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A SYSTEMS APPROACH FOR RE-ENGINEERING HOSPITAL OPERATING ROOM SCHEDULING POLICIES

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ABSTRACT

With the recent changes in the American healthcare system, it is becoming increasingly challenging for hospitals to produce a positive bottom line. The operating room presents itself with a strong potential for helping hospitals bring in revenue. However, in order to be profitable, operating rooms must schedule cases in such a way that optimizes utilization and pleases all stakeholders. Stakeholders include physicians, patients, staff, and hospital administrators. Clearly with so many stakeholders whom have a variety of preferences, this scheduling process can be very challenging. While there has been previous research on this topic, there are still conflicting views on which scheduling method is optimal. This study aims to explore several methods of scheduling cases in the operating room, and determine which method is most beneficial to a hospital. This research utilizes MATLAB to run a computer simulation, which models an operating room and the arrival of surgical cases. Performance measures are then used to compare the simulated schedules.

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Chapter 1

Introduction

1.1 Introduction

This chapter will provide some basic background on the hospital operating room (OR), and its importance in the hospital. This chapter also includes a brief discussion of OR scheduling, and why optimization of this schedule is so important. Following the background section, the overarching problem of OR scheduling will be discussed, after which the research objectives of this thesis will be explained. Finally, the structure and organization of this thesis will be outlined.

1.2 Background and Motivation

The operating room (OR) is both a major revenue generator and an expensive resource in hospitals across the United States. Many ORs are faced with numerous surgical cases each and every day. This sizeable patient volume causes the daily operations in the OR to have an extremely large impact on many departments throughout the hospital. In order for a hospital to perform at high standards and to avoid long wait times for patients, it is vital that OR operations flow smoothly.

In most cases, the OR alone determines the surgical schedule for a hospital; however, the impact of the surgical schedule spreads much greater than just the throughout the OR. In fact, the OR schedule will have an effect on the whole hospital in regards to operational and quality performance. The most common method for scheduling cases in the OR is a block method, in which individual service lines or surgeons have reserved block times for elective surgeries. These elective blocks are assigned to surgeons or surgical specialties based on historical caseload and utilization rates. The surgeons or service lines then add in individual cases to the block time. There may also be a few rooms that are assigned no blocks so that they will be vacant and available in the case of an emergent patient. Although block scheduling does have some benefits, it generally generates substantial variability and low predictability of both OR utilization time and the number of cases performed during block time. This variability exacerbates the already present challenge of expensive staffing and resource allocation in the OR.

Besides reducing financial efficiency, variability in surgical caseload may also have a negative impact on the quality of care in the operating room. A large demand on the OR may cause the OR physicians and staff to become stressed, increasing the chance of medical errors. Furthermore, when there is a high influx of emergency cases and the capacity of the trauma rooms is exceeded, previously scheduled elective surgeries must be delayed or cancelled in order to accommodate the emergency cases. This often results in patient dissatisfaction due to the longer wait times for elective patients. Clearly current methods of OR scheduling are problematic and there is a great need for improvement. Re-engineering OR scheduling policies has the potential to significantly improve OR operations and overall system performance.

A relatively new method of scheduling that some hospitals have adopted is one in which elective cases and emergency cases are separated, and an appropriate number of operating rooms are solely dedicated to emergency cases each day. Users of this scheduling policy claim that it creates higher predictability and efficiency within the OR; however, there is a lack of studies and research to fully validate this claim and establish the conditions under which this policy should be used. While the policy may work well in some ORs, it may not be well suited for other ORs. Various factors such as current OR utilization, room turnover times, impatient bed occupancy, type of surgeries performed, and staffing policies must all be considered before instituting a new scheduling policy. Adopting a new OR scheduling policy without prior study and examination could negatively impact not only the OR, but the entire hospital system.

1.3 Problem Statement

With the financial challenges that hospital and operating room administrators are currently facing, it is now more than ever extremely important to develop a strong scheduling strategy that can optimize operating room use. Optimal OR scheduling is not only capable of producing greater revenue for a hospital, but it may also increase both patient satisfaction as well as physician satisfaction.

Although there have been various studies in the past that have looked into optimizing the scheduling of OR cases, researchers have not agreed upon one method that trumps the rest. This is most likely due to the great variability that exists between the OR suites at different hospitals. That said, the there is plenty of room for further evidence as to what kinds of scheduling strategies and methods generally result in greater operating room utilization.

1.4 Research Objectives

The objective of this research is to develop optimal OR scheduling policies that will enable a hospital to maximize total system performance based on a given set of system metrics. The strategy for reaching this goal consists of two major tactics. First, a literature search will be conducted in order to better understand the pressures and challenges related to creating an operating room schedule and to gain a greater understanding of the overall picture. Secondly, simulations and statistical learning will be used to accurately predict which scheduling strategies can help optimize the OR schedule. The intended outcome of this project is a proposal with scheduling policies that may be used to optimize a hospital operating room schedule.

1.5 Thesis Structure

This thesis begins with a literature review that covers several topics including changes in the healthcare system, the importance of the operating room within a hospital, and computer simulation of an operating room. Following the literature review, a methodology of this research is provided. The results and analysis are then presented in chapter four. Final conclusions and future work are provided in chapter five. While the most important data is contained within the results and analysis section, further data along with MATLAB code can be found in the appendix.

Chapter 2

Literature Review

2.1 Introduction

This literature review will first provide a brief explanation of what the hospital environment looks like today. It will then delve into certain aspects of the Affordable Care Act, and how these aspects are affecting hospitals and the way that they operate. After covering the Affordable Care Act, the literature review will touch upon hospital revenues, and the role that the operating room plays in bringing in money into a hospital. Following this, an explanation of operating room utilization and its importance will be provided, after which several scheduling strategies will be identified. Lastly, the literature review will cover simulation and how simulation can be used as a tool in operating room scheduling.

2.2 The Hospital Environment

The average hospital has a dynamic and constantly changing environment. Physicians, nurses, and staff alike must constantly adapt to new medical protocols and procedures in order to adhere to the highest standard of care for their patients. Recent legislation in the healthcare market, specifically the Affordable Care Act, have placed further pressures on healthcare providers to be open to adjustments and modifications. Hospitals may need to change some of their standard treatment strategies in an effort to improve both efficiency and quality of care.

2.3 The Impact of the Affordable Care Act on Hospitals

One of the most obvious goals of the Affordable Care Act (ACA) is to provide high-quality healthcare to the millions of Americans that were uninsured prior to the passing of the ACA. The approach to do so includes the creation of health insurance exchanges where individuals and businesses alike can purchase private insurance plans. Health plans will also be required to implement quality improvement strategies, and report the quality data to the public (Goodrich, 2013). Furthermore, research into alternative methods of healthcare delivery such as care coordination and team-based care will be established in an effort to drive systems-based improvement, and reduce hospital readmissions and hospital acquired conditions. There will also be funding to create the Patient Centered Outcomes Research Institute, which will perform an assessment of various medical treatments and evaluate which treatments work best for which populations of patients.

While there has been a lot of focus on what the Affordable Care Act will mean for Americans on the patient side of the healthcare equation, the ACA will also have a strong impact on hospitals. Perhaps one of the biggest challenges that hospitals and hospital administrators must tackle as a result of the ACA is the transition from healthcare systems being paid based on volume, to instead being paid based on value. Treatments that a hospital provides must improve the health outcomes of the patient, or else the hospital will not reap any financial rewards from treating the patient. Along the lines of this trend is the value-based purchasing aspect of the ACA. With the implementation of value-based purchasing, payments will be adjusted according to performance; thus, providers will be rewarded for delivering better health outcomes at a lower cost to beneficiaries, rather than being rewarded for providing a greater volume of services (Goodrich, 2013).

There are several other statutes in the ACA that strongly push quality over quantity. One that will directly impact doctors is the Physician Value Modifier Program. Under this program, Medicare fee-for-service payments will be adjusted up or down based on a physician's reported quality metrics. In 2015, physicians may choose to enroll in this program and by 2017 enrollment will be mandatory.

2.4 Hospital Revenues

Clearly, many of the provisions of the Affordable Care Act will change the way that hospitals must operate in order to stay profitable. Many hospitals are already feeling the stress of the current health care environment as seen by their measly financial situations in recent years. In fact, according to Moody's investor's service, Not-for-profit hospitals in the U.S. showed all-time lows for revenue and cash flow for the 2013 fiscal year (Moody's).

Hospitals are facing lower reimbursement pressures from payers on all sides: Medicare, Medicaid, and Commercial Health Insurers. Hospitals are also receiving declining elective patient volumes due to the stagnant economy. Furthermore, hospitals are now required to manage bundled payments and fee-for-service payments all at once (Goldstein, 2011). All of the above-mentioned financial troubles, coupled with nursing shortfalls and rising inpatient costs do not help to paint a bright picture for the future of hospitals. Hospitals undoubtedly are at a crucial point where they must adjust their workflow and productivity in order to effectively navigate the changing healthcare environment, or else face debilitating financial consequences.

2.4.2 Profit Opportunities in the Operating Room

As stated by the Healthcare Financial Management Association, the healthcare industry is at a point of "profitless growth." The beds in the hospital are occupied and it appears that all resourced are being fully utilized; however profits are at a standstill. Almost a third of hospitals in the U.S. have negative total margins, and are actually losing money on each patient that comes into the hospital (HFMA 2002).

In a situation like this, the operating room stands as the single biggest profit opportunity for hospitals (2002). The OR is both the largest revenue producer and cost center in hospitals. It brings in approximately 42% of the average healthcare organization's revenue, and accounts for a proportionate share of an organization's spending. The average hospital's operating room runs at about 68% capacity, thus it clearly presents itself with a great opportunity to improve margins. In fact, scheduling just one additional surgical case each day could result in as much as $1.8 million in additional annual revenue for a hospital (HFMA, 2002).

The Healthcare Financial Management Association identified several aspects of the OR that could be targeted in order to both increase profitability and improve care delivery. First, a hospital could initiate comprehensive performance management in order to measure the effectiveness of planned process improvement. Second, an organization could improve its resource standardization and utilization by developing standard protocols to be followed regularly, and metrics to measure the success in doing so. Finally, a hospital can improve operating room profits by streamlining the workflow. This can be done so by identifying best practices and streamlining work processes in order to improve clinical outcomes, enhance predictability, and improve profitability. Specific opportunities to improve workflow in the OR are listed in the table below.

Table 1. Opportunities to Improve Operating Room Workflow Identified by HFMA

Improve on-time case starts
Reduce downtime
Automate manual activities
Improve sequencing of events
Improve scheduling
Reduce clinical staff time focused on non-clinical activities
Increase patient charge capture

2.5 Operating Room Utilization

As the operating room has such a great potential for hospital profit, it is important that a hospital makes the best use of its OR as possible. OR utilization is equal to the time an OR is in use (set-up, surgery, clean-up) divided by the time that an OR is available and staffed (Dexter, 1999). In the past, before there were the challenges of managed care and capitated payments, operating rooms were run on a first come first serve basis, and generated a strong revenue doing so (Mazzei, 1999). The downside to this method was that as the OR schedule was filled more quickly with patients, it was difficult for doctors to schedule elective cases.

The solution to this was to block off time for specific surgeons and surgical specialties. This often better appeased the surgeons' requests as well since it made their schedules more predictable. Blocking off time did often result in lower OR utilization; however, it was not seen as a large problem since OR utilization rates as low as 20% still were capable of producing some profit for the hospital (Mazzei, 1999).

Recent changes in healthcare have brought greater importance to operating room utilization. Reimbursement for OR cases has decreased due to capitated payment plans, decreased fee for service rates, as well as decreased diagnosis related group payments (Mazzei 1999). Also, there is a high number of surgical cases that must be handled by busy surgical teams, making the scheduling process quite challenging. Hospitals are no longer capable of haphazardly scheduling OR cases and still expecting to make a profit; strong operating room utilization is now of the utmost importance.

With the growing financial pressures of the current healthcare market, hospital and OR managers are faced with the question of how to best schedule OR cases so as to maximize OR use. It is also important to keep in mind how scheduling may affect the patient's experience. A patient's experience will be sculpted by a variety of factors such as their physical health, how long he/she was treated, how long it took to complete registration, the wait time before the procedure, and whether or not medical staff were polite (Popa, 1993). If administrators choose to go with the block scheduling method, several factors must be determined. These factors include deciding which surgeons or surgical specialties should be assigned block time. Furthermore, they must establish and enforce a suggested utilization rate for the block time.

Clearly these decisions should be made based on historical data and facts; unfortunately, it is often challenging to do so without some subjectivity. However, whenever at all possible, OR scheduling decisions should be made without consideration to emotional and/or political issues. Administrators should focus on historical OR and surgeon data, (from a long-term history as data from the past few months is not likely to fully exhibit the intricacies of the OR). Some examples of the historical data that can be examined for bettering OR utilization provided by William Mazzei's "Maximizing Operating Room Utilization: A Landmark Study" are provided in the table below.

Table 2. OR Data that may be Studied

Average Case Duration
Average Patient Wait Time for Surgery
Number of Hours in Each Block
Number of Blocks per Surgeon
Scheduling Strategy
Surgeon's Convenience
Availability of OR for Emergency
Availability of Open Time for Surgeons without Blocks

A few of the key points that Mazzei's study uncovered are that full day blocks generally allow for greater OR utilization than do half-day blocks, and increasing the wait time for elective surgeries from one week to two weeks increased OR utilization by a median value of 13%. In general, Mazzei's study found that greater utilization of the operating room can have a profound effect on the financial well-being of a hospital. In fact, he found that a 10% improvement in OR usage would allow a hospital to close three

ORs in a thirty OR suite without decreasing the number of surgeries. Savings-wise, this is equivalent to negating the cost of all anesthetic drugs (1999).

2.6 Scheduling

As evident by the factors that affect patient experience mentioned earlier, the overall patient flow plays a large role in the overall patient experience. This flow of patients is largely affected by the schedule that administrators choose to implement. Poor scheduling could result in adverse effects on patients and physicians along with poor use of space, staff, and time (Popa 1993). There are several different strategies that hospital and operating room managers may choose to use as they determine how to schedule cases in the OR. The three primary strategies are open schedule, block schedule, and modified block schedule.

Under an open scheduling strategy, patients are assigned OR time on a first come, first serve basis. This strategy is often seen to provide a large amount of flexibility to both patients and physicians, however it does come with its own set of disadvantages. Some of these disadvantages include delays due to waiting for the surgeon to arrive, and gaps between cases (Popa 1993).

With a block scheduling strategy, OR time is blocked off for specific surgeons or surgical specialty. In general, the time remains blocked until a certain number of hours beforehand (typically 24-72 hours), at which point the unused blocked time is made open to other surgeries (Popa 1993). Block time is determined by studying the history of cases at that facility for each specialty and each surgeon. This method of scheduling simplifies the staffing pattern and offers greater time predictability for the surgeons. Some disadvantages with block scheduling are that there may be underutilization of the OR due to a block not being filled, and physicians without block time may find it difficult to gain access to an operating room.

The third fundamental method of scheduling, modified block scheduling, combines aspects of an open schedule with aspects of a block schedule. The majority of OR time is blocked off as in a block schedule; however, there is also open time available for those physicians who do not have blocked time, or for procedures which cannot be completed in just one time block. As in block scheduling, the blocks in modified block scheduling are determined according to the history of cases. The amount of open time required for physicians without blocks also needs to be determined. The blocked time should be reviewed and adjusted on a regular basis to ensure maximum OR utilization. Physicians tend to appreciate the predictability of their work-time under this method of scheduling. Having block time also may increase efficiency, as it is more logical for a physician to perform all of his or her procedures in one day versus over several days (Popa 1993). Some physicians may however find a modified block schedule limiting during times of increased surgical demand, and there is risk of a backlog occurring. One strong method that can be used to determine what kind of schedule best works for an OR is computer simulation.

2.7 Simulation

As defined by Jerry Banks in his textbook, *Discrete-Event System Simulation*, simulation is the imitation of the operation of a real-world process or system over time (2005). By using a simulation model, researchers can determine how a system would change as time passes. Specific alterations can be made to the model in order to answer a multitude of “what if” questions (Banks et al, 2005).

Simulation is an efficient approach to predicting how changes to a system will impact the system’s performance. A simulation that is performed prior to implementing any changes to a system can often save a lot of valuable time and money. Besides being a useful tool for analyzing adjustments to existing systems, simulation can also be used as a design tool to help determine the set-up of a new system, which will allow for optimum efficiency. Each simulation will have a set of measures of the performance of the system; these are known as the numerical parameters.

There are several situations in which a simulation model should and should not be used. Some cases in which a simulation should be used include: when changes can be simulated and observed in a model, when changing certain inputs can demonstrate which variables have the greatest impact, and when one would like to test out policies prior to implementation. Simulations should not be used in cases in which a problem can be solved using common sense, when a problem can be solved analytically, or when the cost of running a simulation exceeds the savings (Banks et al, 2005).

The steps in a simulation study are depicted in the figure below.

Figure 1. Steps in a Simulation Study

http://www.nawouak.net

2.7.2 Operating Room Simulation

Simulation can be used to solve the operating room scheduling problem by developing a mathematical model to simulate the OR case scheduling. The Operating Room can be considered a discrete system, one in which the state variables change at a discrete set of points in time (Banks, 2005). In this case, the state variable is patients arriving, and these patients do indeed only arrive at discrete points in time. The OR is a good place to use simulation as there is uncertainty involved with patient cases, thus it would be extremely difficult to solve for the best schedule analytically.

Previous studies have been completed using computer simulation to study OR scheduling strategies. Dexter's 1999 study mimicked OR suites and scheduling systems using computer-based simulation. He found that it was extremely helpful to use simulation as several of their models resulted in poor OR utilization which could have been financially damaging to a hospital if implemented in the actual operating room. Another benefit of OR simulation is that one can determine the percent change in OR utilization due to change in a single variable (Mazzei 1999). On the other end of the spectrum, simulating the OR with a computer-based model also allows one to study the effects of multiple uncertainties. These may include patient volume, patient case types, number of emergency cases, etc. Studying the effects of these variables experimentally would be extremely challenging, thus computer simulation is a great strategy for determining how to optimize an operating room schedule.

Chapter 3

Methodology

3.1 Introduction

This chapter provides an overview of the methodology of this thesis. Manual simulation of an operating room schedule was first performed. Following this manual scheduling activity, MATLAB was used to code for a simulation model that represents an OR schedule. This chapter describes the steps involved in the creation and validation of the MATLAB code. Lastly, this chapter previews the analysis that was performed on the output of the code.

3.2 Scheduling Conception and Design

3.2.1 Performance Measures

Prior to any operating room simulation, several performance measures needed to be established. Performance measures are the specific measures by which to evaluate the quality of a given OR schedule. There are a myriad of factors that affect the quality of an OR schedule. Perhaps the most obvious performance measure of an operating room schedule is utilization: a comparison of the number of hours that an OR was in use, and the number of hours that it was available. Some performance measures focus strictly on the procedures or cases, such as the number of procedures that were started on time and the number of procedures that ended on time. Other performance measures focus instead on the people involved in the system; for example, performance measures that are impacted by the patients are the number of patients seen in a week, the number of patients that were seen on their preferred date, and the number of patients that were seen at their preferred time. Of course, the patients are not the only people involved in the OR, so there are also performance measures that revolve around the physicians and staff such as the number of surgeons that were required to work overtime and the number of anesthesiologists or other staff that were required to work overtime.

The above list of performance measures is by no means exhaustive, yet it already poses an enormous demand on a simulation if the simulation is to judge a schedule based on all of the listed performance measures. To narrow the scope of this thesis and to simplify the simulation, the performance measures were narrowed down to two primary factors. The first, is operating room utilization which has a large impact on an OR suite's revenue and bottom line. OR utilization is measured in this study by the number of hours that were over or underutilized by the OR. The second performance measure that is focused on is patient satisfaction. Patient satisfaction is determined by how many patients are seen at their scheduled time, compared to how many scheduled patients are bumped due to the arrival of an emergency case.

3.2.2 Manual Scheduling

Before simulating an operating room system via computer simulation, it was important to achieve a better understanding of the challenges that are faced when creating an OR schedule. In order to understand these challenges, several daily OR schedules were created and analyzed by hand. Daily patient cases were randomly created; patient cases varied in duration and time preference for the patient. The cases were then fit into a daily OR schedule like a puzzle. There were multiple ways to fit the cases into a schedule, so each schedule was then analyzed based on the performance measures of utilization and patient satisfaction.

3.3 Model Creation

3.3.1 Creation of an Instance

After the manual scheduling activity, a computer simulation was created to model a single operating room schedule on a larger scale. The simulation model was created in several steps using the program, MATLAB. First, MATLAB code was written to generate an instance. In other words, code was written to generate the arrivals of patients into the OR during the time frame of a week. In order to do so, a blocked schedule was first constructed. The blocked schedule was comprised of four types of surgical cases, labeled one through four for simplicity. Cases were blocked for the hours of 8:00AM to 5:00PM, Monday through Friday. The blocked schedule represents the ideal case schedule in the OR; however, the schedule that actually occurs most often differs from the ideal. For the instance of the actual occurring schedule, each type of surgery was assigned a probability of actually occurring if there was time blocked off for it in the schedule. Based on the probabilities, the code created a new matrix representing the OR schedule that actually occurred for the week.

3.3.2 Addition of Emergency Cases

One of the factors that most often creates differences between the ideal blocked schedule and the schedule that actually occurs in the OR is the arrival of emergency cases. This was mimicked in the instance by once again using probability. The instance code was written so that there was a small probability (10%) that an emergency case would arrive at each hour. If an emergency case did arrive, it would be immediately scheduled, often resulting in bumping out a previously scheduled case.

3.3.3 Calculating Performance Measures

Equally as important as the creation of the instance, is a section of code that analyzes the occurring schedule based on performance measures. As mentioned before, the performance measures that were focused on for this research were OR utilization and patient satisfaction. OR utilization was found by subtracting the number of hours that the OR was in use from the number of hours that the OR had been blocked for use each day. If this resulted in a negative number, it indicated there was underutilization of the OR; a positive number indicated overutilization of the OR. This section of the code was first written separately to ensure that it functioned correctly, after which it was added to the existing code, which coded for the creation of an instance.

3.3.4 Addition of a Second Operating Room

In order better represent an operating room suite, a second OR was created in the code. The process to do so was relatively simple, as the code for a single OR that was already created was essentially duplicated. The code for calculating values for the performance measures for one OR was also replicated for the second OR.

3.3.5 Validation

The code was validated in several ways. First, each section of the code was run individually to ensure that it functioned properly. If a section output any values, the values were checked manually to make sure they were correct. With the addition of each new section of code, this validation process was repeated.

3.4 Schedule Comparisons

Due to the nature of the operating room and the large number of possibilities through which to schedule cases, analytically solving for the best schedule is nearly impossible. Thus, rather than trying to solve for the best schedule initially, the original blocked schedule was modified several times with the intent of improving the performance of the OR. After each modification, the code was run fifteen times and the fifteen results were summed. Through this method, a strong blocked schedule was found.

One struggle that many hospitals have in creating their OR schedules is whether to reserve an operating room solely for emergency cases, or to schedule the operating rooms so that they have some block time for elective cases and some block time for emergency cases. Both of these scheduling methods were simulated and analyzed. The results of each method were compared using T-Tests.

Chapter 4

Results and Analysis

4.1 Introduction

This chapter presents the results and findings of the operating room simulation model. This chapter will first describe the findings that were discovered via the manual scheduling activity. It will then review the findings from the MATLAB simulation model, which modeled a single operating room. Lastly, this chapter will present the findings from a two-OR simulation model, which compared two different methods of scheduling.

4.2 Manual Scheduling

The purpose of the manual scheduling activity was to gain a greater understanding of the intricacies and challenges of creating an operating room schedule. Perhaps the most significant finding from this activity is the level of difficulty there is in appeasing all parties involved with the OR. Patients have time preferences, doctors do not want to work overtime, and hospital administrators want high operating room utilization rates; it is virtually impossible to satisfy all of these stakeholders with one OR schedule. In fact, in almost all of the manually created schedules, the schedule that best fit the desires of the doctor nearly never matched with the schedule that best fit the desires of the patient. This activity also demonstrated that it is extremely challenging to have consistent utilization rates. As the daily cases vary, there is a strong probability for an OR to be both underutilized, or overutilized. The manually created schedules and notes are displayed below.

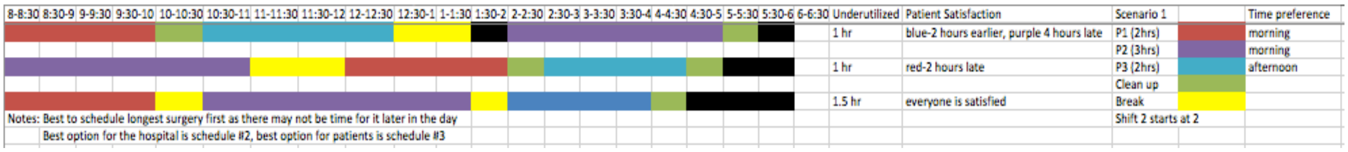

Figure 2. Manual Schedule Example 1

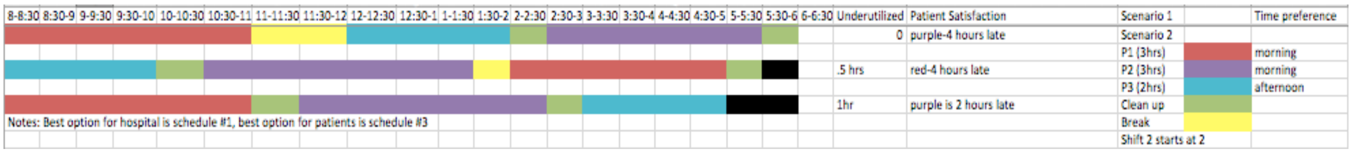

Figure 3. Manual Schedule Example 2

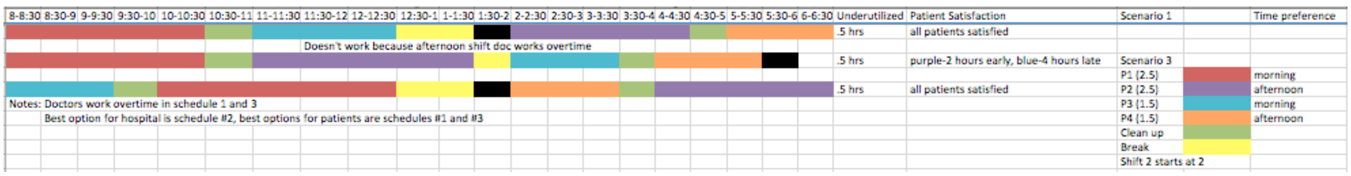

Figure 4. Manual Schedule Example 3

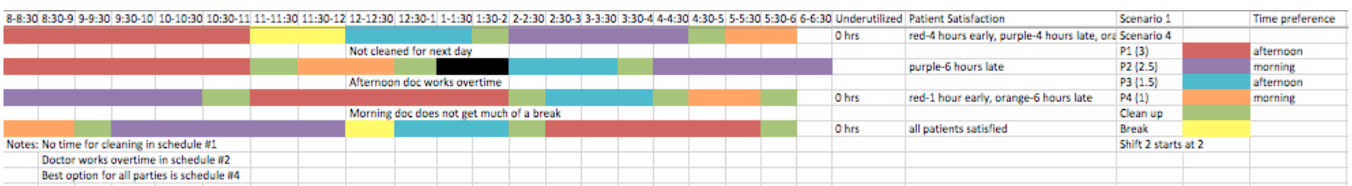

Figure 5. Manual Schedule Example 4

4.3 Single Operating Room Simulation Model

As discussed in chapter three of this thesis, a block schedule was created and then slightly modified several times in order to improve the schedule's performance based on utilization and the patient satisfaction. Utilization was measured based on the number of hours that an OR was over or underutilized. Patient satisfaction was measured based on the number of unhappy patients; patients were considered "unhappy" if their case was bumped due to the arrival of an emergency case. The tables below display the schedule modeled by the simulation, and the resulting data from fifteen runs. For the schedule tables, a "1" in the status column indicates an occupied OR. Surgery types are numbered one through four. For the utilization tables, values are in terms of hours; negative values indicate underutilization and positive values indicate overutilization.

Table 3. Single OR Schedule 1

	Monday		Tuesday		Wednesday		Thursday		Friday	
Time	Status	Type	Status	Type	Status	Type	Status	Type	Status	Type
8	1	1	1	3	1	3	1	2	1	4
9	1	1	1	3	1	3	1	2	1	4
10	1	1	1	3	1	3	1	2	1	4
11	1	1	0	0	1	3	1	2	0	0
12	0	0	1	1	0	0	0	0	0	0
13	1	2	1	1	1	4	1	1	1	3
14	1	2	1	1	1	4	1	1	1	3
15	1	2	1	1	1	4	1	1	1	3
16	1	2	0	0	1	4	1	1	1	3
17	0	0	0	0	1	4	0	0	1	3

Table 4. Single OR Schedule 1 Utilization Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-3	-3	-1	-1	0	-8
2	-1	0	-2	0	2	-1
3	1	-1	0	-2	0	-2
4	-1	-2	-1	-1	0	-5
5	1	0	0	0	0	1
6	0	0	0	-1	-1	-2
7	-2	-1	0	0	-1	-4
8	-1	1	-1	0	0	-1
9	-2	0	-2	-1	0	-5
10	-1	0	-1	-1	0	-3
11	-1	-1	-3	-1	0	-6
12	-1	-1	-1	0	-1	-4
13	0	0	-1	0	0	-1
14	-1	-1	0	-1	0	-3
15	-2	0	0	-1	-3	-6
					Weekly Average:	-3.33

Table 5. Single OR Schedule 1 Unhappy Patients Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	0	0	0	1	1
2	0	0	0	0	1	1
3	2	0	0	0	0	2
4	1	0	0	0	2	3
5	1	0	1	0	0	2
6	1	1	0	0	0	2
7	0	0	0	1	0	1
8	0	1	0	0	0	1
9	0	0	0	0	0	0
10	0	0	1	0	1	2
11	0	0	0	0	0	0
12	0	1	1	1	0	3
13	0	0	1	0	0	1
14	0	0	1	0	1	2
15	0	0	2	2	0	4
					Weekly Average:	1.87

Table 6. Single OR Schedule 2

	Monday		Tuesday		Wednesday		Thursday		Friday	
Time	Status	Type	Status	Type	Status	Type	Status	Type	Status	Type
8	1	1	1	3	1	3	1	2	1	4
9	1	1	1	3	1	3	1	2	1	4
10	1	1	1	3	1	3	1	2	1	4
11	1	1	0	0	1	3	1	2	0	0
12	0	0	1	1	0	0	0	0	0	0
13	1	1	1	1	1	3	1	2	1	4
14	1	1	1	1	1	3	1	2	1	4
15	1	1	1	1	1	3	1	2	1	4
16	1	1	0	0	1	3	1	2	1	4
17	0	1	0	0	1	3	0	0	1	4

Table 7. Single OR Schedule 2 Utilization Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	-1	-1	0	-1	-3
2	0	0	-2	0	0	-2
3	0	-2	0	-1	0	-3
4	0	-1	-1	-1	-1	-4
5	0	1	-1	-1	-1	-2
6	0	0	0	-1	0	-1
7	0	0	-1	-1	-1	-3
8	0	0	-2	0	0	-2
9	-1	0	0	-2	1	-2
10	0	-1	0	2	0	1
11	-1	-2	-1	0	-1	-5
12	-1	-1	0	0	0	-2
13	1	1	-2	-1	-2	-3
14	1	0	0	1	-1	1
15	0	0	-2	-1	1	-2
					Weekly Average:	-2.13

Table 8. Single OR Schedule 2 Unhappy Patients Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	0	1	0	1	2
2	0	1	0	0	1	2
3	0	0	0	0	0	0
4	0	0	1	0	0	1
5	0	1	0	0	0	1
6	0	0	1	0	0	1
7	1	0	0	0	0	1
8	0	0	1	0	0	1
9	1	0	0	0	1	2
10	0	0	1	2	1	4
11	0	0	0	0	1	1
12	0	0	0	2	0	2
13	1	1	0	0	0	2
14	0	1	0	1	1	3
15	0	0	1	2	2	5
					Weekly Average:	1.87

Table 9. Single OR Schedule 3

	Monday		Tuesday		Wednesday		Thursday		Friday	
Time	Status	Type	Status	Type	Status	Type	Status	Type	Status	Type
8	1	1	1	3	1	3	1	2	1	4
9	1	1	1	3	1	3	1	2	1	4
10	1	1	1	3	1	3	1	2	1	4
11	1	1	1	3	1	3	1	2	0	0
12	0	0	0	0	0	0	0	0	0	0
13	1	3	0	0	1	1	1	2	1	4
14	1	3	0	0	1	1	1	2	1	4
15	1	3	1	1	1	1	1	2	1	4
16	1	3	1	1	1	1	1	2	1	4
17	1	3	1	1	1	1	0	0	1	4

Table 10. Single OR Schedule 3 Utilization Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-1	-1	-1	1	0	-2
2	0	2	-1	0	-1	0
3	-3	1	-1	0	-1	-4
4	0	-1	0	0	-1	-2
5	-3	0	-1	0	1	-3
6	0	0	-1	0	-1	-2
7	0	0	0	-1	-2	-3
8	-1	0	1	0	0	0
9	0	1	-1	0	0	0
10	-1	-2	-1	0	0	-4
11	0	0	0	-1	-1	-2
12	-1	1	-1	0	-1	-2
13	-1	-2	-2	0	0	-5
14	0	-2	-2	0	0	-4
15	0	-2	0	0	0	-2
					Weekly Average:	-2.33

Table 11. Single OR Schedule 3 Unhappy Patients Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	0	0	1	1	2
2	0	1	1	0	1	3
3	0	1	0	1	0	2
4	1	1	1	0	0	3
5	0	0	0	0	1	1
6	0	0	0	0	0	0
7	0	0	1	2	0	3
8	1	0	1	0	1	3
9	0	1	0	0	0	1
10	0	1	0	2	0	3
11	0	0	0	0	0	0
12	1	1	0	0	1	3
13	0	0	0	0	2	2
14	0	1	0	0	1	2
15	0	0	0	0	1	1
					Weekly Average:	1.93

Table 12. Single OR Schedule 4

	Monday		Tuesday		Wednesday		Thursday		Friday	
Time	Status	Type	Status	Type	Status	Type	Status	Type	Status	Type
8	1	1	1	3	1	3	1	2	1	4
9	1	1	1	3	1	3	1	2	1	4
10	1	1	1	3	1	3	1	2	1	4
11	1	1	1	3	1	3	1	2	0	0
12	0	0	0	0	0	0	0	0	0	0
13	1	1	0	0	0	0	1	2	1	4
14	1	1	0	0	1	3	1	2	1	4
15	1	1	1	1	1	3	1	2	1	4
16	1	1	1	1	1	3	1	2	1	4
17	1	1	1	1	1	3	0	0	1	4

Table 13. Single OR Schedule 4 Utilization Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-1	-1	-2	0	0	-4
2	0	0	-2	0	0	-2
3	-3	0	0	0	0	-3
4	0	-2	-1	0	0	-3
5	-1	0	-1	0	0	-2
6	0	-1	0	-1	-1	-3
7	0	-1	-1	-1	-1	-4
8	0	-2	-1	-2	0	-5
9	-1	0	-1	0	-2	-4
10	1	0	-1	0	0	0
11	0	-2	-1	-1	0	-4
12	-3	0	-1	-1	1	-4
13	-1	0	0	0	-1	-2
14	-1	0	0	0	-1	-2
15	0	1	-2	0	0	-1
					Weekly Average:	-2.87

Table 14. Single OR Schedule 4 Unhappy Patients Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	1	0	0	0	0	1
2	0	1	1	1	1	4
3	0	0	0	1	0	1
4	0	0	0	1	0	1
5	1	0	1	1	1	4
6	0	0	0	0	0	0
7	0	0	1	0	1	2
8	0	0	0	0	0	0
9	0	0	0	0	1	1
10	1	1	0	0	1	3
11	0	0	0	1	2	3
12	0	1	1	0	1	3
13	0	0	1	1	1	3
14	0	0	1	0	1	2
15	1	1	0	1	0	3
					Weekly Average:	2.07

Table 15. Single OR Schedule 5

	Monday		Tuesday		Wednesday		Thursday		Friday	
Time	Status	Type	Status	Type	Status	Type	Status	Type	Status	Type
8	1	1	1	3	1	3	1	2	1	4
9	1	1	1	3	1	3	1	2	1	4
10	1	1	1	3	1	3	1	2	1	4
11	1	1	1	3	0	0	1	2	0	0
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	1	2	1	4
14	0	0	0	0	1	1	1	2	1	4
15	1	3	1	1	1	1	1	2	1	4
16	1	3	1	1	1	1	1	2	1	4
17	1	3	1	1	1	1	0	0	1	4

Table 16. Single OR Schedule 5 Utilization Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-2	0	0	0	-1	-3
2	0	-2	2	0	0	0
3	0	-1	-1	0	-1	-3
4	0	-1	-1	1	0	-1
5	-1	0	0	0	0	-1
6	-1	-1	1	-1	0	-2
7	1	-2	0	0	0	-1
8	1	0	-1	0	0	0
9	-1	0	-1	-1	0	-3
10	0	1	-2	-1	-2	-4
11	0	0	0	-1	-1	-2
12	-3	0	0	0	-1	-4
13	1	-1	-1	1	-1	-1
14	-1	-1	-1	0	-1	-4
15	0	1	1	-1	-1	0
					Weekly Average:	-1.93

Table 17. Single OR Schedule 5 Unhappy Patients Results

Trial Number	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	0	1	0	0	1
2	1	0	1	0	2	4
3	0	0	1	0	1	2
4	0	0	0	1	0	1
5	0	1	0	1	1	3
6	0	0	1	0	0	1
7	1	0	0	0	1	2
8	1	0	0	0	1	2
9	0	0	0	0	0	0
10	0	1	0	1	0	2
11	0	0	0	1	0	1
12	0	1	0	0	0	1
13	1	1	0	1	1	4
14	1	0	0	1	0	2
15	0	1	1	0	0	2
					Weekly Average:	1.87

Various observations can be made from the above data. First, the greater the number of hours blocked for a type 1 surgery, the greater the utilization. This is due to the fact that type 1 surgeries were given the greatest probability of actually occurring if scheduled (followed by type 2, then 3, then 4). Along these same lines, days that were block scheduled all day for type 1 had very strong utilization; however, this manner of scheduling often left some days of the week with all type 3 or type 4 surgeries, resulting in poor utilization.

A greater number of breaks scheduled in the day resulted in fewer disruptions of the schedule due to emergency arrivals. This is especially true with long breaks scheduled in the middle of the day. Besides scheduling more breaks (which often is not even an option for hospitals), there is not much that can be done to reduce the number of unhappy patients. If an emergency case comes in at a time that an elective surgery was scheduled, the emergency case takes precedence and the elective case is bumped.

From the above tables, it can be concluded that schedule 5 produced the best results of the five block schedules that were simulated. For this reason, schedule 5 was used in the next simulation of this research which compared two methods of scheduling a two OR suite.

4.4 Two-Operating Room Suite Simulation Model

In this section of the research, two methods of scheduling a two-OR suite were studied. The first method consisted of one OR running with a full block schedule. The block schedule was schedule 5 from the previous section. The second OR was left open for emergency cases. All emergency cases would go into the OR 2 unless there was already an emergency surgery being performed there, in which case the second emergency surgery would bump the existing surgery in OR 1.

The second method of scheduling a two-OR suite consisted of each OR room running with a half-block, half-open schedule. The schedules were made in such a way that if OR 1 was blocked for elective surgery, then OR 2 would be open and vice versa. Emergency surgeries were always placed in an open OR if one was available. Both of these scheduling methods were simulated twice: once with a 10% chance of an emergency case coming in each hour, and once with a 30% chance of an emergency case coming in each hour. A summary of the results from these two methods of scheduling is presented in the tables below. Further data can be found in appendices B and C.

4.4.2 Data Set 1: 10% Probability of Emergency Case

Table 18. Full-Block/Open and Half-Block/Open Comparison

	Room 1 Utilization Average	Room 2 Utilization Average	Average Weekly Utilization	Room 1 Unhappy Patients Average	Room 2 Unhappy Patients Average	Average Total Unhappy Patients
Full Block/Open	-2.40	-24.87	-13.64	1.03	0.00	1.03
Half Block/Open	-12.13	-13.00	-12.57	0.43	0.53	0.97

Table 19. Full-Block/Open and Half-Block/Open Utilization Comparison

Full Block/Open: Summed Utilization	Half Block/Open: Summed Utilization
-29	-32
-28	-36
-29	-21
-28	-27
-41	-32
-30	-29
-22	-22
-33	-28
-32	-22
-23	-27
-25	-22
-26	-27
-29	-21
-21	-29
-26	-32
-23	-15
-26	-22
-35	-27
-23	-23
-22	-22
-26	-17
-35	-19
-22	-27
-29	-23
-28	-30
-28	-23
-20	-25
-24	-25
-34	-23
-21	-26
T-Test:	0.073

Table 20. Full-Block/Open and Half-Block/Open Unhappy Patients Comparison

Full Block/Open: Summed Unhappy Patients	Half Block/Open: Summed Unhappy Patients
1	2
0	1
1	4
1	1
0	1
1	1
2	2
1	1
2	1
1	2
1	1
1	2
1	1
2	0
1	0
2	0
1	2
0	0
1	0
0	1
0	2
0	0
2	0
0	0
1	0
1	0
3	1
2	1
0	0
2	2
T-Test:	0.763372109

4.4.3 Data Set 2: 30% Probability of Emergency Case

Table 21. Full-Block/Open and Half-Block/Open Comparison

	Room 1 Utilization Average	Room 2 Utilization Average	Average Weekly Utilization	Room 1 Unhappy Patients Average	Room 2 Unhappy Patients Average	Average Total Unhappy Patients
Full Block/Open	1.97	-3.03	-0.53	6.63	0.00	6.63
Half Block/Open	-2.23	-2.57	-2.40	2.43	2.13	4.57

Table 22. Full-Block/Open and Half-Block/Open Utilization Comparison

Full Block/Open: Summed Utilization	Half Block/Open: Summed Utilization
-10	1
-2	-6
4	-5
-7	-3
6	-14
2	-3
-3	-3
-10	-2
5	5
-6	-8
4	-1
-2	-9
1	2
1	-3
-5	0
1	-7
4	0
-4	-6
-2	-13
0	-3
-5	-2
0	-11
0	-6
6	-13
3	-14
3	-6
-6	-3
-9	2
3	-7
-4	-6
T-Test:	0.0139

Table 23. Full-Block/Open and Half-Block/Open Unhappy Patients Comparison

Full Block/Open: Summed Unhappy Patients	Half Block/Open: Summed Unhappy Patients
6	4
4	3
5	1
7	5
9	5
7	5
4	5
6	3
10	4
5	5
7	5
7	6
9	7
5	6
5	7
9	7
9	5
5	4
6	2
5	7
6	4
9	1
7	5
7	3
7	4
7	5
6	6
4	5
8	6
8	2
T-Test:	4.169E-05

As evident from the above tables, a half-block, half-open schedule resulted in better utilization and fewer unhappy patients compared to the full-block/open schedule for the scenario where there was a 10% probability of an emergency case. The half-block/open schedule also resulted in fewer unhappy patients with a 30% probability of emergency cases as well. On the other hand, the full-block/open schedule produced better average utilization than the half-block/open method when there was a 30% probability of emergency. It is important to note however, that OR 1 in the full-block/open was over-utilized. Many ORs may not have the necessary funds and resources to staff an OR for more hours than it scheduled for.

T-Tests comparing the average weekly utilization and number of unhappy patients resulting from each method of scheduling showed that there is indeed a significant difference between both the utilization and unhappy patients achieved with each method of scheduling when there is a 10% chance of an emergency case coming in. Thus, scheduling a half-block, half-open schedule is more beneficial when the rate of emergency arrivals is 10%. On the other hand, the T-Tests show that for the scenario where there is a 30% probability for an emergency case, there is in fact no significant difference between the results of the two scheduling methods.

Chapter 5

Conclusions and Future Work

5.1 Conclusions

Based on the performance measures of utilization and patient satisfaction that were studied in this research, it can be concluded that the optimal schedule for an OR or an OR suite depends on the probability of the arrival of an emergency case. If there is a relatively low probability (~10%), then this research shows that scheduling each OR in a half-block, half-open manner is a strong method for achieving good utilization and few unhappy patients. On the other hand, if there is a relatively higher probability for the arrival of emergency cases (~30%) then there is not a significant difference in fully block scheduling one OR and leaving a second OR open compared to scheduling both ORs in a half-block, half-open method.

5.2 Future Work

There are many factors that impact the quality of an operating room schedule. As this research only focused on two of these factors, there is a significant level of uncertainty in the results. Each hospital is unique, and has its own set of criteria that it finds most important when creating an operating room schedule. In order to create an optimal OR schedule, the scheduler must consider the individual hospital and the needs and desires of its stakeholders.

The current MATLAB simulation code can be improved upon by using data from an actual hospital. The types of surgeries, the probability that a type of surgery occurs, and the probability for emergency cases can all be adjusted to match the hospital being studied. This way, the results will be capable of better predicting how different methods of scheduling cases in the OR will impact the hospital.

Appendix A

MATLAB Simulation Code

```
% blocked schedule

b=[1   1   1   0   1   3   0   0   1   3   0   0   1
       2   0   0   1   4   0   0
   1   1   0   0   1   3   0   0   1   3   0   0   1
       2   0   0   1   4   0   0
   1   1   0   0   1   3   0   0   1   3   0   0   1
       2   0   0   1   4   0   0
   1   1   0   0   1   3   0   0   0   0   0   0   1
       2   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0
       0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   1
       2   0   0   1   4   0   0
   0   0   0   0   0   0   0   0   1   1   0   0   1
       2   0   0   1   4   0   0
   1   3   0   0   1   1   0   0   1   1   0   0   1
       2   0   0   1   4   0   0
   1   3   0   0   1   1   0   0   1   1   0   0   1
       2   0   0   1   4   0   0
   1   3   0   0   1   1   0   0   1   1   0   0   0
       0   0   0   1   4   0   0];

b2=[1  0   0   0   1   0   0   0   1   0   0   0   1
       0   0   0   1   0   0   0
   1   0   0   0   1   0   0   0   1   0   0   0   1
       0   0   0   1   0   0   0
   1   0   0   0   1   0   0   0   1   0   0   0   1
       0   0   0   1   0   0   0
   1   0   0   0   1   0   0   0   1   0   0   0   1
       0   0   0   1   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0
       0   0   0   0   0   0   0
   1   0   0   0   1   0   0   0   1   0   0   0   1
       0   0   0   1   0   0   0
   1   0   0   0   1   0   0   0   1   0   0   0   1
       0   0   0   1   0   0   0
   1   0   0   0   1   0   0   0   1   0   0   0   1
       0   0   0   1   0   0   0
   1   0   0   0   1   0   0   0   1   0   0   0   1
       0   0   0   1   0   0   0
   0   0   0   0   0   0   0   0   1   0   0   0   0
       0   0   0   0   0   0   0];
```

```
unhappy_patients=zeros(1,5);
unhappy_patients2=zeros(1,5);

% column titles

status=[1 5 9 13 17];
type=[2 6 10 14 18];
patient=[3 7 11 15 19];
time=[4,8 12 16 20];

a=zeros(10,20);
a2=zeros(10,20);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Room1

% matrix of random numbers between 0 and 1 for probability of type of
% surgery occurring
x=rand(10,5);

% random number for probability of emergency
y=rand(10,5);
% for loop to calculate actual occuring scheduled surgeries
for i=1:5
   for j=1:10

       if isequal(1,b(j,type(i)) && (x(j,i)>0) && (x(j,i)<.9))
          a(j,type(i))=b(j,type(i));

       elseif isequal(2,b(j,type(i)))&& (x(j,i)>0) && (x(j,i)<.8)
             a(j,type(i))=b(j,type(i));

             elseif isequal(3,b(j,type(i)))&& (x(j,i)>0) && (x(j,i)<.9)
             a(j,type(i))=b(j,type(i));

             elseif isequal(4,b(j,type(i)))&& (x(j,i)>0) && (x(j,i)<.8)
             a(j,type(i))=b(j,type(i));


        end
   end
end

% for loop to add in emergency surgeries
for i=1:5
   for j=1:10
       if (y(j,i)>0) && (y(j,i)<.3)
          a(j,type(i))=911;
          if a(j,type(i))==911 && (y(j,i)>0) && (y(j,i)<.5)
```

```
            a((j+1),type(i))=911;
        end
    end
    end
end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%
 % Room 2

 % random number for probability of emergency
y=rand(10,5);


% for loop to add in emergency surgeries to room 2
for i=1:5
    for j=1:10
        if (y(j,i)>0) && (y(j,i)<.3)
            a2(j,type(i))=911;
            if a2(j,type(i))==911 && (y(j,i)>0) && (y(j,i)<.5)
                a2((j+1),type(i))=911;
        end
    end
    end
end

% for loop to move emergencies from room 1 to room 2

for i=1:5
    for j=1:10
        if a(j,type(i))==911 && a2(j,type(i))==0
            a(j,type(i))=b(j,type(i));
            a2(j,type(i))=911;
        end
    end
end



% for loop to fill in OR status (empty/full) for room 2
for i=1:5
    for j=1:10
        if a2 (j,type(i))~=0
            a2(j,status(i))=1;
        end
    end
end

% for loop to place unhappy patients
```

```
for i=1:5
    for j=2:10
        if a2(j,type(i))==911 && a2 ((j-1),type(i))~=911 && b2 (j,type(i))~=0
            a2(j,time(i))=1;
        end
    end
end
% for loop to calculate over(+) or under(-) utilization
for i=1:5
    for j=1:10
        utilization2(j,i)=a2(j,status(i))-b2(j,status(i));
    end
end
   utilization2;
   disp('Operating Room 2 Data')
   disp('Hours of over(+) or under(-) utilization each day')
   utilization2=sum(utilization2)




    % for loop to fill in schedule with patients
 % monday
 p=1;
 a2(1,patient(1))=p;
for i=1
     for j=2:10

         if a2 (j,type(i))~=0 && a2 ((j),type(i))~=a2((j-1),type(i))
             p=p+1;
              a2(j,patient(i))=p;

         else
             a2(j,patient(i))=0;
         end
     end
end
% tuesday
p=p+1;
a2(1,patient(2))=p;
for i=2
     for j=2:10

         if a2 (j,type(i))~=0 && a2 ((j),type(i))~=a2((j-1),type(i))
             p=p+1;
              a2(j,patient(i))=p;

         else
             a2(j,patient(i))=0;
```

```
        end
    end
end
 % wednesday
    p=p+1;
a2(1,patient(3))=p;
for i=3
    for j=2:10

        if a2 (j,type(i))~=0 && a2 ((j),type(i))~=a2((j-1),type(i))
            p=p+1;
             a2(j,patient(i))=p;

        else
            a2(j,patient(i))=0;
        end
    end
end
 % thursday
    p=p+1;
a2(1,patient(4))=p;
for i=4
    for j=2:10

        if a2 (j,type(i))~=0 && a2 ((j),type(i))~=a2((j-1),type(i))
            p=p+1;
             a2(j,patient(i))=p;

        else
            a2(j,patient(i))=0;
        end
    end
end
 % friday
    p=p+1;
a2(1,patient(5))=p;
for i=5
    for j=2:10

        if a2 (j,type(i))~=0 && a2 ((j),type(i))~=a2((j-1),type(i))
            p=p+1;
             a2(j,patient(i))=p;

        else
            a2(j,patient(i))=0;
        end
    end
end
  a2;
```

```
 %%%%%%%%%%%%%%%%%%%%%%%% Room 1
 %%%%%%%%%%%%%%%%%%%%%%%% Results
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 % for loop to fill in OR status (empty/full)
for i=1:5
   for j=1:10
      if a (j,type(i))~=0
         a(j,status(i))=1;
      end
   end
end

% for loop to calculate unhappy patients
for i=1:5
   for j=2:10
      if a(j,type(i))==911 && a ((j-1),type(i))~=911
         a(j,time(i))=1;
      end
   end
end
% for loop to calculate over(+) or under(-) utilization
for i=1:5
   for j=1:10
      utilization(j,i)=a(j,status(i))-b(j,status(i));
   end
end
  utilization;
  disp('Operating Room 1 Data')
  disp('Hours of over(+) or under(-) utilization each day')
  utilization=sum(utilization)


  % for loop to calculate number of patients who were not happy with their
  % surgery time
 for i=1:5
     for j=1:10
        if a (j,time(i))~=0
           unhappy_patients(i)=unhappy_patients(i)+1;

        end
     end
 end
  disp('Number of patients each day who were not happy with their scheduled surgery time')
  unhappy_patients


   % for loop to fill in schedule with patients
 % monday
 p=1;
```

```
 a(1,patient(1))=p;
for i=1
    for j=2:10

        if a (j,type(i))~=0 && a ((j),type(i))~=a((j-1),type(i))
            p=p+1;
             a(j,patient(i))=p;

        else
            a(j,patient(i))=0;
        end
    end
end
% tuesday
p=p+1;
a(1,patient(2))=p;
for i=2
    for j=2:10

        if a (j,type(i))~=0 && a ((j),type(i))~=a((j-1),type(i))
            p=p+1;
             a(j,patient(i))=p;

        else
            a(j,patient(i))=0;
        end
    end
end
 % wednesday
    p=p+1;
a(1,patient(3))=p;
for i=3
    for j=2:10

        if a (j,type(i))~=0 && a ((j),type(i))~=a((j-1),type(i))
            p=p+1;
             a(j,patient(i))=p;

        else
            a(j,patient(i))=0;
        end
    end
end
 % thursday
    p=p+1;
a(1,patient(4))=p;
for i=4
    for j=2:10

        if a (j,type(i))~=0 && a ((j),type(i))~=a((j-1),type(i))
```

```
            p=p+1;
             a(j,patient(i))=p;

        else
            a(j,patient(i))=0;
        end
    end
end
 % friday
    p=p+1;
a(1,patient(5))=p;
for i=5
    for j=2:10

        if a (j,type(i))~=0 && a ((j),type(i))~=a((j-1),type(i))
            p=p+1;
             a(j,patient(i))=p;

        else
            a(j,patient(i))=0;
        end
    end
end

a;
a2;

% room1_utilization=zeros(30,5);
% room1_unhappy=zeros(30,5);
% room2_utilization=zeros(30,5);
% room2_unhappy=zeros(30,5);

k=30;

room1_utilization(k,:)=utilization(1,:);
room1_unhappy(k,:)=unhappy_patients(1,:);
room2_utilization(k,:)=utilization2(1,:);
room2_unhappy(k,:)=unhappy_patients(1,:);

room1_utilization
room1_unhappy
room2_utilization
room2_unhappy
```

Appendix B

Full-Block, Full-Open OR Data

Data for 10% Probability of Emergency Arrival:

Table 24. Room 1 Utilization

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	0	-1	-1	0	-2
2	0	0	-2	0	0	-2
3	-2	0	-1	-1	-1	-5
4	0	-2	-1	-1	0	-4
5	-1	0	0	-2	-1	-4
6	0	0	0	-2	-1	-3
7	-1	1	-1	0	-1	-2
8	-1	0	-1	-3	1	-4
9	-1	-2	-1	1	-2	-5
10	-2	0	0	-2	0	-4
11	-1	-1	-1	-1	0	-4
12	-1	-1	-1	0	0	-3
13	-1	0	-1	0	0	-2
14	0	-1	0	0	-1	-2
15	0	0	0	-2	0	-2
16	0	0	0	-2	-1	-3
17	0	0	0	-1	0	-1
18	0	-1	-1	-1	-1	-4
19	-1	0	0	0	0	-1
20	0	0	0	0	0	0
21	0	0	0	-2	0	-2
22	-1	-1	0	-1	0	-3
23	0	-1	-1	0	0	-2
24	0	0	0	0	0	0
25	-1	0	-1	0	-1	-3
26	-1	0	0	0	0	-1
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	-1	0	0	-1	-1	-3
30	0	0	1	-1	-1	-1

Weekly Average: -2.4

Table 25. Room 1 Unhappy Patients

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	1	0	0	0	0	1
2	0	0	0	0	0	0
3	1	0	0	0	0	1
4	0	0	0	0	1	1
5	0	0	0	0	0	0
6	0	0	1	0	0	1
7	1	1	0	0	0	2
8	0	0	0	0	1	1
9	0	0	1	1	0	2
10	1	0	0	0	0	1
11	0	0	0	0	1	1
12	1	0	0	0	0	1
13	0	1	0	0	0	1
14	0	0	0	1	1	2
15	1	0	0	0	0	1
16	1	0	1	0	0	2
17	1	0	0	0	0	1
18	0	0	0	0	0	0
19	0	0	1	0	0	1
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	1	1	2
24	0	0	0	0	0	0
25	0	0	0	1	0	1
26	0	0	0	0	1	1
27	1	1	0	1	0	3
28	0	1	1	0	0	2
29	0	0	0	0	0	0
30	0	0	1	1	0	2

Weekly Average: 1.03

Table 26. Room 2 (Open Schedule) Utilization

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-4	-5	-7	-7	-4	-27
2	-4	-7	-5	-4	-6	-26
3	-3	-6	-7	-6	-2	-24
4	-3	-6	-8	-6	-1	-24
5	-8	-6	-9	-8	-6	-37
6	-6	-6	-3	-6	-6	-27
7	-3	-2	-5	-2	-8	-20
8	-8	-5	-7	-5	-4	-29
9	-4	-6	-5	-5	-7	-27
10	-3	-1	-7	-6	-2	-19
11	-4	-5	-5	-5	-2	-21
12	-3	-8	-4	-4	-4	-23
13	-6	-5	-4	-6	-6	-27
14	-2	-5	-8	-1	-3	-19
15	-3	-8	-5	-6	-2	-24
16	-3	-2	-3	-6	-6	-20
17	-7	-3	-5	-4	-6	-25
18	-5	-7	-7	-5	-7	-31
19	-3	-3	-5	-6	-5	-22
20	-4	-6	-7	-3	-2	-22
21	-4	-4	-6	-6	-4	-24
22	-8	-8	-7	-5	-4	-32
23	-3	-4	-9	-2	-2	-20
24	-8	-5	-5	-6	-5	-29
25	-6	-4	-8	-1	-6	-25
26	-8	-6	-4	-6	-3	-27
27	-3	-5	-5	-3	-4	-20
28	-6	-4	-6	-5	-3	-24
29	-8	-8	-6	-3	-6	-31
30	-1	-6	-4	-4	-5	-20

Weekly
Average: -24.87

Data for 30% Probability of Emergency Arrival:

Table 27. Room 1 Utilization

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	1	0	1	0	-2	0
2	0	1	-1	0	0	0
3	0	0	1	1	1	3
4	1	2	0	0	-1	2
5	2	1	3	1	0	7
6	0	0	0	1	-1	0
7	0	0	0	0	2	2
8	-1	0	0	0	0	-1
9	1	2	1	2	2	8
10	-1	0	0	0	0	-1
11	2	3	0	0	0	5
12	0	1	0	0	-1	0
13	1	1	2	1	0	5
14	0	1	0	1	-1	1
15	0	0	0	0	0	0
16	1	0	0	1	-1	1
17	0	-1	1	0	1	1
18	0	0	0	1	0	1
19	1	0	0	0	0	1
20	1	2	1	0	1	5
21	1	-1	-1	-1	0	-2
22	1	-1	2	1	1	4
23	2	0	2	2	0	6
24	0	2	2	0	1	5
25	0	-1	2	1	0	2
26	2	-1	1	1	0	3
27	1	0	0	0	-1	0
28	0	0	0	0	0	0
29	0	2	0	0	0	2
30	-2	0	1	-1	1	-1

Weekly
Average: 1.97

Table 28. Room 1 Unhappy Patients

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	2	1	2	0	1	6
2	0	1	0	2	1	4
3	0	2	1	1	1	5
4	2	1	1	2	1	7
5	3	3	1	1	1	9
6	0	2	1	2	2	7
7	1	1	1	0	1	4
8	1	1	1	1	2	6
9	3	2	2	2	1	10
10	1	2	0	1	1	5
11	2	2	0	1	2	7
12	2	1	1	2	1	7
13	2	2	2	2	1	9
14	1	1	1	1	1	5
15	1	0	2	1	1	5
16	2	2	1	3	1	9
17	2	1	3	2	1	9
18	1	1	0	2	1	5
19	2	0	1	1	2	6
20	1	2	1	0	1	5
21	2	2	1	0	1	6
22	2	1	2	2	2	9
23	1	0	2	2	2	7
24	1	2	1	1	2	7
25	1	2	1	1	2	7
26	1	1	3	1	1	7
27	2	0	0	2	2	6
28	1	2	0	0	1	4
29	1	1	2	2	2	8
30	1	3	1	1	2	8

Weekly
Average: 6.63

Table 29. Room 2 (Open Schedule) Utilization

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-1	-2	-2	-2	-3	-10
2	2	-1	-2	0	-1	-2
3	1	1	-2	0	1	1
4	-1	-3	-4	-1	0	-9
5	1	-1	-1	1	-1	-1
6	-1	0	-1	2	2	2
7	0	-4	-2	0	1	-5
8	-4	-1	-1	-3	0	-9
9	2	-1	1	-2	-3	-3
10	0	2	-2	-3	-2	-5
11	1	-1	-3	2	0	-1
12	0	-4	1	-1	2	-2
13	-2	0	-2	-1	1	-4
14	1	0	-2	0	1	0
15	-4	0	-1	0	0	-5
16	0	2	0	1	-3	0
17	0	0	1	1	1	3
18	-2	1	-3	-1	0	-5
19	2	-3	-3	1	0	-3
20	-2	0	-3	-2	2	-5
21	1	2	-1	-4	-1	-3
22	-1	-4	-2	2	1	-4
23	0	-4	-2	0	0	-6
24	-3	0	1	2	1	1
25	2	1	-1	1	-2	1
26	-1	-1	1	2	-1	0
27	-2	-6	1	1	0	-6
28	-3	0	-3	0	-3	-9
29	0	0	-1	1	1	1
30	-2	2	-1	0	-2	-3

Weekly
Average: -3.03

Appendix C

Half-Block, Half-Open OR Data

Data for 10% Probability of Emergency Arrival:

Table 30. Room 1 Utilization

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-4	-3	-5	-3	-2	-17
2	-3	-4	-6	-3	-5	-21
3	-5	1	-3	0	-4	-11
4	-1	-4	-4	-2	-2	-13
5	0	-4	-4	-2	-2	-12
6	-3	-4	-3	-2	-1	-13
7	-2	-1	-4	-2	-3	-12
8	-1	-2	-4	-4	-2	-13
9	0	-4	0	-3	-2	-9
10	-5	-3	-2	-4	0	-14
11	-2	-5	-2	-3	-2	-14
12	-2	-4	-4	-3	-2	-15
13	0	-3	-3	-3	-2	-11
14	-5	-5	0	-4	-2	-16
15	-2	-2	-5	-3	-4	-16
16	1	-4	-3	-1	-2	-9
17	-5	-1	-2	-1	-4	-13
18	-2	-2	-3	-2	-2	-11
19	-3	-3	-2	-3	0	-11
20	-2	-2	-4	-2	0	-10
21	-2	-3	-2	-1	0	-8
22	-1	1	-1	-1	-4	-6
23	-3	-4	-1	-4	-1	-13
24	-1	0	-4	-1	-2	-8
25	-2	-4	-4	-2	0	-12
26	-1	-3	-1	-3	-4	-12
27	0	-2	-2	-1	0	-5
28	-4	0	-2	-4	-5	-15
29	-1	-2	-1	-4	-5	-13
30	-4	-1	0	-2	-4	-11

Weekly
Average: -12.13

Table 31. Room 1 Unhappy Patients

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	0	1	0	0	1
2	0	0	0	0	0	0
3	0	0	1	1	0	2
4	0	0	0	1	0	1
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	1	1
9	0	0	0	0	0	0
10	0	1	0	0	1	2
11	0	0	1	0	0	1
12	0	0	0	0	0	0
13	0	1	0	0	0	1
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	1	0	0	0	0	1
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	1	0	0	0	0	1
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	1	0	1
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	1	1

Weekly
Average: 0.43

Table 32. Room 2 Utilization

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-2	-4	-4	-2	-3	-15
2	-3	-5	-3	-2	-2	-15
3	-2	-5	1	-2	-2	-10
4	-4	-3	-4	1	-4	-14
5	-3	-4	-4	-4	-5	-20
6	-3	-5	-1	-4	-3	-16
7	-1	-2	-2	-2	-3	-10
8	-1	-4	-3	-5	-2	-15
9	-3	-2	-3	-2	-3	-13
10	-4	-3	-5	-3	2	-13
11	-2	-1	0	-4	-1	-8
12	-2	-3	-4	-1	-2	-12
13	-1	-1	-6	-1	-1	-10
14	-3	-4	0	-4	-2	-13
15	-3	-4	-3	-3	-3	-16
16	-1	-1	-2	-2	0	-6
17	-1	-2	-1	-2	-3	-9
18	-3	-2	-3	-5	-3	-16
19	-1	0	-3	-3	-5	-12
20	-2	-2	-4	-2	-2	-12
21	-1	-1	-1	-3	-3	-9
22	-4	-1	-1	-2	-5	-13
23	-3	-2	-4	-4	-1	-14
24	-3	-1	-5	-5	-1	-15
25	-4	-4	-5	-1	-4	-18
26	-4	1	-3	-1	-4	-11
27	-5	-4	-4	-2	-5	-20
28	-2	-1	-2	-3	-2	-10
29	-2	0	-4	-2	-2	-10
30	-4	-3	-3	-4	-1	-15

Weekly
Average: -13

Table 33. Room 2 Unhappy Patients

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	1	0	0	0	1
2	0	1	0	0	0	1
3	1	0	0	1	0	2
4	0	0	0	0	0	0
5	1	0	0	0	0	1
6	0	0	0	0	1	1
7	0	1	0	0	1	2
8	0	0	0	0	0	0
9	0	0	1	0	0	1
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	1	0	1	0	0	2
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	1	0	0	1
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	1	0	0	1
21	0	0	1	0	0	1
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	1	0	0	0	0	1
29	0	0	0	0	0	0
30	0	1	0	0	0	1

Weekly
Average: 0.53

Data for 30% Probability of Emergency Arrival:

Table 34. Room 1 Utilization

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	-2	1	0	0	-1
2	0	-3	-1	2	-2	-4
3	-2	1	1	-1	-1	-2
4	1	1	1	-4	1	0
5	-1	-3	0	-1	-2	-7
6	-2	1	1	0	0	0
7	0	-1	1	0	-2	-2
8	-1	1	1	1	-1	1
9	2	2	0	0	1	5
10	-1	0	0	-1	-3	-5
11	-2	1	1	2	0	2
12	-2	0	-1	-2	0	-5
13	-1	0	0	1	1	1
14	1	0	-1	0	0	0
15	1	1	-1	1	-4	-2
16	-2	0	-3	0	-1	-6
17	1	2	0	-3	0	0
18	-1	0	-1	-1	1	-2
19	0	0	0	0	-4	-4
20	-1	1	-2	-2	0	-4
21	1	2	0	1	2	6
22	-3	0	-4	0	-1	-8
23	-2	-1	0	-1	-1	-5
24	2	-5	0	0	-2	-5
25	1	-1	-1	0	-5	-6
26	-2	0	1	-3	0	-4
27	2	-1	-5	0	0	-4
28	1	0	-1	0	1	1
29	0	-2	-2	-3	-1	-8
30	2	-1	0	-1	1	1

Weekly Average: -2.23

Table 35. Room 1 Unhappy Patients

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	1	0	1	1	0	3
2	0	0	0	0	1	1
3	0	0	0	1	0	1
4	0	0	0	0	1	1
5	1	1	0	0	1	3
6	1	1	1	0	0	3
7	0	0	2	0	0	2
8	0	0	1	0	0	1
9	1	1	1	0	1	4
10	0	1	0	0	0	1
11	1	1	0	1	0	3
12	0	1	1	1	1	4
13	1	0	0	1	1	3
14	1	1	1	0	1	4
15	1	0	1	1	0	3
16	1	1	1	0	1	4
17	1	1	1	0	0	3
18	0	1	0	0	0	1
19	0	0	1	0	0	1
20	0	1	1	2	1	5
21	0	0	0	1	1	2
22	0	0	0	0	0	0
23	0	1	1	0	0	2
24	1	0	0	1	0	2
25	0	1	1	1	0	3
26	0	1	1	0	0	2
27	1	0	1	1	1	4
28	1	0	0	0	1	2
29	1	0	1	1	0	3
30	1	1	0	0	0	2

Weekly
Average: 2.43

Table 36. Room 2 Utilization

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	-1	1	0	1	1	2
2	-1	1	0	-1	-1	-2
3	-3	2	0	0	-2	-3
4	0	1	-3	-2	1	-3
5	-1	-1	0	-4	-1	-7
6	-1	1	1	-3	-1	-3
7	-2	0	1	0	0	-1
8	-3	2	-1	0	-1	-3
9	0	2	-2	-1	1	0
10	1	1	-1	-3	-1	-3
11	1	-1	-4	1	0	-3
12	-3	-3	-1	1	2	-4
13	1	0	0	-1	1	1
14	1	0	-2	-2	0	-3
15	-1	2	1	0	0	2
16	0	1	-1	-1	0	-1
17	1	0	1	-1	-1	0
18	-1	1	-3	-1	0	-4
19	-2	0	-2	-1	-4	-9
20	-1	1	-1	1	1	1
21	-1	-2	-5	0	0	-8
22	-1	1	-3	1	-1	-3
23	1	0	1	-3	0	-1
24	-2	2	-4	-2	-2	-8
25	-2	-1	-3	1	-3	-8
26	1	-1	-2	-1	1	-2
27	-2	2	1	2	-2	1
28	2	1	-2	1	-1	1
29	1	-1	1	0	0	1
30	1	1	-5	-3	-1	-7

Weekly Average: -2.57

Table 37. Room 2 Unhappy Patients

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
1	0	1	0	0	0	1
2	0	0	1	1	0	2
3	0	0	0	0	0	0
4	1	1	0	1	1	4
5	0	1	1	0	0	2
6	0	0	1	0	1	2
7	1	1	0	1	0	3
8	1	0	0	0	1	2
9	0	0	0	0	0	0
10	1	1	1	1	0	4
11	1	0	1	0	0	2
12	0	1	0	0	1	2
13	2	0	1	1	0	4
14	0	1	1	0	0	2
15	1	1	1	1	0	4
16	1	1	0	1	0	3
17	1	0	1	0	0	2
18	1	1	0	0	1	3
19	0	0	0	0	1	1
20	0	1	1	0	0	2
21	0	1	0	1	0	2
22	0	0	0	0	1	1
23	0	0	1	1	1	3
24	0	0	1	0	0	1
25	0	0	0	1	0	1
26	1	0	0	1	1	3
27	0	0	1	1	0	2
28	0	1	1	0	1	3
29	0	1	1	1	0	3
30	0	0	0	0	0	0

Weekly
Average: 2.13

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ACADEMIC VITA

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PROFESSIONAL EXPERIENCE

GE Healthcare Commercial Leadership Program Intern, Wauwatosa, WI

Point of Care Ultrasound Inside Sales Specialist May-Aug. 2014

- Created $600K+ in new sales opportunities for the Point of Care Ultrasound team through cold-calling, tradeshow, and marketing activities
- Developed three new product mailers to generate interest in GE's newly launched ultrasound products
- Organized and lead four roundtables with GE Healthcare executives for the intern class

Interventional Marketing Specialist May-Aug. 2013

- Implemented a tracking system to push engagement with the sales team and increase visibility of opportunities in the field
- Generated and led a sales advisory board to capture feedback from objections and leverage best practices amongst the interventional team
- Supported win-loss analysis by performing deep-dive into loss reasons for the Cardiovascular X-ray business
- Worked with a team of four interns to develop hospital break-in strategies for the senior account manager of a seven-hospital health network

LEADERSHIP & INVOLVEMENT

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