	251.0	100	
				18.5	24.2	100	No
Std Deviation of Report Cycle Time	40.1	21.1	4.2	16.7	132.0	100	
				2.7	16.0	100	No
Patient WIP	1.4	1.2	0.2	1.0	7.8	100	
				0.6	2.1	100	No
Report WIP	2.0	1.2	0.2	1.5	8.3	100	
				0.64	2.08	100	No
Machine Utilization	0.000588 0	0.1	0.0	0.3	0.5	100	
				0.3	0.5	100	Yes
Technologist Utilization	0.3	0.1	0.0	0.6	1.0	100	
				0.4	0.7	100	No
Patient Throughput	-0.1	12.3	2.4	69.0	113.0	100	
				73.0	123.0	100	Yes
Reports Throughput	-0.1	12.3	2.4	70.0	113.0	100	
				73.0	123.0	100	Yes

Table B.24 Comparison of Means for Ultrasound Performance Measures with Five Modalities and a Patient Throughput Of 440

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	385.0	162.0	32.2	88.1	806.0	100	
				28.8	32.2	100	No
Std Deviation of Patient Cycle Time	165.0	72.5	14.4	37.3	369.0	100	
				3.2	9.4	100	No
Report Cycle Time	400.0	161.0	32.0	104.0	817.0	100	
				28.9	31.3	100	No
Std Deviation of Report Cycle Time	165.0	72.7	14.4	37.1	368.0	100	
				3.0	7.7	100	No
Patient WIP	7.8	8.4	1.7	2.5	34.9	100	
				1.8	20.9	100	No
Report WIP	8.3	8.4	1.7	2.9	35.4	100	
				1.77	20.9	100	No
Machine Utilization	-0.107 0	0.0	0.0	0.6	0.7	100	
				0.7	0.8	100	No
Technologist Utilization	0.0332 0	0.1	0.0	0.9	1.0	100	
				0.8	1.0	100	No
Patient Throughput	-14.8	5.7	1.1	88.0	88.0	100	
				89.0	117.0	100	No
Reports Throughput	-14.8	5.7	1.1	85.0	88.0	100	
				89.0	117.0	100	No

Table B.25 Comparison of Means for Computed Tomography Performance Measures with Five Modalities and a Patient Throughput Of 440

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	173.0	118.0	23.4	67.0	657.0	100	
				30.7	85.0	100	No
Std Deviation of Patient Cycle Time	83.6	45.2	9.0	35.4	316.0	100	
				2.7	16.9	100	No
Report Cycle Time	209.0	117.0	23.2	81.3	666.0	100	
				18.7	23.8	100	No
Std Deviation of Report Cycle Time	83.6	45.2	9.0	35.1	312.0	100	
				2.7	17.1	100	No
Patient WIP	6.9	5.5	1.1	2.1	33.6	100	
				1.1	3.9	100	No
Report WIP	7.5	5.5	1.1	2.5	34.0	100	
				0.83	3.54	100	No
Machine Utilization	-0.0393 0	0.1	0.0	0.4	0.8	100	
				0.4	0.8	100	No
Technologist Utilization	0.28 0	0.1	0.0	0.8	1.0	100	
				0.5	0.9	100	No
Patient Throughput	-7.2	12.5	2.5	95.0	122.0	100	
				91.0	149.0	100	No
Reports Throughput	-7.4	12.5	2.5	95.0	123.0	100	
				92.0	148.0	100	No

Table B.26 Comparison of Means for Mammography Performance Measures with Five Modalities and a Patient Throughput Of 440

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	163.0	95.9	19.0	57.5	515.0	100	
				20.9	30.4	100	No
Std Deviation of Patient Cycle Time	80.8	39.4	7.8	32.2	202.0	100	
				8.1	27.5	100	No
Report Cycle Time	183.0	95.6	19.0	84.7	543.0	100	
				27.1	35.5	100	No
Std Deviation of Report Cycle Time	81.0	39.6	7.9	32.2	203.0	100	
				8.2	26.9	100	No
Patient WIP	3.1	3.2	0.6	1.4	15.5	100	
				0.7	5.9	100	No
Report WIP	3.6	3.2	0.6	1.9	16.1	100	
				0.836	6.1	100	No
Machine Utilization	-0.0318 0	0.1	0.0	0.3	0.5	100	
				0.3	0.6	100	No
Technologist Utilization	0.2	0.1	0.0	0.7	1.0	100	
				0.5	0.9	100	No
Patient Throughput	-4.5	10.1	2.0	63.0	90.0	100	
				59.0	107.0	100	No
Reports Throughput	-4.5	10.1	2.0	63.0	90.0	100	
				58.0	107.0	100	No

Table B.27 Comparison of Means for Nuclear Medicine Performance Measures with Five Modalities and a Patient Throughput Of 440

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	419.0	208.0	41.2	175.0	1190.0	100	
				92.1	115.0	100	No
Std Deviation of Patient Cycle Time	191.0	86.5	17.2	73.1	478.0	100	
				12.5	49.7	100	No
Report Cycle Time	436.0	204.0	40.5	201.0	1180.0	100	
				96.0	119.0	100	No
Std Deviation of Report Cycle Time	192.0	87.2	17.3	72.7	487.0	100	
				12.5	49.6	100	No
Patient WIP	0.7	3.9	0.8	1.1	16.2	100	
				1.0	12.0	100	Yes
Report WIP	0.9	3.9	0.8	1.3	16.4	100	
				1.03	12	100	No
Machine Utilization	-0.1	0.1	0.0	0.6	0.9	100	
				0.6	1.0	100	No
Technologist Utilization	0.0	0.1	0.0	0.7	1.0	100	
				0.6	1.0	100	Yes
Patient Throughput	-1.7	3.7	0.7	21.0	29.0	100	
				17.0	31.0	100	No
Reports Throughput	-1.7	3.8	0.7	21.0	29.0	100	
				17.0	31.0	100	No

APPENDIX C

The following charts are the results of experiment 3, and include summary statistics and the mean comparisons of the current versus the future state at F.F. Thompson Hospital.

Table C.1 Output Summary of Current F.F. Thompson Hospital Operations/ Week

Performance Measure	Total	Radiology	Ultrasound	Computed Tomography	Mamography	Nuclear Medicine
Patient Cycle Time	43.100 ± 1.60	21.900 ± 0.112	31.500 ± 0.123	45.300 ± 1.870	30.800 ± 0.649	400.000 ± 36.800
Standard deviation of Patient Cycle Time	81.700 ± 7.62	9.850 ± 0.288	6.270 ± 0.217	24.900 ± 2.330	18.600 ± 0.913	172.000 ± 15.600
Information Cycle Time	61.300 ± 1.59	41.900 ± 0.190	47.800 ± 0.208	51.600 ± 1.900	56.200 ± 0.699	421.000 ± 36.500
Standard Deviation of Information Cycle Time	81.800 ± 7.54	10.300 ± 0.296	7.410 ± 0.272	25.600 ± 2.300	19.400 ± 0.874	172.000 ± 15.500
Machine Utilization	0.921 ± 0.008	0.389 ± 0.005	0.287 ± 0.005	0.603 ± 0.013	0.328 ± 0.008	0.929 ± 0.017
Technician Utilization	1.650 ± 0.018	0.343 ± 0.004	0.268 ± 0.005	0.373 ± 0.015	0.373 ± 0.008	0.729 ± 0.022
Patient WIP	11.300 ± 0.58	2.600 ± 0.033	1.200 ± 0.021	1.750 ± 0.090	1.190 ± 0.036	4.580 ± 0.555
Report WIP	15.500 ± 0.59	4.850 ± 0.065	1.770 ± 0.033	1.930 ± 0.093	2.120 ± 0.050	4.790 ± 0.557

Table C.2 Summary of Future FF Thompson Operations/Week

Performance Measure	Total	Radiology	Ultrasound	Computed Tomography	Mamography	Nuclear Medicine
Patient Cycle Time	31.800 ± 0.35	21.400 ± 0.095	30.600 ± 0.106	43.900 ± 1.610	29.800 ± 0.484	121.000 ± 2.970
Standard deviation of Patient Cycle Time	26.300 ± 0.899	9.780 ± 0.271	5.510 ± 0.206	23.700 ± 1.920	18.600 ± 0.682	38.200 ± 2.960
Information Cycle Time	35.000 ± 0.35	24.500 ± 0.085	33.700 ± 0.103	39.900 ± 1.610	39.200 ± 0.481	128.000 ± 2.970
Standard Deviation of Information Cycle Time	26.400 ± 0.90	8.850 ± 0.235	5.000 ± 0.165	23.700 ± 1.920	18.500 ± 0.653	38.300 ± 2.950
Machine Utilization	0.941 ± 0.01	0.314 ± 0.004	0.213 ± 0.004	0.601 ± 0.012	0.337 ± 0.007	0.504 ± 0.020
Technician Utilization	1.320 ± 0.017	0.252 ± 0.003	0.194 ± 0.004	0.369 ± 0.014	0.318 ± 0.006	0.349 ± 0.017
Patient WIP	8.000 ± 0.12	2.640 ± 0.029	1.180 ± 0.024	1.720 ± 0.075	1.190 ± 0.027	1.270 ± 0.074
Report WIP	7.980 ± 0.12	2.620 ± 0.028	1.180 ± 0.024	1.440 ± 0.072	1.430 ± 0.030	1.310 ± 0.076

Table C.3 Overall Performance Measure Comparison of Means Current vs. Future System at F.F. Thompson Hospital

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	11.3	8.0	1.8	30.3	72.8	100	
				28.9	37.4	100	No
Std Deviation of Patient Cycle Time	55.4	37.9	7.5	24.0	217.0	100	
				18.8	39.8	100	No
Report Cycle Time	28.3	7.9	1.8	47.8	89.8	100	
				32.0	40.4	100	No
Std Deviation of Report Cycle Time	55.4	37.4	7.4	24.8	210.0	100	
				18.8	39.8	100	No
Patient WIP	3.3	2.8	0.8	7.1	21.9	100	
				8.7	9.5	100	No
Report WIP	7.5	2.9	0.8	10.8	28.3	100	
				8.7	9.5	100	No
Machine Utilization	0.0	0.1	0.0	0.8	1.1	100	
				0.8	1.1	100	No
Technologist Utilization	0.3	0.1	0.0	1.4	1.9	100	
				1.1	1.5	100	No

Table C.4 Radiology Performance Measure Comparison of Means Current vs. Future System at F.F. Thompson Hospital

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	0.4	0.7	0.1	20.7	23.2	100	
				20.3	22.8	100	No
Std Deviation of Patient Cycle Time	0.1	1.9	0.4	6.4	14.3	100	
				6.4	13.8	100	Yes
Report Cycle Time	17.3	1.0	0.2	40.1	44.8	100	
				23.6	25.7	100	No
Std Deviation of Report Cycle Time	1.5	1.8	0.4	6.9	15.3	100	
				6.2	12.2	100	No
Patient WIP	0.0	0.2	0.0	2.2	3.1	100	
				2.3	3.0	100	Yes
Report WIP	2.2	0.3	0.1	4.1	5.7	100	
				2.3	3.0	100	No
Machine Utilization	0.1	0.0	0.0	0.3	0.5	100	
				0.3	0.4	100	No
Technologist Utilization	0.1	0.0	0.0	0.3	0.4	100	
				0.2	0.3	100	No

TableC.5 Ultrasound Performance Measure Comparison of Means Current vs. Future System at F.F. Thompson Hospital

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	0.9	0.9	0.2	30.1	33.2	100	
				29.6	32.4	100	No
Std Deviation of Patient Cycle Time	0.8	1.6	0.3	3.6	9.7	100	
				3.3	9.5	100	No
Report Cycle Time	14.1	1.2	0.2	45.7	50.4	100	
				32.6	35.3	100	No
Std Deviation of Report Cycle Time	2.4	1.6	0.3	5.2	12.7	100	
				3.6	8.1	100	No
Patient WIP	0.0	0.2	0.0	1.0	1.5	100	
				0.9	1.5	100	Yes
Report WIP	0.6	0.2	0.0	1.4	2.2	100	
				0.9	1.5	100	No
Machine Utilization	0.1	0.0	0.0	0.2	0.3	100	
				0.2	0.3	100	No
Technologist Utilization	0.1	0.0	0.0	0.2	0.3	100	
				0.2	0.2	100	No

Table C.6 Computed Tomography Performance Measure Comparison of Means Current vs. Future System at F.F. Thompson Hospital

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	1.4	12.7	2.5	30.3	76.6	100	
				33.1	67.0	100	Yes
Std Deviation of Patient Cycle Time	1.2	15.7	3.1	9.2	62.1	100	
				8.4	53.1	100	Yes
Report Cycle Time	11.7	12.8	2.5	36.8	84.6	100	
				28.7	62.5	100	No
Std Deviation of Report Cycle Time	1.9	15.5	3.1	10.2	63.3	100	
				8.1	53.0	100	Yes
Patient WIP	0.0	0.6	0.1	1.0	3.3	100	
				1.0	2.7	100	Yes
Report WIP	0.5	0.6	0.1	1.1	3.6	100	
				0.8	2.4	100	No
Machine Utilization	0.0	0.1	0.0	0.4	0.8	100	
				0.4	0.7	100	Yes
Technologist Utilization	0.0	0.1	0.0	0.2	0.6	100	
				0.2	0.5	100	Yes

Table C.7 Mammography Performance Measure Comparison of Means Current vs. Future System at F.F. Thompson Hospital

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	1.0	4.4	0.9	24.6	45.1	100	
				25.4	36.9	100	No
Std Deviation of Patient Cycle Time	0.0	6.4	1.3	9.7	37.6	100	
				11.0	29.0	100	Yes
Report Cycle Time	17.1	4.7	0.9	49.5	70.2	100	
				34.7	46.3	100	No
Std Deviation of Report Cycle Time	0.9	6.1	1.2	11.1	36.3	100	
				11.4	28.6	100	Yes
Patient WIP	0.0	0.2	0.0	0.8	1.8	100	
				0.9	1.6	100	Yes
Report WIP	0.7	0.3	0.1	1.5	2.9	100	
				1.1	1.9	100	No
Machine Utilization	0.0	0.1	0.0	0.2	0.5	100	
				0.2	0.4	100	Yes
Technologist Utilization	0.1	0.0	0.0	0.3	0.5	100	
				0.2	0.4	100	No

Table C.8 Nuclear Medicine Performance Measure Comparison of Means Current vs. Future System at F.F. Thompson Hospital

Performance Measure	Mean Difference	Standard Deviation	95% CI Half-width	Minimum Value	Maximum Value	Number of Observations	Are means equal at 5% Level?
Patient Cycle Time	280.0	183.0	36.4	139.0	1040.0	100	
				92.1	171.0	100	No
Std Deviation of Patient Cycle Time	134.0	78.5	15.6	55.5	444.0	100	
				12.0	88.1	100	No
Report Cycle Time	293.0	182.0	36.1	164.0	1050.0	100	
				99.6	178.0	100	No
Std Deviation of Report Cycle Time	133.0	77.9	15.4	55.1	430.0	100	
				14.1	88.8	100	No
Patient WIP	3.3	2.7	0.5	0.8	15.2	100	
				0.6	2.3	100	No
Report WIP	3.5	2.7	0.5	1.0	15.5	100	
				0.6	2.3	100	No
Machine Utilization	0.4	0.1	0.0	0.6	1.0	100	
				0.3	0.8	100	No
Technologist Utilization	0.4	0.1	0.0	0.4	0.8	100	
				0.2	0.6	100	No

APPENDIX D

This thesis document carries a Computer Disk (CD) that contains files used or developed during this research. It contains the simulation programs written to generate data for the experiments, files regarding data used to perform experiments 1, 2 & 3 and a copy of the thesis report.