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Simulation analysis of capacity and scheduling methods in the hospital surgical suite

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SIMULATION ANALYSIS OF CAPACITY AND SCHEDULING METHODS IN THE HOSPITAL SURGICAL SUITE

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Abstract

With health-care costs rising and an aging population, the health-care industry is progressively faced with the problem of growing demand and diminishing reimbursements. Hospital administration is often faced with a lack of quantifiable data regarding surgical suite capacity and the impact of adding new surgical procedures. With the inherent variation in surgery due to unique procedures and patients, accurately measuring maximum capacity in the surgical suite through mathematical models is difficult to do without making simplifying assumptions. Several hospitals calculate their operating room (OR) efficiencies by comparing total OR time available to total surgical time used. This metric fails to account for the required non-value added tasks between surgeries and the balance necessary for patients to arrive at the OR as soon as possible without compromising patient satisfaction. Since surgical suites are the financial engine for many hospitals and the decisions made with regard to the surgical suite can significantly impact a hospital's success, this thesis develops a methodology through simulation to more accurately define current and potential capacity levels within the surgical suite. Additionally, scheduling policies, which schedule patients based on the variability of their surgical time as well as the implementation of flexible ORs capable of servicing multiple operation genres, are examined for individual and interaction effects with regard to surgical suite capacity, patient waiting times, and resource utilization. Through verification and validation, the model is shown to be an effective tool in representing patient flow and testing policies and procedures within the surgical suite. An application to the surgical suite at Chenango Memorial Hospital (Norwich, NY) illustrates the methodology and potential impacts of this research.

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1 Introduction

There is growing concern regarding the rising cost of healthcare in the United States. The impact of increasing healthcare costs is making basic health coverage unaffordable for both businesses and individuals. The consumer price index shows that an important split is expanding between the two dominant sectors in the economy: services and goods. In 2003 prices for services rose 3.2 percent over the course of a year while prices for manufactured goods fell 1.5 percent (Stiles, 2003). Lagging sales and increased healthcare costs are creating major losses for many corporations. After a recent quarterly loss of $1.6 billion, General Motors, Inc. proposed a restructuring effort which would cut healthcare for union retirees by 25 percent, which would result in about one billion in cash savings a year (Carty, 2005). Many employers are beginning to pass on the costs of healthcare to employees. For those individuals not covered by an employer, rising healthcare costs are resulting in an increased number of individuals who are uninsured. “In 2003, 45 million Americans under the age of 65 lacked health insurance. National surveys consistently show that the primary reason people are uninsured is because health coverage is too expensive” (Kaiser Commission, 2004).

Another major issue facing healthcare providers is a changing demographic. “From 1950 to 2000 the proportion of the population age 75 years and over rose from 3 to 6 percent. By 2050 it is projected that 12 percent, or one in eight Americans, will be 75 years of age or over” (National Center for Health Statistics, 2004). Research shows that the elderly require not only more service, but the services tend to be more expensive, including operations such as cataract and hip replacement surgeries. This increase in the elderly population, therefore, means that hospitals must be prepared to meet a greater demand.

Hospitals today are faced with several pressures such as increasing equipment costs, a shortage of qualified healthcare professionals, and limited hospital facilities. With healthcare costs rising and an aging population, the healthcare industry is progressively faced with the problem of growing demand and diminishing revenue. Many hospital executives are faced with a lack of quantifiable data regarding surgical suite capacity and the impact of adding new surgical procedures. If the caseload is increased beyond the standard maximum capacity, patient satisfaction decreases due to increased waiting times, surgeons and nurses become physically and mentally drained, and the hospital incurs the cost of overtime. The ultimate goal for hospital administration and the foundation for this work is to care for the largest number of patients while maintaining the highest standards of patient care and satisfaction.

2 Problem Statement

The chasm that exists between trying to satisfy an increasing number of U.S. citizens requiring healthcare while a decreasing percentage of the population can afford adequate coverage is expanding. In order to provide affordable healthcare to a larger audience, efficient utilization of resources within the healthcare industry is crucial for providing a low-cost service to an increasing number of patients. In order to remain profitable while providing quality patient care, many hospitals are looking for ways to improve their system. Accurately determining a facility's maximum capacity is the first step in the improvement process.

This motivation of this thesis is in part to aid a local hospital in addressing some of the aforementioned issues that are common among U.S. hospitals. First, the hospital was interested in comparing traditionally reported OR utilization statistics, calculated by the ratio of procedural time used to total OR time available, to total OR utilization taking into account all value-added and non value-added activities. Second, the hospital was interested in comparing the current utilization with its maximum capacity. Finally, since the OR was not utilized to its full capacity, resource levels were modified to determine potential maximum utilization.

The proper capacity metric will provide administration with a solid understanding of potential patient volumes under current conditions. Additionally, understanding the actual amount of available OR time which takes into account all of the non-value-added processes will support administration with new surgeon hires and resource acquisition decisions. As hospitals become more efficient, more patients can be seen, lowering the cost of care per patient, while maintaining, if not increasing, profitability and patient satisfaction.

Due to the complexity of healthcare systems and their inherent variability, simulation is

widely used for analysis in hospitals. Consequently, a simulation modeling methodology is introduced that can be used to determine the current efficiency of a surgical suite, the potential maximum capacity of the suite, and how either changing resources or adding surgical procedures affect surgical suite performance. Finally, this model will also determine the interaction effects between scheduling policies, which schedule patients based on their expected operation time variability, as well as the implementation of flexible ORs, which are capable of servicing multiple operation genres with regard to surgical suite capacity.

3 Literature Review

There are several important areas of background and research that are relevant to the problem outlined. First, a background to the current state of healthcare and trends in volume are reviewed to provide an understanding for the need of analysis within the field. Next, a description of the surgical suite, its costs, and its processes is given to explain the system under consideration along with the common scheduling techniques which govern patient arrival. Finally, studies on surgical suite improvement are discussed along with those which use simulation. The following research on a few individual aspects of healthcare will provide a background as to the importance and feasibility of improvements within the field.

3.1 The Current State of Healthcare

Businesses that provide healthcare benefits to employees tend to be affected most by the rising cost of healthcare. The additional costs incurred by these businesses are then passed on to the consumer. "Ford spent $3.2 billion on healthcare in 2003 for 560,000 employees, retirees, and their dependents. The costs added $1,000 to the price of every Ford car and truck built in the United States" (Mayne, 2004). Hospitals can work to slow the increasing cost of healthcare by optimizing productivity of facilities such as surgical suites.

3.1.1 Surgical Trends

As this thesis will be looking primarily at surgical suites, also referred to as ambulatory care units, surgical trends are of interest. One important trend is the advancement in surgical equipment. New technology is estimated to account for almost 50 percent of the total increase in

the cost of healthcare over the last 30 years (Kaiser Commission, 2004). Advances in technology are also allowing for more complex operations to be performed on an outpatient basis. Accordingly, in 2002, 63 percent of all surgical operations in community hospitals were performed on outpatients, up from 51 percent in 1990, and 16 percent in 1980 (National Center for Health Statistics, 2004). Surgical suites are where the majority of these outpatient operations will be performed, which further stresses the importance of being able to care for an increasing number of patients.

3.1.2 The Surgical Suite

For many hospitals, surgical suites are the financial engine that drives a significant portion of the hospital's overall profitability. Depending on the size of the hospital and the surrounding area, surgical suites can range from a single operating room to well over 50. In this section of the hospital, most patients are scheduled in advance to undergo an elective surgery. The types of surgeries that can be performed often include, but are not limited to cardiac, dental, obstetrics, ophthalmology, oncology, ENT (Ear Nose Throat), plastic, urology, orthopedic, and other general surgeries. Within these categories there are an ever increasing number of surgeries that can be performed.

3.1.3 Patient Flow

The patient flow, or the sequence of processes encountered by the patient from arrival to discharge, is largely determined by the type of surgery the patient is undergoing. Recording patient procedure and recovery times is standard procedure at surgical suite and hospital

facilities. Not only do surgeries differ in their flow, procedural minutes, anesthesia administering, and recovery but also in the time required for paperwork processing, pre-surgery examination, and medicinal preparation. Furthermore, the patient's type of surgery determines operating room cleaning time, equipment preparation, and doctoral dictation. A hospital must be able to specify all process times associated with a particular procedure and the percentage of patients who receive that particular surgery. All of these variables must be captured in the simulation model in order to accurately determine maximum capacity.

3.1.4 Resources

The general surgical suite will usually consist of triage or interview rooms, preparation rooms, operating rooms, and recovery beds. Personnel usually consist of Health Care Aids, Registered Nurses, Surgeons, and Operating Room Teams. Health Care Aids complete pre-surgery interviews, paperwork, cleaning, and some patient preparation. Registered Nurses often assist in patient preparation, paperwork, physical examinations, and drug administering. An Operating Room Team is usually assigned to a surgeon or a certain operation type. Their responsibilities include preparing the surgical equipment, in-patient preparation, surgical assistance, and room cleanup.

3.2 Scheduling of Procedures

The health-care literature contains many references concerning the scheduling of operating room procedures. Before reviewing the literature in the examination of scheduling policies, an overview of block scheduling will be discussed.

3.2.1 Block Scheduling

Block scheduling is the common method for allocating operating room time to each surgeon. Any surgeon may hold several blocks during a given week. A single block may be either four or eight hours depending on the length of the operations performed by the surgeon. Formatting the OR schedule in blocks allows surgeons to know exactly which days and times they will be in the OR, which eases the scheduling of private office practices. At the same time, this system aids the OR manager in booking certain times of the day that would otherwise be considered undesirable, thereby increasing utilization of the facility (Murphy et al., 1985). To increase the flexibility of a block schedule, the blocks may be released a few days in advance to surgeons not performing operations on a regular basis. This strategy allows sub-specialists who cannot schedule cases far in advance to have increased access to the facility (Murphy et al., 1985). Setting the length of the blocks can create inefficiencies. When the block is too large, underutilization results and when the block is too small, overtime may occur.

3.2.2 Scheduling Policies

When examining scheduling polices of surgeries within block schedules, simulation has been widely used. Dexter's (1999) work used simulation to examine the appropriate amount of block time to allocate to surgeons and how far in advance to schedule the elective operations. His findings concluded that OR utilization can be maximized by allocating block time depending on the expected total hours of elective cases, scheduling patients in the first available block within four weeks, and otherwise scheduling patients in overflow time outside of the block (Dexter 1999).

Lovejoy and Li (2002) investigated the trade-offs among the wait to get on a schedule, scheduled procedure start-time reliability, and hospital profits. After performing a sensitivity analysis, results showed that without making major capital expenditures, such as adding additional operating rooms, the optimal method for expanding OR capacity was to extend OR hours of operation.

A common theme in much of the literature is setting start times to minimize the sum of overage and underage costs. Weiss (1990) tackles this problem in a hospital setting and shows the optimality of a critical fractile policy and the importance of operation sequence. "The costs that must be balanced are (1) the idle time costs if the estimated starting time is later than the actual available start time, and (2) the surgeon's waiting time if the estimated starting time is before the actual ending time of the previous case" (Weiss, 1990). Weiss tested certain scheduling rules using simulation, based on the variation in the procedure. The scheduling rules tested were to schedule the cases by increasing variance, decreasing variance, and through random selection. Figure 1 from Weiss's work shows that when smaller α, where α represents the variability associated with operation length, (mean = 2.0) are scheduled first, both waiting and idle times are minimized.

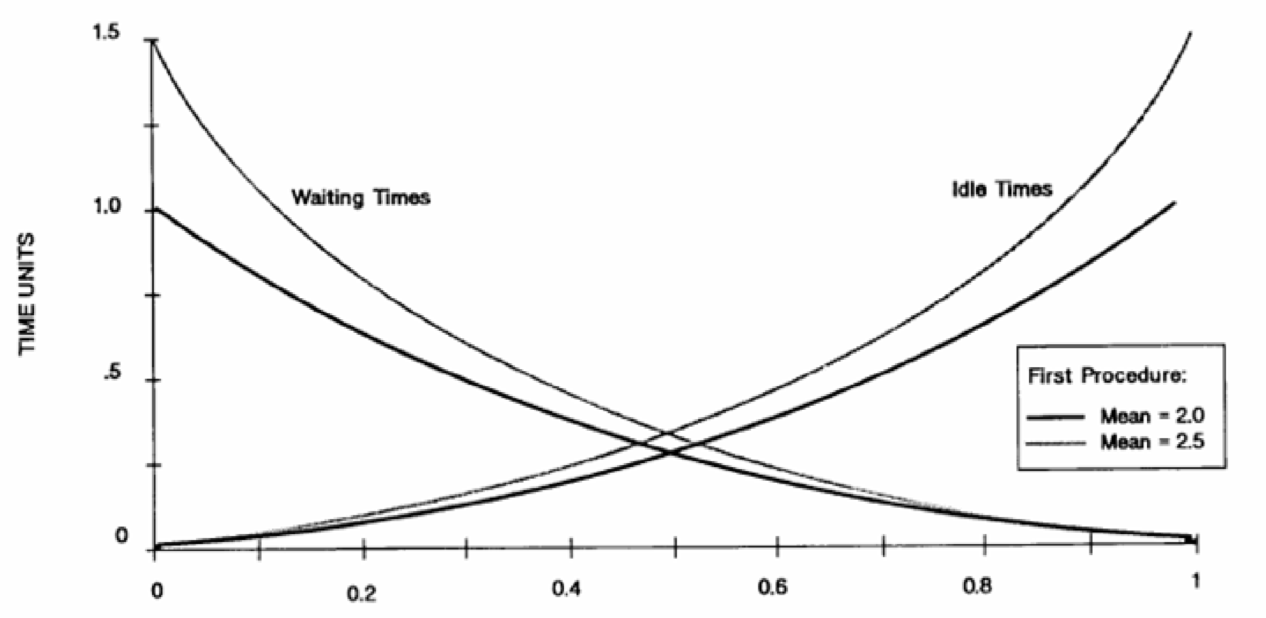

Figure 1: Waiting and Idle Time for Uniform Distributions (Weiss, 1990)

Scheduling procedures by increasing variation contradicts the usual hospital procedure of scheduling the longer, more complex cases first. Weiss makes the assumption in his model that the surgical day ended when the last procedure was over. Reducing the time between the start of the first operation to the completion of the last operation would mean that waiting and idle times are minimized.

3.3 Hospital Performance Research

There has been extensive research on ways to improve efficiencies within healthcare. For emergency units, understanding trends in emergency arrivals while trying to streamline processes has and continues to be a constraint from achieving higher levels of productivity. In the surgical suite, where most patients are electively scheduled for surgery, there are a number of areas in which research has been performed in an attempt to both increase profit and improve patient

satisfaction. These include but are not limited to resource and equipment acquisition, the implementation of scheduling policies, and streamlining patient flow.

3.3.1 Efficiency Gains

Efficiency gains can refer to a number of areas including individual resources, such as OR teams, the operating room itself, or the system as a whole. The following research varies in respect to the specific area in which improvement initiatives are aimed and how they are quantified.

Massachusetts General Hospital used parallel processing in order to both reduce time in OR and total time in systems for patients. Friedman et al. (2006) experimented with parallel processing by taking patients undergoing hernia repairs under local anesthesia with intravenous sedation and dividing them into a control group and an experimental group. Patients in the control group received their anesthesia in the operating room at the start of the surgery, which is standard operating procedure for most hospitals. The experimental group received their anesthesia in the preparation room by the surgeon while the operating room was being cleaned and set up. While the operative time for the control group and the experimental group were nearly identical, the total time in system was significantly shorter for the experimental group.

In attempts to minimize the costs of necessary but unprofitable procedures in the operating room, operating room management has made the reduction of time in the operating room a priority. Krupka and Sandberg (2006) found that while streamlining operations only saved a few minutes per case, redesigning perioperative systems can significantly increase operating room throughput. Although not all case mixes benefit from the required additional

resources, the additional expense required to achieve throughput improvements is more than offset by financial gains. In order for this approach to be successful, the hospital must be able to determine to what degree high throughput environments are implemented.

While this research has been helpful to the hospitals under investigation, they fail to provide quantitative data which can be applied to the general surgical suite.

3.3.2 Simulation in Healthcare

Several tools are available for quantifying and analyzing current capacity and for determining potential process improvements within industry. Staff and administration have, in the past, been skeptical in the ability to accurately represent hospital operations through mathematical methods. Analyzing the health-care industry in a similar manner to a manufacturing environment is becoming increasingly accepted. Simulation provides a way for hospitals to accurately analyze and improve their processes.

One of the first barriers one may find while attempting to simulate a type of health-care service is determining the appropriate degree of complexity for the model. While modeling, an analyst will begin to reach a tradeoff point where model complexity becomes too expensive or time consuming. In the Determination of Operating Room Requirements experiment, Lowery and Davis (1999) found that “to simplify model development, yet meet the desired objectives of the project, it was determined that it was not necessary to model the specialties’ utilization of operating room time outside their allocated blocks” (Lowery 1999). This is an example of reaching the tradeoff point, where the modeling needed to accurately model these performance measures is beyond the scope of the project.

Performance data on health-care systems are becoming increasingly available with the widespread implementation of computer-based information systems; but even with the implementation of these systems, the rapidly changing nature of healthcare today often precludes the availability of data for an extended period of time under the same set of input conditions (Baesler 2003). Often sufficient data is not available. Weng and Houshmand (1999) found in their study that since there were very few overall observations, triangular and uniform distributions could be used and verified through expert knowledge" (Weng and Houshmand 1999).

Once the input distributions are in place, the model must be validated. Many nurses and administrators doubt the ability of a computer simulation to accurately model health-care systems since "there may be high variability in model outputs due to the high variability in patient behavior and care requirements" (Standridge 1999). Since common validation techniques rely on comparing output from the model to the actual system, validating a model with as much variation as found in healthcare can be difficult. While the statistical analysis may not prove that the two systems are the same under certain conditions, what is most important is that the performance measure of interest is a good approximation to the real system, not necessarily the entire system output.

3.3.3 Simulation in Health-care Research

Simulation has now been widely used in healthcare, specifically for analyzing system and operating room capacity. Simulation is a good tool for this environment due to the large amount of variability between surgeries and complex patient routing and scheduling. Simulation is a

good fit for analysis in clinical settings as reported by Isken et al. (1999) and Morrison and Bird (2003). The following research continues to search for efficiency improvements within hospitals, now with the use of simulation.

Feyrer et al. (2006) created three simulation models to represent three scenarios of interest to a particular hospital, the status quo (the current established sequence involved in the operation section of the clinical pathway), the sequence after elimination of the wait for transfer to the operating room, and the sequence after changing the preparation of the operating table so that anesthesia is administered in parallel to OR preparation rather than waiting until the patient is in the operating room. The results of 1,000 simulation runs in each case indicated a significant reduction in the total patient throughput time both in the elimination of time spent waiting to transfer to the operating room and in parallel process organization.

Ramis, Palma, and Baesler (2001) utilized simulation to evaluate different alternatives of operation for a projected center for ambulatory surgery. The conclusion was that the maximum throughput of daily surgeries is achieved, 10 in total, by dedicating two beds to the preparation of the patient, five beds to the transitory hospitalization and using a longest-patient-time scheduling rule in the operating rooms maximizes patient throughput, which contradicts the findings of Weiss (1990).

A similar study was performed for a private hospital in Chile by Baesler and Jahnsen (2003). A simulation model was used to create a curve for predicting the behavior of the variable patient's time in system and estimate the maximum possible demand that the system can absorb. A design of experiments was also conducted in order to define the minimum number of physical and human resources required to serve the demand.

Another study conducted at one of Norway's largest hospitals in 2003 by Martin et al. demonstrated how simulation is contributing to satisfying stakeholders' demands for increased efficiency and rates of return as well as improving the potential for geriatric patients recovery and reducing the number of 'corridor beds,' which are considered a fire hazard. The study was able to accurately analyze the administration's concerns.

Simulation is now common in assisting surgical suites to improve patient flow through the system without large capital expenditures. One aspect common to the literature is that the findings and simulation models were not generalized to provide useful information to several hospitals; instead, all of the findings were specific to a single facility. Those papers which were generalized often had contradicting results as shown by Ramis, Palma, and Baesler (2001) and Weiss (1990). A review of the literature shows that there is a need for a general simulation model which is able to provide information regarding maximum capacity, as well as quantifying the capacity gained by creating operating rooms that are capable of servicing multiple surgical operations and employing a best-practice scheduling policy.

4 Simulation Methodology for Surgical Suites

Within the next decade in the United States, it is expected that the sixty-and-over population will more than quadruple (Census, 2004). The effect of this demographic shift will place more pressure on health-care providers to accommodate an increasing number of patients due to the increased health-care needs of an aging population. Likewise, as discussed in the literature review, medical technology continues to provide patients with new treatment options, which also increases the number of patients who wish to be seen. This research will attempt to determine current capacity in the surgical suite along with potential maximum capacity. In order to achieve this, there are several methods to be modeled and analyzed individually.

As previously discussed, with the complex environment of surgical suites, mathematical and traditional methods cannot accurately represent the system. To obtain meaningful results, simulation is used to model and analyze the system under consideration.

A simulation model can create a virtual representation of a surgical suite. The model can then be run to mimic all of the activities that take place in the surgical suite in a specified time frame. During the replications of the model, patients flow through the surgical suite encountering all of the steps and processes that would occur in the actual hospital setting. The virtual representation of the surgical suite allows for the complexity and variability to easily be taken into account. The simulation model also allows for hospital administration to test new scheduling and staffing policies without the risk associated with testing on the actual system.

To reduce the time required to build a model and to also reduce the run time, model simplifications and assumptions were made. One common simplification is to model the surgical suite by providing a common mix of large and small operations with varying degrees of

operational variability. This simplification can work well for many studies but is insufficient for studies specifically determining potential maximum capacity, which is in large part a function of operation mix, operation length, and variability. Optimizing OR utilization becomes very difficult without specifically modeling the patient mix of each particular surgical suite. The use of realistic data when building a model of a surgical suite is necessary for the creation of a representative simulation.

4.1 Hospital Data Acquisition

The best data to use to determine the capacity of a facility is actual patient data and operation times from the hospital under examination. Standard operating procedure for many surgical suites includes collecting daily patient times along with monthly and yearly reviews of total number of patients receiving a particular operation. While this data will change over time and may even be cyclical, the most recent data set available is best since procedures and operation times are constantly increasing and improving.

Since this research was driven by a specific surgical suite interested in better understanding their capacity, their particular data set was used. First and foremost, the data to be collected was patient flow throughout the surgical suite. Secondly, processing times, types of operations being performed, percentages of patients receiving a specific operation, and resource levels were necessary to build a representative simulation model.

Many surgical suites, while differing in size, available staff and equipment, and operations, have very similar patient flows. The patient flow witnessed as the surgical suite under consideration is shown in Figure 2. This patient flow is common between many surgical suites.

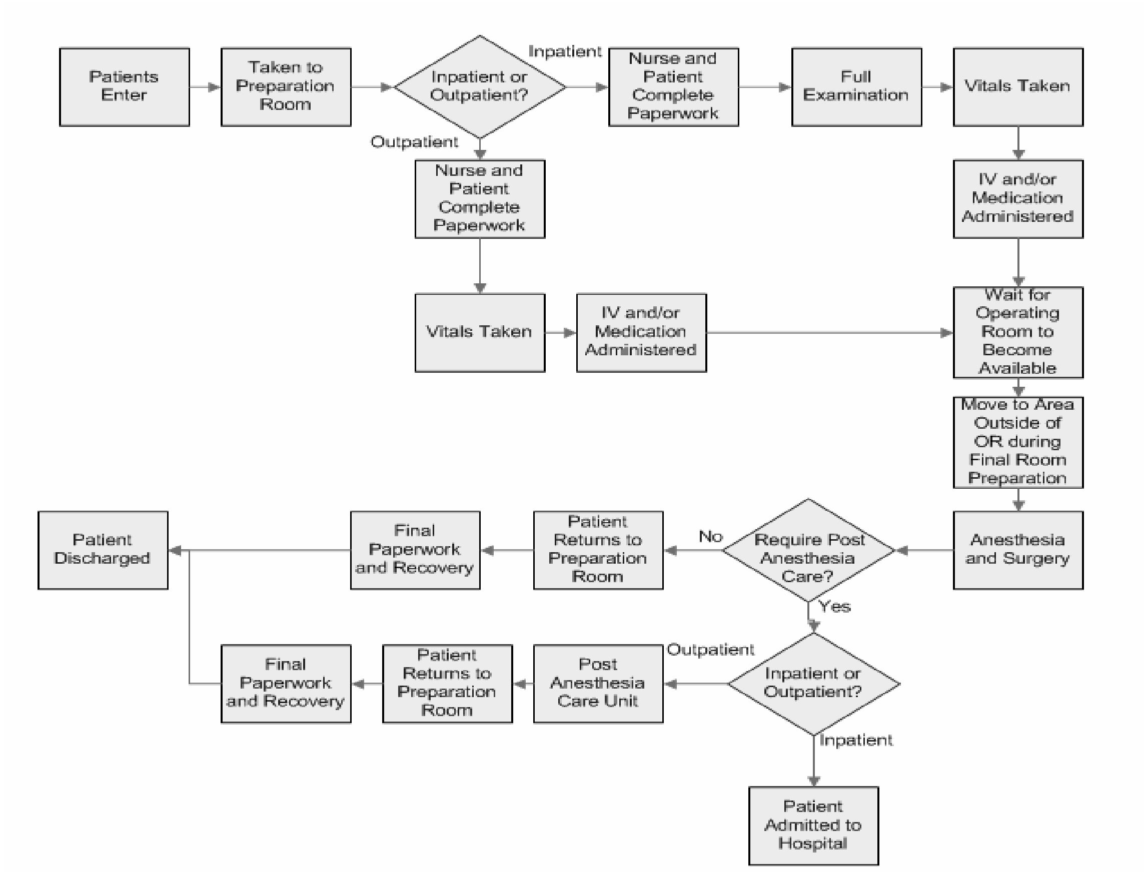

Figure 2: Patient Flow through Surgical Suite

As patients enter on the day of their surgery, they commonly check in at a centralized location within the hospital. As they enter the surgical suite, they are taken to a preparation room where they are given a gown to change into. Soon after, a nurse will enter to complete the final paperwork to be signed by the patient prior to surgery, take vitals, and prepare the patient with any necessary IV or medication administering prior to surgery. Depending on the severity of the operation, a check of the skin and bowels may be performed. The patient will then wait in the preparation room until the OR to be used becomes available. In some cases, patients may wait in a separate waiting area outside of the OR if patient volume is high and additional preparation

rooms are needed. As soon as the OR becomes available, the patient is wheeled in on a bed into the room. The equipment is cleaned and prepared by the OR team as the anesthesiologist administers the anesthesia. The surgeon enters to perform the operation. At the end of surgery, the patient is cleaned and taken to either the post anesthesia care unit (PACU), to an overnight room in another area of the hospital, or back to a preparation room depending on the type of surgery. As soon as the patient has recovered and is back in the preparation room, a final check is given by a nurse, paperwork is completed, and the patient is discharged.

Processing times at each of these steps can vary greatly, especially within the OR. Because of this, a user interface will allow for the time in OR along with associated variability to be specified by facility. As previously mentioned, standard operating procedure includes the compilation of yearly operating times by procedure as a comparison to previous years and national statistics. For example, the surgical suite under consideration collects both procedural minutes and anesthesia minutes by operation. Procedural minutes represent the total time the surgeon is actually performing the surgery on the patient. Anesthesia minutes correspond to the total time from which the patient enters the OR to when the patient leaves for recovery. These values are then compared to two comparative, and non-competing, surgical suites from different areas of the country.

In addition to the total minutes by procedure compiled yearly, nurses complete a daily ambulatory worksheet documenting each patient and the time he is admitted to the surgical suite, the time he enters the OR, the time he enters post anesthesia care recovery, the time he returns to a preparation room, and finally, the time he is discharged, as shown in Table 1. The ambulatory worksheet is often filled out by hand by the nurses and also includes private patient information

such as name and age. This data was collected for two months from the participating surgical suite to create a more recent table of procedural and anesthesia minutes, along with the collecting variability associated with each operation and the percentage of patients receiving a particular operation. This data also serves as the basis by which the simulation model will be validated.

Table 1: Example of Ambulatory Worksheet for a Particular Day

Procedure	**Admittance Time**	**OR**	**PACU**	**Return to Room**	**Discharge**
Thumb Pulley Release	8:49	10:25	N/A	11:00	12:10
Carpal Tunnel	6:36	7:55	8:40	9:25	10:30
Umbilical Hernia Repair	7:01	7:20	8:45	9:45	11:45
Varicose Veins	8:59	11:05	13:05	14:05	16:10
Umbilical Hernia Repair	7:48	9:08	10:40	11:55	14:50
Shoulder Arthroscopy	9:52	11:10	12:40	13:25	14:50

Finally, yearly numbers by operation type are compiled and can be used as a basis for patient creation within the simulation model. Administrators also use this data to predict future finances based on surgeon acquisition. These scenarios can more accurately be predicted with the use of simulation.

4.2 Model Development

As shown above, many facilities have years of data that can be extremely useful in capturing operating time averages and variability. Observation and/or expert opinion can be used to determine preparation, paperwork, cleaning, dictation, and equipment restocking times. In order to determine maximum capacity, patients, represented by entities, are continuously added

to the system. The patient flow diagram shown in Figure 2 is used as the basis for the flow of the model logic. As patients enter the system they are assigned all necessary attributes associated with their procedure based on the percentages selected by the user.

Besides the processes necessary for the patient to directly progress through the surgical suite, there are several non-value-added activities which greatly affect the availability of the suite's resources, and thus the maximum capacity. The non-value-added activities which are modeled separately include cleaning the preparation room, preoperative interviews, case charges, future surgery paperwork, OR preparation, OR cleaning, and the restocking of surgical equipment.

4.2.1 Iterations in Model Development

Several iterations of models were created in the pursuit of defining an accurate measure of capacity. The first model of the OR was equipped with an Excel spreadsheet in which the user defines the surgery type and arrival times of all incoming patients. This model, while useful for scheduling policy analysis, is not a proper method for evaluating capacity since the arrivals are not random.

The second model iteration was divided by surgery type since each OR works independently of one another. Surgical operations were determined by percentages defined by hospital staff and historical data as entities were continuously entering the system. These models, though, did not account for the interaction of different types of patients in preparation and recovery.

The next models were broken down by day, since the block schedule employed by the

hospital will allocate four- or eight-hour blocks to particular surgery types. Block schedules are common in surgical suites and are employed such that surgeons can schedule private practices around surgeries. While block schedules are far from optimal and frequently change with the addition of surgeons, they present unique constraints and must be considered when modeling. The final model assumes that overtime is not available in the OR such that if the expected procedure time for each patient is greater than the available time left in the day, the patient will leave the system. The assumptions made while developing the model may not be true for every facility and most can be easily modified.

4.2.2 Model Assumptions

Although simulation is used to reduce the number of assumptions, there are still some areas within the model which require clarification.

- Surgeons are not explicitly modeled but are assumed to be included as part of the OR team. The surgical suite was modeled under the assumption that the surgeon was not a constraining resource.
- Entity creation is not schedule dependent. Depending on whether the model is collecting statistics on capacity or scheduling policies, a fixed number of entities are created at time zero and are held until the appropriate time for patient admission.
- Overtime is not taken into consideration. Although there are times in which surgical complications require the OR team to stay past the scheduled availability, these cases are not modeled. All patients are sampled prior to entering the operating room to determine if there is sufficient time remaining in the scheduled day to complete their scheduled

operation.

- After-hours patient recovery is assumed but not modeled. Patient statistics are collected at the specified end of day. Although there is commonly an after-hours nurse for patients still in the recovery stage after surgery, these patients are counted as throughput and their time in system statistics will be recorded even though they still may require a small amount of recovery.
- Patient waiting times inherent in the ambulatory worksheet patient times are assumed to be minimal and insignificant.
- For capacity studies, each operation type is constrained to one operating room which is equipped with the necessary tools to operate on that particular surgical genre.
- For the designed experiment, each operation type has anywhere from one to fifty possible operating rooms for the surgery.
- The entity/patient in the designed experiment is required to sample available ORs by looping; there must be a delay imbedded in the loop such that the simulation model is able to execute at a reasonable speed.
- Variability is represented as a percentage of total average operating time.
- Flexibility will refer to the ability of entire operation genres that can be performed in more than one operating room. Full flexibility, or the ability of any operation to be performed in any operating room will be tested along with partial flexibility, or the ability of an operation to be performed in more than one but not all ORs.

4.3 Verification and Validation

The verification and validation of the model was performed through face validity by hospital administration and through historical data validation. Face validity refers to asking people knowledgeable about the system whether the model and/or its behavior are reasonable. This was performed by monitoring surgical suite operations for one week and receiving direction from staff and administration throughout the creation of the model. At the end of the observation time, the model was reviewed with administration to ensure that all processes critical to analyzing the desired performance measures were included.

Ambulatory worksheets were compiled over two months from the hospital to create a representative patient mix by day. For example, all Tuesday ambulatory worksheets were collected for the months of June and July 2005. According to the surgical suites block schedule, only ophthalmology and obstetrics surgeries are performed on Tuesdays. The dataset suggested that over June and July, 79% of the patients seen received ophthalmology operations, while 21% received obstetrics operations. According to the ambulatory worksheets, patients would spend, on average, 49 minutes in the operating room and 225 minutes total in the surgical suite.

Model 3, as described in Appendix H was used for this validation with 79% of patients entering receiving ophthalmology surgeries and 21% receiving obstetrics surgeries. Simulation results for Time in OR (Anesthesia Minutes) show 49.62 minutes and 206 minutes for Total Time in System on average. A two-sample t-Test was used to test for equal means between the historical data and the simulation results.

Test Statistic: T = $\frac{Y_1 - Y_2}{\sqrt{\frac{S_1^2}{N_1} - \frac{S_2^2}{N_2}}}$

Critical value with v degrees of freedom: v = $\frac{(\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2})^2}{\frac{(\frac{S_1^2}{N_1})}{(N_1 - 1)} + \frac{(\frac{S_2^2}{N_2})}{(N_2 - 1)}}$

Hospital Time in OR: Avg. = 48.64 Std. Dev. = 35.09 N = 24
Simulation Time in OR: Avg. = 49.62 Std. Dev. = 21.23 N = 4500
Test Statistic = 0.1366
T-Value t(.025, ∞) = 1.9599

Hospital Time in System: Avg. = 224.79 Std. Dev. = 179.67 N = 24
Simulation Time in System: Avg. = 206.00 Std. Dev. = 92.10 N = 4500
Test Statistic = 0.5119
T- Value = t(.025, ∞) = 1.9599

Therefore, we do not reject the null hypothesis. The means are equal.

The validation shows that the simulation model of the surgical suite is not significantly different from the hospital's actual surgical suite. The difference in the standard deviations can be attributed to the small sample size of available data for the system under study. Monday through Thursday were tested and also reinforce that the simulation model is an adequate tool to represent and analyze the actual system.

5 Capacity Analysis

5.1 Scope

The goal of the capacity analysis experiment is to develop an understanding of how closely administration is currently estimating current and potential maximum capacity. Many hospitals calculate efficiency and capacity by comparing total daily operating minutes used, which refers to the busy time from which a patient enters the OR to when the patient leaves, to total daily operating minutes available. This metric, while commonly used by administration, does not account for the preparation variation and resource availability in preparing a patient prior to entering the OR. While one could schedule patients such that there is always a patient ready to enter the OR, this scheduling method is unrealistic since the policy would often result in large patient waiting times. While OR performance is critical to hospital profitability, poor patient satisfaction due to long waiting times can have serious negative affects to a hospital, especially if that hospital is not near maximum capacity.

5.2 General Methodology

The simulation model is designed to aid a hospital in evaluating the current efficiency of a surgical suite, the potential maximum capacity of the suite, and how either changing resources or changing the set of surgical procedures performed would affect surgical suite performance. The simulation model is constructed using the Rockwell Software simulation package Arena. While the model is based on a particular hospital, the simulation model is generalized such that any facility can easily input their own data to determine capacity and efficiencies. Each user is able to input the percentage of patients receiving a certain genre of surgery (e.g. orthopedic).

Next, the user can specify up to ten types of surgeries within each genre along with how long the surgery takes, what percentage of patients within that genre receive that particular surgery, whether an inpatient or outpatient procedure, the operating room the procedure will use, and the time to administer anesthesia. Resources such as nurses, OR teams, and preparation rooms can also be specified.

As previously described, the patient flow diagram shown in Figure 2 is used as the basis for the flow of the model logic. As soon as the patient enters the preparation room, the nurse will complete any remaining paperwork with the patient and provide them with a surgical gown. The nurse then leaves to give the patient time to change. If the patient is to remain in the hospital overnight, a thorough examination is conducted. Vitals are then taken for each patient and medication or an IV is administered if necessary. At this point the patient is now ready for surgery and must wait for their assigned OR to become available. As soon as the OR is available, the patient moves on their bed or chair to a holding area next to the OR. The patient waits for the OR team before entering the room. As soon as all parties are present, the patient will enter the room as previously assigned. The patient is first prepped and given the appropriate anesthesia. When the anesthesia has set in, the procedure begins. At the end of the surgery the patient is cleaned and taken to either the post anesthesia care unit (PACU) or a preparation room for recovery, depending on the type of surgery performed. The room is cleaned by the OR team and becomes available for the next patient.

If the patient was sent to PACU, they remain there for a certain amount of time depending on their procedure. Inpatients receive their post anesthesia care in the overnight ward of the hospital. Some patient types may not require post anesthesia care and can be taken directly

to the preparation room. All other outpatients are taken back to a preparation room after PACU for final recovery and examination before being discharged.

Understanding capacity is critical for hospitals looking to support resource acquisition decisions in response to a growing demand. Although increasing patient throughput could both meet new demand and increase revenue, it should not be achieved at the cost of patient satisfaction. Statistics of interest include the number of each patient type seen, the time in system, utilization for operating rooms, OR teams, nurses, or any other potentially constraining resource.

The surgical suite to be modeled currently consists of eleven preparation rooms, four operating rooms (ORs), and a sufficiently large number of beds in the post anesthesia care unit. The preparation rooms and PACU beds can be used by any patient type. The OR's on the other hand, are each equipped with surgical devices focused towards particular surgery types. General and obstetric surgeries can often be performed in the same room along with a few other exceptions. It should be noted that this lack of flexibility can have a significant impact on the level of efficiency achieved.

There are currently two health-care aids (HCAs) and six registered nurses (RNs) assigned to the preparation area for pre-surgery preparation, paperwork, and discharge. While the surgical suite is scheduled to be open nine hours per day, two of the six RNs are scheduled after hours such that any patients exiting the OR near the end of the day can stay for recovery and proper discharge. There are a total of twelve surgeons who operate with the help of an OR team. The OR team is responsible for re-stocking equipment before each surgery, assisting the surgeon during surgery, and immediately cleaning the room in preparation for the next patient. There are

a total of three OR teams, such that three ORs can be utilized simultaneously. The surgical genres offered by the hospital include orthopedics, general, obstetrics, ophthalmology, and ENT. There are currently a total of 24 different surgeries performed.

5.3 Results

The administration at the hospital under investigation had formed a capacity team consisting of surgeons, head nurses, schedulers, and the chief financial officer. They created the following chart to visually depict where they believed they currently stood with regard to surgical suite capacity, target OR levels, and future OR levels, as shown in Figure 2. The current OR level capacity was calculated by adding all of the anesthesia minutes for the entire 2004 year, which was calculated to be 229,577 and dividing by total OR minutes available, which was calculated to be 374,400. The target and future levels were then forecasted by the team given expected new surgeon hires and additional equipment purchases. Additionally, the resources that are thought to be necessary to achieve such throughput are identified for each target and future level.

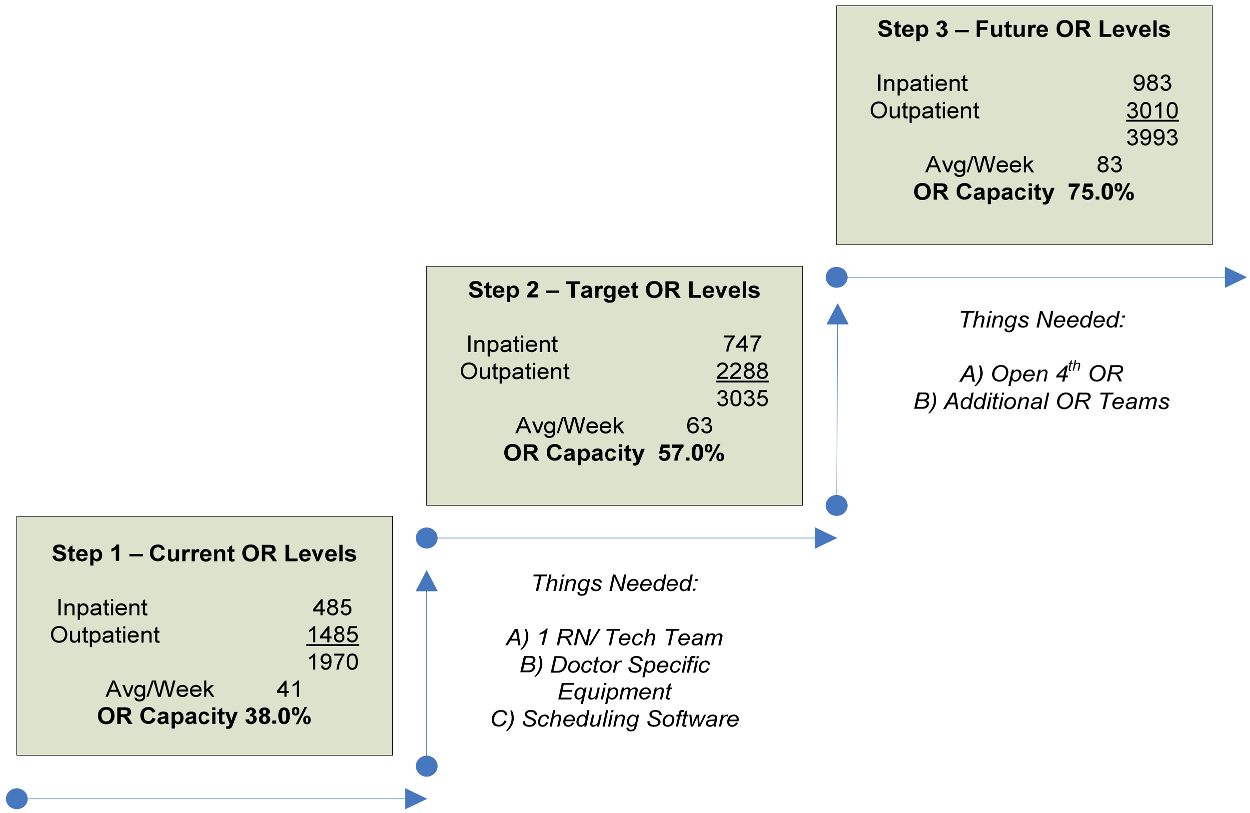

Figure 3: Surgical Capacity Team Forecasts

The values forecasted by the surgical capacity team are significantly different from those suggested by the simulation model. In order to determine the current surgical suite efficiency (which takes into account all preparation, operating time, and recovery) the total number of patients capable of being treated currently was compared against the surgical suite's monthly maximum capacity patient throughput.

Since the current system uses block scheduling where surgical genres are scheduled based on a weekly block schedule, a replication consisted of one week where the operations performed each day followed with the block. A total of 100 replications were run for each type of surgery. First, the simulation model was run under current surgery loads. The results for the

current system are shown in Table 2. Next the simulation model was run under a condition to determine the maximum capacity of the system without overtime. The results for the system under maximum capacity are shown in Table 3. Additionally, the simulation was tested with the addition of a fourth, flexible operating room, as shown in Table 4.

The current state simulation model uses the ambulatory worksheets of June and July 2005 to estimate the average number of each type of patient seen daily. The average monthly throughput of the simulation follows, with a weekly patient total of 41. This simulation generated throughput is consistent with the current average patients per week approximated by the surgical capacity team. This average corresponds to a monthly average of 164 patients, which actually exceeds winter months during 2006. (The volume statistics for 2006 show patient totals for January through July as (139, 150, 150, 142, 182, 155, and 185 respectively.) Thus, these capacity statistics are up to date with the current system.

Table 2: Current State Capacity Statistics

	Monday			Tuesday			Wednesday			Thursday			Friday	
	Ort.	Gen.	GYN	GYN	Gen.	Eyes	ENT	Gen.	Eyes	Ort.	GYN	Eyes	ENT	Gen.
# of Patients Treated	6	2	1	1	2	7	2	2	3	5	2	2	1	5
OR Utilization	54%	35%	6%	7%	33%	42%	24%	30%	17%	46%	17%	13%	12%	68%
Avg. Time in OR (min)	64.6			49.62			61.19			51.04			80.79	
Avg. Time in System	194.53			206			182.19			176.35			249.78	

The maximum capacity state, Figure 3, is constructed by the percentage of operation types observed in the current state system (for example, Monday will still have 66% of the patients receive an Orthopedic surgery, 22% receive General surgery, and 12% receive Obstetrics surgery). In this state, entities are continuously added to the simulation model to determine maximum capacity. The following table depicts the total possible number of operations that can be performed under the current structure and resources available at the hospital. The simulation suggests that without the addition of resources, monthly throughput can service 272 patients.

Table 3: Maximum Capacity Statistics

	Monday			**Tuesday**			**Wednesday**			**Thursday**			**Friday**	
	Ort.	Gen.	GYN	GYN	Gen.	Eyes	ENT	Gen.	Eyes	Ort.	GYN	Eyes	ENT	Gen.
# of Patients Treated	7	3	2	2	3	9	5	4	8	8	5	5	2	5
OR Utilization	76%	59%	24%	18%	59%	80%	62%	66%	59%	83%	46%	36%	44%	84%

The number of additional patients that can be cared for without any additional resources is useful information for hospital administration. However, Table 3 shows that even in the maximum capacity state at the surgical suite, on average, no one operating room will exceed 84% utilization once the system as a whole is considered. This is due to the room preparation and cleanup required between surgeries as well as patient preparation prior to surgery. This gap can also be attributed to the fact that no overtime is available, where each entity representing a patient is evaluated for anesthesia time before entering the OR to ensure overtime does not occur.

Assuming the demand is present, Chenango is capable of servicing 68 patients per week (272 patients per month) under current conditions. Large swings in case variability may decrease this value significantly. The simulation model suggests that the current system is performing at roughly 60% efficiency.

Chenango Memorial currently has only four functional ORs but a total of five operating rooms. Since administration was curious as to the added capacity given that the OR was properly equipped to serve a large number of operations, the following scenario depicts the addition of an extra, flexible, operating room. This analysis shows the maximum benefit associated with the addition of the 5th operating room. This scenario must also assume the addition of an OR team. Table 4 statistics are given for the daily patient percentages used in the current and maximum capacity states.

Table 4: Capacity with the addition of a 5th Operating Room

	Monday			**Tuesday**			**Wednesday**			**Thursday**			**Friday**	
	Ort.	Gen.	GYN	GYN	Gen.	Eyes	ENT	Gen.	Eyes	Ort.	GYN	Eyes	ENT	Gen.
# of Patients Treated	10	5	3	2	4	16	6	5	10	10	6	5	3	8
OR Utilization	65%	55%	22%	18%	51%	60%	54%	57%	53%	70%	40%	31%	42%	66%
OR 4 Utilization	67%			66%			67%			59%			71%	

The addition of a flexible OR increases the maximum capacity of the surgical suite by approximately 37%. This scenario, when demand is present, is capable of servicing 93 patients per week (372 per month), given that the daily operation mix remains the same.

5.4 Conclusions

Underestimating surgical suite utilization can result in poor administrative decisions. If administrators assume they are utilizing the OR at 38% of its capacity when they are actually utilizing 60%, they may believe there is room for additional surgeons or additional scheduled surgeries when this may not be the case. These results imply the calculation of *OR efficiency* = [*Total Operating Minutes Used / Total Operating Minutes Available]* as insufficient and misleading. Knowing exactly how many additional patients are capable of being seen, by surgery type, will assist administration in making proper surgeon and equipment acquisition decisions.

6 Scheduling Policies and Flexible Operating Rooms

As discussed in the literature review, there is some contradiction between the best practice scheduling policies proposed by previous researchers. Weiss (1990) showed that scheduling the least variable cases in the beginning of the day minimized the elapsed time of operations throughout a day given a fixed number of patients. This is logical, since beginning the day with a largely variable case allows the variation to permeate throughout the rest of day to subsequent patients. This variation disrupts patient waiting time, pushing the performance measure of total time in system farther away from the goal of achieving high levels of patient satisfaction.

To the contrary Ramis, Palma, and Baesler (2001) found that highest efficiency was achieved when scheduling the longest case first. Variability in surgical procedures is often directly correlated to the total time of the operation. This is confirmed by the data provided by the hospital under investigation for this study. One school of thought that would support this type of scheduling policy is that of human factors. Many hospitals schedule the longer, more variable, cases in the morning when the surgeon is mentally fresh and fatigue does not interfere with the operation.

While there is contradiction in the capacity research, the state of the surgeon is undoubtedly an important factor. Furthering the capacity research by examining scheduling policies based on operation variability will be of interest from both a cognitive and productivity perspective. Additionally, since many hospitals wish to employ flexible operating rooms, this factor will be investigated for its affects on capacity levels and interaction with the scheduling policies.

6.1 Scope and Methodology

The simulation model, as previously described, is common to many surgical suite patient flows. There will be varying degrees of difference between all facilities, so while this model is extremely general and changes can be easily made, this analysis may not be suitable for all facilities. We will discuss the methodology in which patients are scheduled within the simulation, based on their variability, and also how the flexible operating rooms were modeled.

In order to perform a designed experiment which tests both scheduling policies and operating room flexibility, four models with slight variations were used to run the experiment. One model is built such that patients can be scheduled by their variability and several different types of operations genres are run each day. A second variation was built such that multiple operation genres are run each day with patients entering the system randomly, not based on their operation's variability. Lastly, there were two variations which were run on a daily block schedule where only one operation genre is serviced each day with patients scheduled randomly or based on their operation variability.

There are several ways to set up a simulation model such that patients are arriving in a fashion based upon the difficulty of their operation or the variability in their procedure. One option is to set up an Excel spreadsheet in which each patient is scheduled in a deterministic or predetermined fashion. While this method would allow for interarrival times to be specified prior to initialization, there would not be stochastic selection of operation types based upon a given percentage of operation genres. Instead, the simulation was set up such that all patients are given a set of attributes stochastically, are grouped together in a queue, are sorted by their operation variability attribute, and are picked out of the queue, one at a time, based on some common

interarrival schedule. In order to build a sufficient queue which can fully evaluate a specific scheduling policy, all patients were created at time zero. The number of patients created follows with the operation mix common to the surgical suite under investigation. While selecting multiple operating rooms means that patient throughput can greatly increase, we maintain the number of patients entering each model and instead compare total patient time in system as a measure of the suite's capacity. This method allows for consistency between the model variations which correspond to the different factorial levels in the designed experiment.

After the patients arrive, they are assigned total variance which takes the maximum possible operating time minus the minimum possible operating time, per the user as entered in the interface, for a total variance attribute. The patients then enter a queue which is either ranked by increasing or decreasing total variance. For every patient, a control entity is created which will pull the actual patient out of the queue every forty minutes, which is the common scheduling separation between arriving patients at the hospital under investigation. This arrival process can be seen in Figure 4. Time in system for the patient begins after the entity leaves this process.

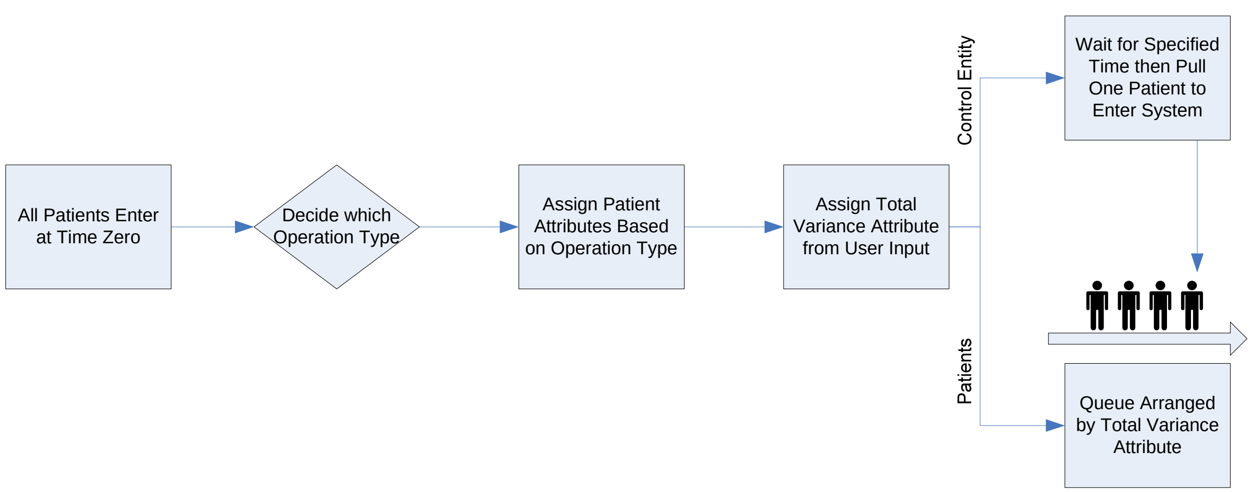

Figure 4: Patient Arrival and Sorting

The user must be able to specify all of the potential rooms that an operation type is capable of using. Many operations are restricted to rooms with stationary equipment designed to service a particular operation. The following will describe the logic necessary to link the user defined potential operating room set with entity flow within the model.

The user interface, which will be described in further detail shortly, is vital to creating the matrices necessary in forming resource sets. The user enters all pertinent information about the surgeries the suite is able to perform into the user form, shown in Figure 5. The command button on the far right-hand side will direct the user to a set of possible operating rooms, as shown in Figure 6.

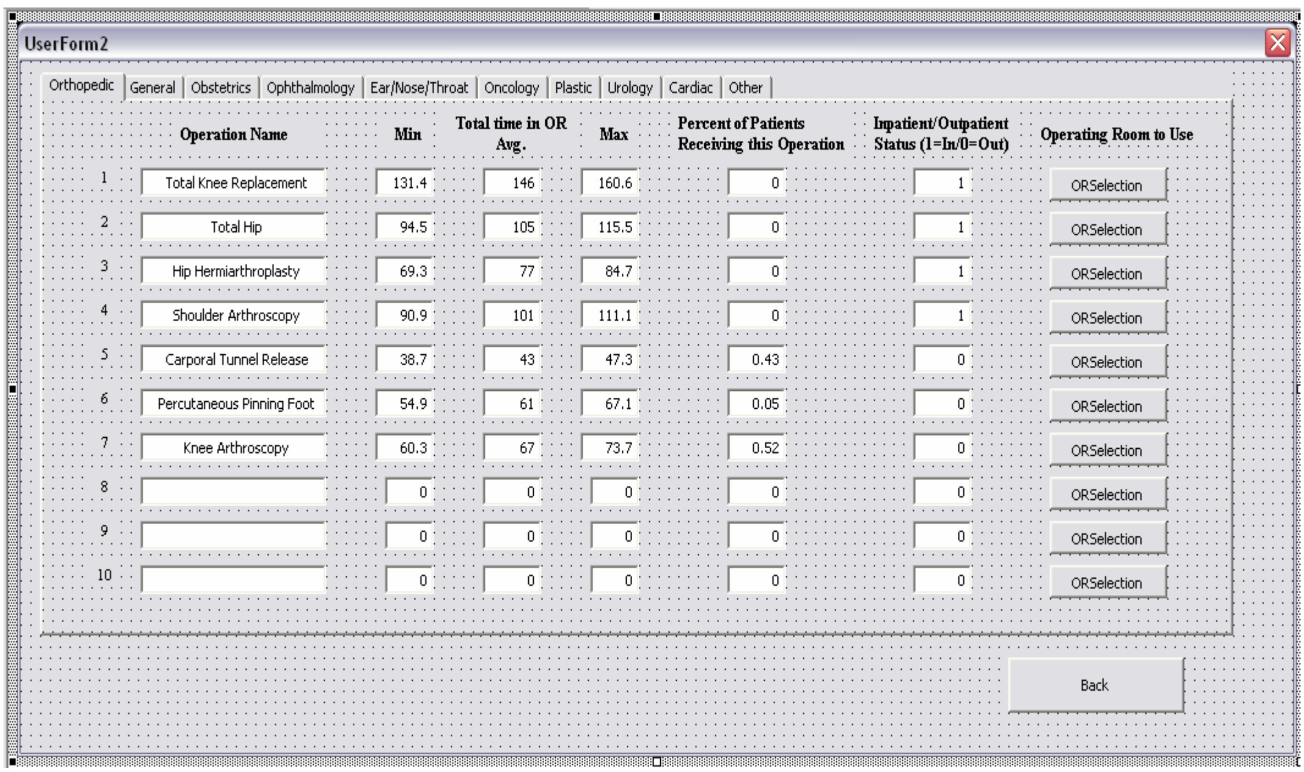

Figure 5: Potential Operations UserForm

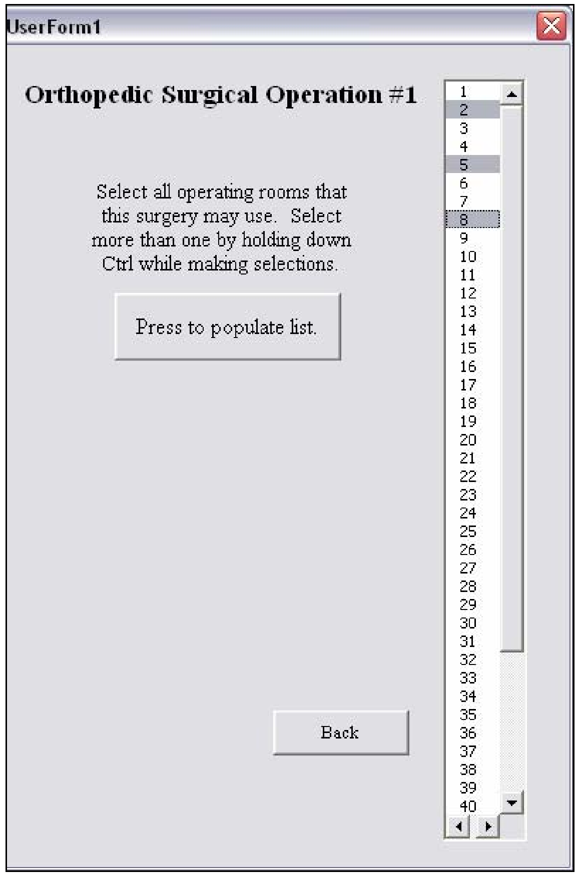

Figure 6: Operating Room Selection UserForm

For each operation, the user can specify exactly which operating rooms can service a particular operation type. After selecting all possible rooms, the selections are stored in the main program model logic which executes at RunBeginReplication. The following VBA code stores the values such that they fill a variable matrix which is defined through VBA and utilized within the Arena simulation software.

```
For i = 0 To 49

 If UserForm1.ListBox1.Selected(i) = True Then

        s.VariableArrayValue(s.SymbolNumber("Index", 1)) = s.VariableArrayValue(s.SymbolNumber("Index",
                                                                                   1)) + 1
        s.VariableArrayValue(s.SymbolNumber("PotentialRooms", 1,
                                      s.VariableArrayValue(s.SymbolNumber("Index", 1)))) = i + 1

 End If
```

Figure 7: Room Selection Code

The code in Figure 7 takes the selected operating rooms from the Operating Room Selection UserForm for Orthopedic Operation Type #1 and indexes the variable array index at each point where a room has been selected. The value of this Index will evaluate to the total number of potential operating rooms. Since there are a total of 100 possible operation types to be specified within the Potential Operations UserForm, this code repeats for each 100 potential operations. The array Index for Orthopedic Operation Type #1 then becomes the first row in the variable array Potential Rooms (100, 50) while the array Index for Operation Type #2 becomes the second row.

The above array and matrix are defined within the modeling section of Arena through a variables element. As the model is initialized prior to running, the operating rooms specified by the user are fed into the variables which will be evaluated within the model logic.

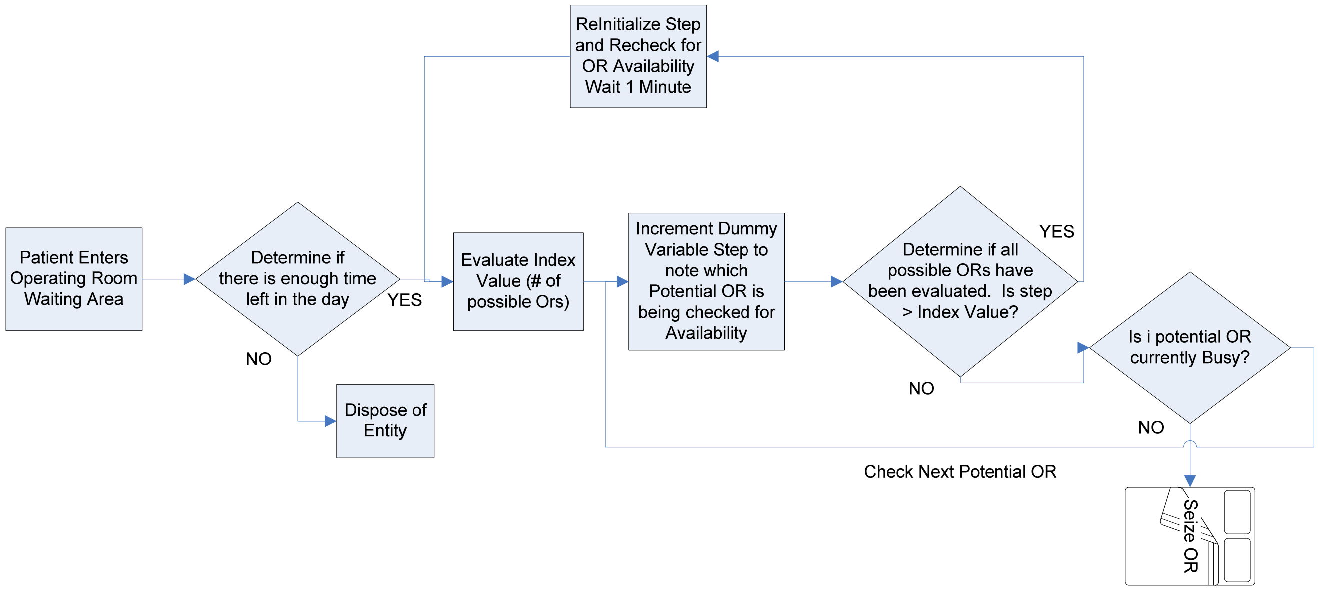

Figure 8: Operating Room Selection Model Logic

The model logic in Figure 8 depicts the loop in which entities travel until one of their potential operating rooms becomes available. As patients finish with their preparation and enter the operating room waiting area, the simulation determines whether an additional patient would potentially require overtime. Since this model assumes that overtime is not available, patients with operating times exceeding the time left in the day are canceled. The Index value or total number of potential operating rooms is set as an attribute which will determine the path by which the entity will travel until an operating room is seized. A dummy variable ‘step’ is assigned and incremented as the entity evaluates the state of their potential operating rooms. If an operating room is currently busy, the entity will increment the variable and assess the state of the next potential operating room by evaluating the resource number “PotentialRooms(OperationType, Step)” in the Operating Rooms resource set. If the OR is available, the patient moves on to seize that OR, if not, he goes back to increment the step variable until all potential ORs have been

checked, waits one minute, reinitializes step to zero, and evaluates the state of all potential ORs again. Note that there is a one-minute delay as entities exhaust their Index array because anything less would drastically lengthen the simulation run time.

6.2 User Interface

The user interface allows the general model to approximate a system's particular surgical suite. The user is able to specify the overall percentage of a certain operation genre, such as orthopedics, specify each specific operation type within each genre, and allocate human and physical resources. The user is presented with these options at the beginning of the simulation run, as shown in Figure 9.

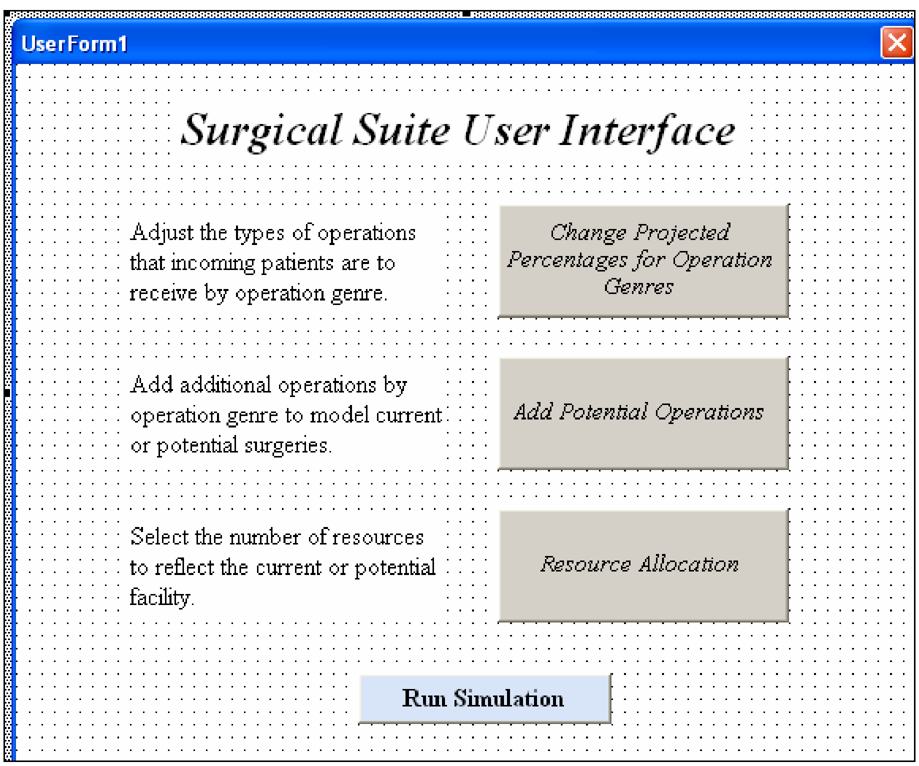

Figure 9: Main Form for User Interface

If the user selects the command button to Change Projected Percentages for Operation Genres, they are presented with the UserForm in Figure 10 in which these changes may be made. While not pertinent to the hospital under investigation, the right-hand side is other surgical genres that may be commonly found in other facilities.

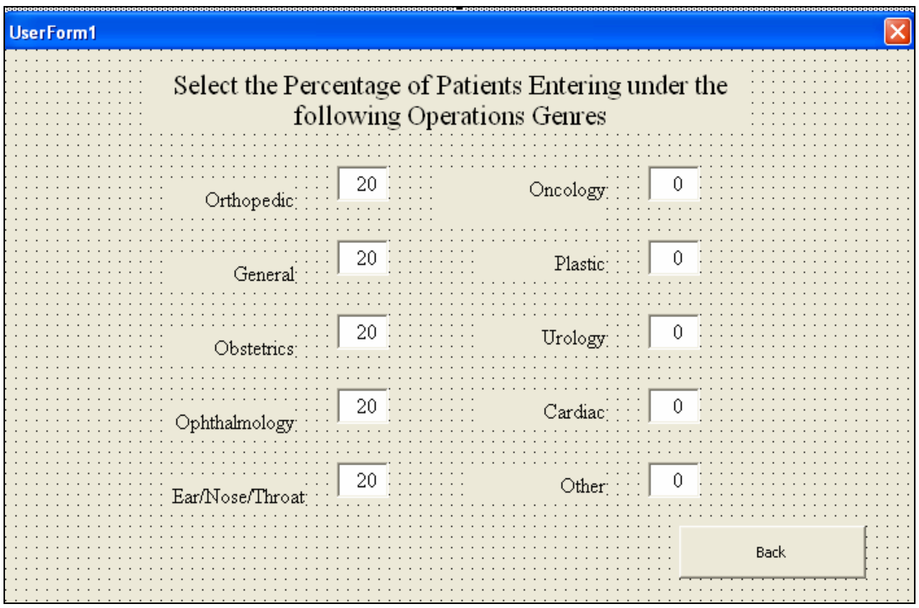

Figure 10: Operation Genre Percentages UserForm

Within orthopedics there are a total of ten operation types which fall into the orthopedics category. Each specific operation type is described by the minimum, average, and maximum operating minutes along with the percentage of patients receiving that operation type within the genre, inpatient or outpatient status, and a command button for selecting potential operating rooms. This UserForm can be seen previously in Figure 5 along with the Operating Room Selection UserForm in Figure 6. There are ten variations to the Potential Operations UserForm and 100 separate but similar UserForms for operating room selection.

Finally, the user can select the number of HCAs, RNs, Secretary Nurses, OR teams, and preparation rooms as shown in Figure 11.

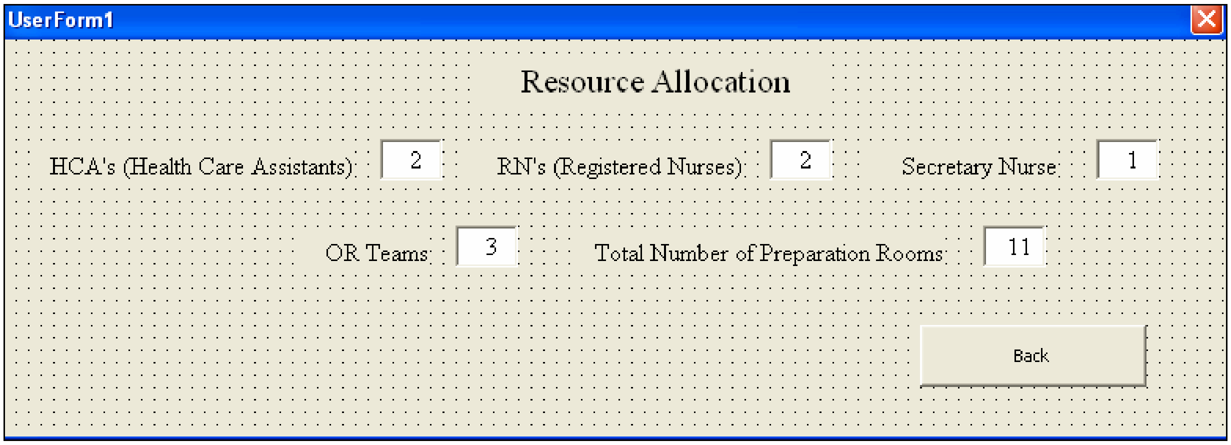

Figure 11: Resource Allocation UserForm

6.3 Design of Experiment

In order to understand the effects of scheduling policies and operating room flexibility and their interaction effects, an experiment was designed for the surgical suite of interest. Along with scheduling policies and OR flexibility, the effects of scheduling only certain operation genres at certain times (block scheduling) are of interest to hospital administration. Having the necessary surgeons on hand at all times is unrealistic, especially at smaller hospitals; we can show through this designed experiment how constraining the block scheduling is. Therefore, the three factors of the designed experiment are operation mix, OR flexibility, and scheduling policy. With regards to operation mix, either one operation type is performed on a specified day each week or any operation can be performed on any given day during the week. Within the OR

flexibility factor, either each operation type is restricted by equipment to one OR or each OR in the facility is able to accommodate any surgical procedure. Scheduling policies will be represented as either scheduling patients randomly or by increasing or decreasing operation variability.

Simulations during the experiment were run for 1,000 replications. One replication represents one work week or five 24 hour days. For one operation daily levels, one entity is created at the beginning of each day. Depending on the day, this entity is replicated an appropriate number of times based on common number of daily patients per operation genre. For example, on Mondays (orthopedic day) the initial entity is replicated 8 times after creation such that there are nine total orthopedic patients to be treated throughout the day. Tuesday through Thursday are as follows: Tuesday (general day) – 6 patients, Wednesday (obstetrics day) – 10 patients, Thursday (ophthalmology day) – 14 patients, Friday (Ear/Nose/Throat day) – 6 patients.

For multiple operation daily levels, 45 patients are created at time zero. Although multiple operation daily scenarios have a significantly larger capacity and can handle far more patients, having like number of patients between levels allows for a more valid comparison of patient total time in system.

The treatment combinations for this experiment and the models used to run them are

1) One Daily Operation / Flexible OR / Decreasing Variation (Appendix G)
2) One Daily Operation / Dedicated OR / Increasing Variation (Appendix G)
3) Multiple Daily Operations / Dedicated OR / Decreasing Variation (Appendix I)
4) One Daily Operation / Flexible OR / Increasing Variation (Appendix G)

5) One Daily Operation / Dedicated OR / Randomly Scheduled (Appendix F)

6) One Daily Operation / Flexible OR / Randomly Scheduled (Appendix F)

7) Multiple Daily Operations / Flexible OR / Increasing Variation (Appendix I)

8) Multiple Daily Operations / Flexible OR / Randomly Scheduled (Appendix H)

9) One Daily Operation / Dedicated OR / Decreasing Variation (Appendix G)

10) Multiple Daily Operations / Dedicated OR / Increasing Variation (Appendix I)

11) Multiple Daily Operations / Flexible OR / Decreasing Variation (Appendix I)

12) Multiple Daily Operations / Dedicated OR / Randomly Scheduled (Appendix H)

6.4 Results

Each treatment combination was replicated 100 times. Individual statistics for patient time in system were read to a text file which was compiled in Excel, Appendix A. The trials were sequenced by a randomly generated factorial design as defined in Minitab. The combined Excel values for the performance measure Total Time in System were input into Minitab where the main effects and interaction effects were graphed with respect to the three factors of interest: operation mix, OR flexibility, and scheduling policy.

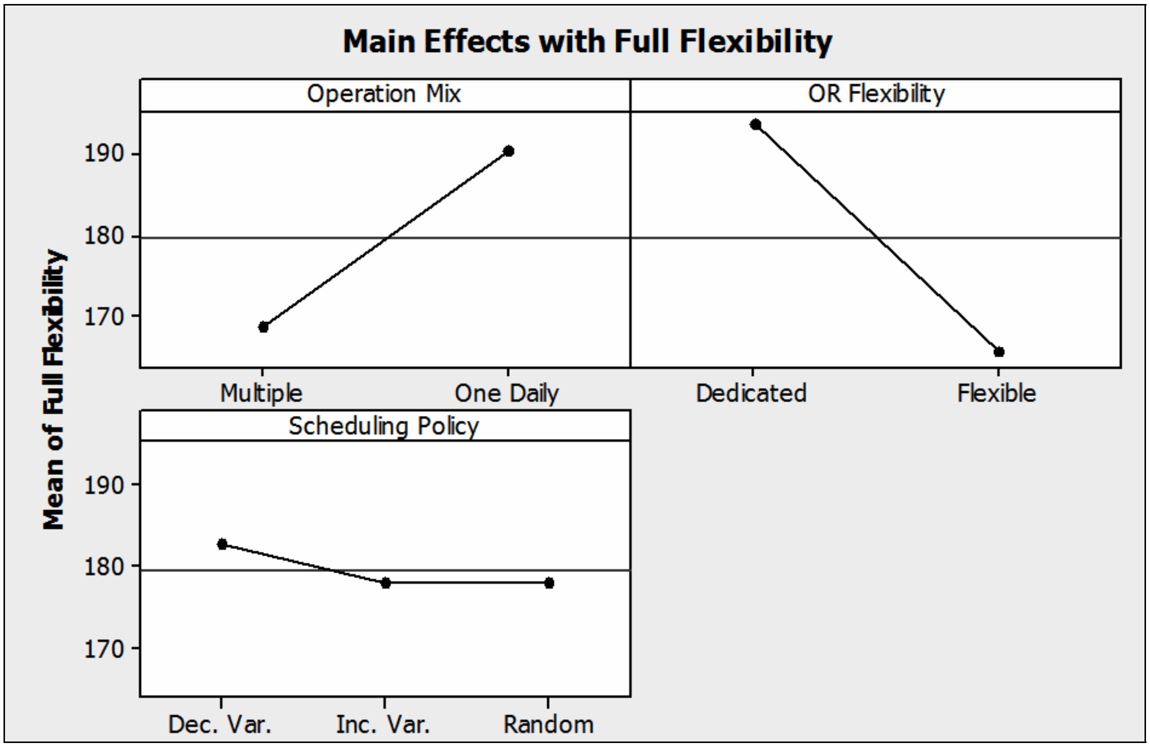

Figure 12: Main Effects Plot for Time in System

We can see from the Main Effects Plot, Figure 12, that having flexible ORs greatly decreases patient time in system. Allowing for multiple operation types each day also decreases total time in system for patients. Additionally, results show that scheduling patients by increasing variability allows for a lower total time spent in system. Although all factors are significant in the ANOVA, as shown in Appendix B, it appears that there is no significant difference between the increasing variability and random scheduling policies.

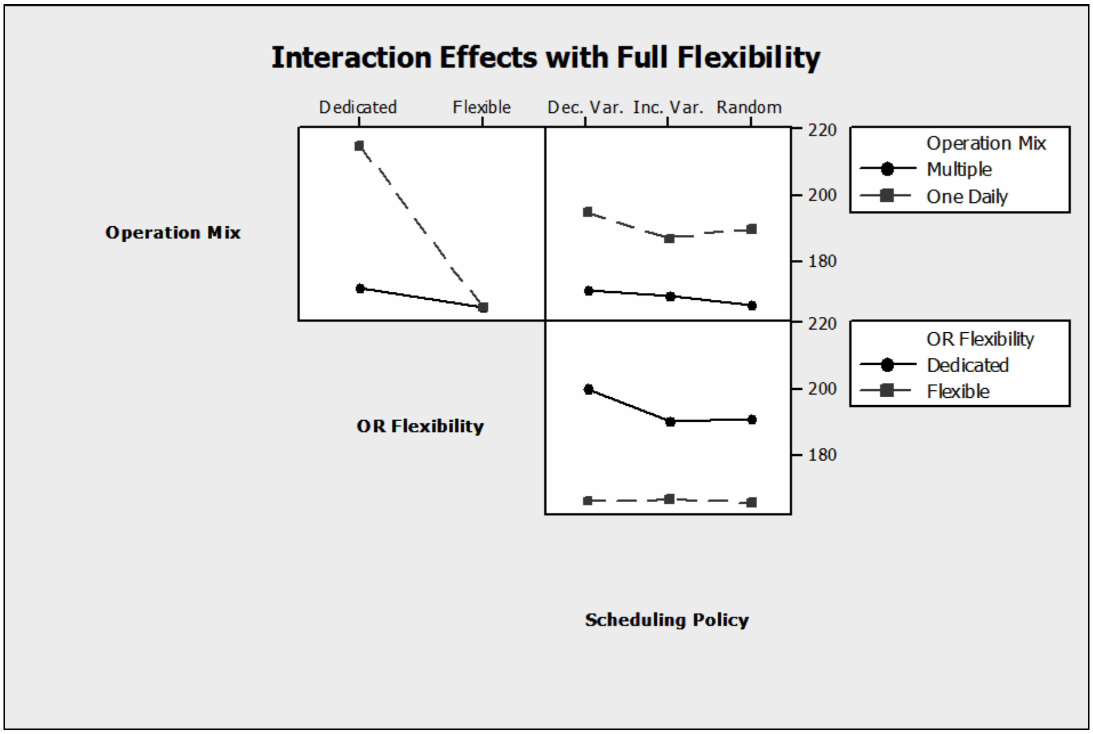

Figure 13: Interaction Plot for Time in System given Full Flexibility

The interaction between the factors at each level is shown above in Figure 13. An interaction effect can be seen with operation mix and OR flexibility. This pictorially shows the approximation of multiple daily operations to one daily operation when there are little to no constraints placed by the operating room.

The main effect for operation mix and its interaction effects would likely be more significant if OR flexibility was not a factor. This is due to the fact that when there is only one operation being performed daily, but patients can choose any operating room, patient time in system approximates the effects of having multiple operations daily with dedicated operating rooms. By examining a more realistic OR flexibility scenario, we should be able to make stronger conclusions regarding the significance of each factor.

OR flexibility shows the largest difference between levels as having completely flexible operating rooms decreases total time in system for patients by 30 minutes on average. This factor, again, is analyzing two extreme cases: total flexibility and zero flexibility.

Testing operating rooms which can service two types of operation genres will give better insight as to the capacity gains of flexible ORs. While the main effects plot for the case of partial flexibility is identical to the main effects plot for full flexibility, the interaction plot, Figure 14, shows slight differences which suggest that some significance may have shifted.

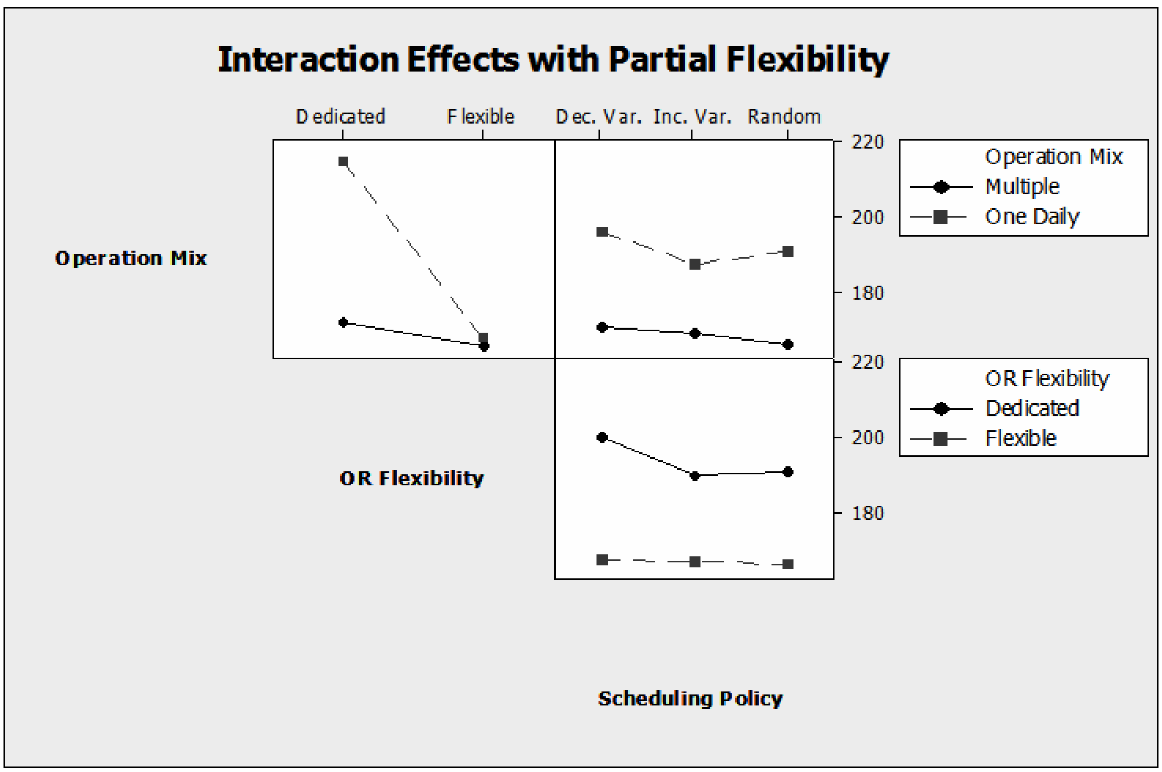

Figure 14: Interaction Plot for Time in System given Partial Flexibility

The differences in significance between each treatment combination can be better examined through Tukey tests. When the OR flexibility level is at the two extremes of dedicated and fully flexible, Figure 15 shows that there is no significant difference between the top seven performing treatment combinations. The tests suggest that with a block schedule and one daily operation, there is a significant difference between each scheduling policy. The following results suggest that in the case of one daily operation block schedules, that patients be scheduled by an increasing variability policy where the complex cases are performed at the end of each day.

Treatment Combinations	Average Time in System	Significance											
MFR	164.82	■											
OFD	164.86	■											
OFR	165.66	■											
OFI	166.03	■											
MFI	166.22	■											
MFD	166.25	■											
MDR	167.83	■											
MDI	172.15		■										
MDD	175.31			■									
ODI	207.62				■								
ODR	213.94					■							
ODD	224.75						■						

Figure 15: Tukey Test for Full Flexibility DOE

As previously mentioned, a more indicative and realistic approach to the designed experiment would allow for partial OR flexibility. This change is more realistic for hospitals with a limited number of surgeons capable of performing similar operations within the surgical suite. The following Tukey test, shown in Figure 16, depicts the differences which can be extracted by paring down the designed experiment.

Treatment Combinations	Average Time in System	Significance											
MFR	164.75	■											
MFI	166.06	■											
MFD	166.52	■											
OFI	167.63	■	■										
OFR	167.81	■	■										
MDR	167.83	■	■										
OFD	168.25		■										
MDI	172.15			■									
MDD	175.31			■									
ODI	207.62				■								
ODR	213.94					■							
ODD	224.75						■						

Figure 16: Tukey Test for Partial Flexibility DOE

As flexibility is lessened, differences between the treatment combinations become a bit more visible. The elimination of the block schedule, which is less likely to occur in underutilized surgical suites, allows for average patient time in system to significantly decrease, increasing

patient throughput. Furthermore, as operating room constraints are tightened, implementation of a best practice scheduling policy, scheduling with increasing variability, will also allow the suite to better utilize available OR time.

6.5 Conclusions

The results of this experiment show that surgical suite operation mix, scheduling policy, and use of flexible ORs are all significant for OR utilization and patient satisfaction within the surgical suite. The combination of the removal of the block schedule and the use of flexible ORs can have the most significant impact on overall patient time in system. When compared to the actual system, time in system under the treatment combination (MRF) is decreased by approximately 20%. Although the creation of flexible operating rooms may require equipment purchases, for hospitals performing near maximum capacity 20% gains may be worth the expenditure.

Scheduling policies appear to be significant when the operating room is dedicated for operation genre. In the case of flexible operating rooms, both full and partial, scheduling policy is significant. This is logical, since the effects of variability propagating through subsequent surgeries will be greatly lessened when the operations are spread across several ORs.

The ability to perform operations in multiple operating rooms proves to be extremely significant in reducing patient time in system. Even in the case of partial flexibility, the main effects far outweigh effects of employing a best practice scheduling policy. The interaction effects of pairing multiple daily operations with flexible ORs allows for the greatest reduction in overall patient time in system.

7 Conclusions and Recommendations for Future Work

7.1 Conclusions

With the cost of healthcare rising and a growing number of people requiring surgery, an understanding of capacity levels within the surgical suite is crucial for hospital administration. Simulation has been shown as a good tool for analysis within the industry. A suite-specific capacity analysis is presented in this thesis as well as two experiments using simulation.

Modeling techniques and methodologies developed during these experiments render indications to hospital administration for the suite under investigation, the general surgical suite, and healthcare analysts and practitioners. The capacity analysis shows that the current practice of defining capacity is insufficient and misleading. When the system as a whole is considered, many surgical suites will find that they are actually performing at levels higher than expected. This information can assist in surgeon and resource acquisition.

Results obtained from the experimental designs provide additional benefits. The first experimental designs investigate how operation mix, scheduling policies, and OR flexibility affect surgical suite capacity as defined by patient time in system. In this case, OR flexibility has two levels, dedicated or full flexibility. While this scenario may not be realistic for some surgical suites, OR flexibility was pared down to levels of dedicated and partial flexibility.

When full flexibility was investigated, no significant difference between treatment combinations was found. Additionally, when operating rooms were dedicated, scheduling policies were significant suggesting that scheduling patients with increasing surgical variability throughout the day is a best practice.

When partial flexibility was investigated, the top performing treatment combinations

were slightly separated suggesting that the elimination of the block schedule, or allowing for multiple daily operation genres to be performed, results in significantly lower patient time in system.

While the analysis of variance shows the statistical significance of flexible ORs and the removal of the block schedule, practical significance is what is ultimately important to the patient. As can be seen in the Tukey tests, the jump from the Multiple/Dedicated/Decreasing (MDD) policy to the One Daily/Dedicated/Increasing (ODI) policy is not only statistically significant but also shows a difference of over 25 minutes to patient time in system. While harder to see the practical significance of five minutes, especially when the surgical suite is underutilized, 25 minutes is enough time for an additional cataract surgery or excision. This additional time could also be used as a buffer to adhere to the schedule of surgery start times. Additionally, these conclusions are based around one hospital's data and may prove to be far more significant, both statistically and practically, when a different set of surgeries are performed. The models created for this experiment were designed such that any facility can easily modify the data to represent their own surgical suite to test how these policies may affect patient flow.

These models and the corresponding analysis may also be helpful when implementing new information technology such as Surgical Information Systems (SIS). These scheduling systems are created to improve the bottom line of the surgical suite by scheduling patients and staff as well as allocating operating and preparation rooms but are often very costly. The models provided may be a way to test IT system solutions before implementation to determine whether the potential effect on a particular surgical suite will be worth the investment.

The conclusions and contributions from this research provide a surgical suite with greater insight on how to improve patient flow and overall surgical suite performance. Methods, modeling code, analysis, and results from the capacity analysis and experimental design can be applied to a number of hospitals to assist in improved utilization of operating room time. This, in turn, can reduce costs, increase patient satisfaction, and make the surgical suite become even more profitable.

7.2 Recommendations for Future Work

While the process improvement will continue to expand within healthcare, this work can be extended to include larger hospitals able to offer a larger number of surgical procedures. The flexible OR and scheduling policies in a different facility may have a different impact on patient throughput. Additionally, the simulation models can be improved to alleviate some of the current assumptions.

Particularly, patients can be more closely monitored to account for waiting times such that only the value-added operations are input parameters for the delay distributions. The ambulatory worksheets used to form patient delays within the surgical suite by operation type have non-value-added activities and waiting times imbedded within them. With closer observation and/or value stream mapping, this error may be removed from the models. With the elimination of this wait time, the statistical significance of the scheduling and OR policies should increase as well as show that additional capacity is available without the addition of resources.

Currently, there are experiments being performed to determine the ability of administering the anesthesia in the preparation room prior to surgery, referred to as parallel

processing. While these types of processes are not currently well supported, other processing changes may be adopted through lean analysis which changes the flow of the patient through the suite. As perioperative systems are redesigned, scheduling and OR policies may have a much different effect on capacity. The models may need to be redesigned themselves or could be improved to make the change of patient flow an aspect that could be adjusted easily by hospital administration.

Finally, identifying the best combination of surgical genres to share the OR may be beneficial for the hospital attempting partial flexibility. There are many different preparation and cleanup procedures necessary for different operations which may make some operations a better pairing candidate than others. This balance may suggest that the suite looking to add operations should add physicians and equipment to the operation genre that is easily paired with other operation types.

The models and suggestions for future work with respect to the analysis presented within this thesis is only useful for the surgical suite administrators who realize that there is always a better way. As with many occupations, there is resistance to change. This resistance is, arguably, most difficult within healthcare since changes to the system and current processes pose a risk to the health of patients. These models provide a starting point for administrators to test potential changes on the system without the associated risk. As these models and analyses are improved upon, the results will become clearer, and, hopefully, those working within the surgical suite will be more comfortable with making changes to the system to both benefit the hospital and the patient.

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APPENDICES

These appendices contain the raw data, analysis results, modeling code, model description, and additional information used to perform the experiments in this thesis.

Appendix A. Output for MFI Treatment Combination

As the treatment combinations were run for each model, the trials were written to a text file, which were compiled in one Excel sheet. The following table is a portion of the results for the OFI treatment combination, as described in section 6.3. Each of the twelve treatment combinations has 100 results for patient time in system in the fully flexible and partial flexibility scenarios. The times in the full- and partial-flexibility columns are the same for those policies with dedicated operating rooms.

Operation Mix	OR Flexibility	Scheduling Policy	Time In System for Full Flexibility	Time In System for Partial Flexibility (2 Possible ORs to choose from)
One Daily	Flexible	Inc. Var.	167.781077	170.357723
One Daily	Flexible	Inc. Var.	164.162494	164.162494
One Daily	Flexible	Inc. Var.	166.059908	169.650735
One Daily	Flexible	Inc. Var.	163.687898	163.775173
One Daily	Flexible	Inc. Var.	164.180546	166.822517
One Daily	Flexible	Inc. Var.	163.040784	169.197838
One Daily	Flexible	Inc. Var.	168.91385	171.367332
One Daily	Flexible	Inc. Var.	169.330369	169.807767
One Daily	Flexible	Inc. Var.	164.755711	168.928505
One Daily	Flexible	Inc. Var.	165.746415	169.336729
One Daily	Flexible	Inc. Var.	165.934361	168.547814
One Daily	Flexible	Inc. Var.	167.244653	167.802646
One Daily	Flexible	Inc. Var.	167.936231	169.586686
One Daily	Flexible	Inc. Var.	161.826598	161.363613
One Daily	Flexible	Inc. Var.	166.04153	168.497751

Appendix B. Analysis of Variance

The following two ANOVA tables, created in Minitab, show the design of experiments, factors, levels, and significance of the full flexibility and partial flexibility trials. The cells from the Excel sheet in Appendix A were imported into Minitab to perform the following analysis.

ANOVA: Full Flexibility

Factor	Type	Levels	Values
Operation Mix	fixed	2	Multiple, One Daily
OR Flexibility	fixed	2	Dedicated, Flexible
Scheduling Policy	fixed	3	Dec. Var., Inc. Var., Random

Analysis of Variance for Full Flexibility, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Operation Mix	1	141468	141468	141468	3057.77	0.000
OR Flexibility	1	234524	234524	234524	5069.14	0.000
Scheduling Policy	2	6040	6040	3020	65.28	0.000
Operation Mix*OR Flexibility	1	144672	144672	144672	3127.03	0.000
Operation Mix*Scheduling Policy	2	2503	2503	1251	27.05	0.000
OR Flexibility*Scheduling Policy	2	6540	6540	3270	70.68	0.000
Operation Mix*OR Flexibility* Scheduling Policy	2	2942	2942	1471	31.79	0.000
Error	1188	54963	54963	46		
Total	1199	593652				

S = 6.80184   R-Sq = 90.74%   R-Sq(adj) = 90.66%

ANOVA: Partial Flexibility

Factor	Type	Levels	Values
Operation Mix	fixed	2	Multiple, One Daily
OR Flexibility	fixed	2	Dedicated, Flexible
Scheduling Policy	fixed	3	Dec. Var., Inc. Var., Random

Analysis of Variance for Partial Flexibility, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Operation Mix	1	157280	157280	157280	3311.45	0.000
OR Flexibility	1	214865	214865	214865	4523.87	0.000
Scheduling Policy	2	7315	7315	3658	77.01	0.000
Operation Mix*OR Flexibility	1	129524	129524	129524	2727.06	0.000
Operation Mix*Scheduling Policy	2	2921	2921	1460	30.75	0.000
OR Flexibility*Scheduling Policy	2	5308	5308	2654	55.87	0.000
Operation Mix*OR Flexibility* Scheduling Policy	2	2466	2466	1233	25.96	0.000
Error	1188	56425	56425	47		
Total	1199	576103				

S = 6.89172   R-Sq = 90.21%   R-Sq(adj) = 90.12%

Appendix C. Tukey Tests

Along with the analysis of variance, confidence intervals were compared for each scenario by each treatment combination. This analysis was the basis for the Tukey tables shown in section 6.4. The first test was run for the models allowing fully flexible ORs while the second test shows the differences when flexibility is constrained by just two ORs.

One-way ANOVA: Full Flexibility – Time in System vs. Treatment Combination

```
Source        DF      SS           MS          F       P
C1            11   538689.4     48971.8     1058.50 0.000
Error       1188   54962.9       46.3
Total       1199    593652.3

S = 6.802  R-Sq = 90.74%  R-Sq(adj) = 90.66%
```

```
                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean  StDev  --------+---------+---------+---------+-
MDD    100  175.31   7.76         (*
MDI    100  172.15   7.63       (*
MDR    100  167.83   5.32    (*)
MFD    100  166.25   4.31   (*)
MFI    100  166.22   5.14   (*)
MFR    100  164.82   4.47  (*)
ODD    100  224.75  10.67                                        *)
ODI    100  207.62  10.05                              (*)
ODR    100  213.94  10.37                                  (*)
OFD    100  164.86   2.58  (*)
OFI    100  166.03   2.75   (*)
OFR    100  165.66   2.64   (*
                           --------+---------+---------+---------+-
                                 176       192       208       224

Pooled StDev = 6.80


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of C1

Individual confidence level = 99.89%
```

One-way ANOVA: Full Flexibility – Time in System vs. Treatment Combination

Source	DF	SS	MS	F	P
C1	11	519678.4	47243.5	994.69	0.000
Error	1188	56425.0	47.5		
Total	1199	576103.4			

S = 6.892 R-Sq = 90.21% R-Sq(adj) = 90.12%

```
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level    N   Mean  StDev  --------+---------+---------+---------+-
MDD    100  175.31   7.76        (*
MDI    100  172.15   7.63      (*
MDR    100  167.83   5.32   (*)
MFD    100  166.52   4.34  (*)
MFI    100  166.06   5.20  (*)
MFR    100  164.75   4.51 (*)
ODD    100  224.75  10.67                                     *)
ODI    100  207.62  10.05                            (*)
ODR    100  213.94  10.37                                (*)
OFD    100  168.25   3.48   (*)
OFI    100  167.63   3.35   (*)
OFR    100  167.81   3.37   (*)
                          --------+---------+---------+---------+-
                                176       192       208       224

Pooled StDev = 6.89


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of C1

Individual confidence level = 99.89%
```

Appendix D. Block Schedule

The following table is the block schedule for Chenango Memorial and was the basis for the current state and future state capacity models described in section 5.3.

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
RM 1	Ortho – all day	GYN – all day	ENT – all day	Ortho – all day	ENT/OPEN
RM 2	General/GYN	General – AM/Open PM	General/Open PM	GYN/General	General/Open
RM 3	--------------	Eyes- AM (MAC only)	Eyes – AM (MAC only)	Eyes------	----------------

In the design of experiment section, the factor for one daily operation would suggest that, for example, Monday would consist of only orthopedic operations. The factor for multiple daily operations suggests that there is no block schedule and any operation can be performed on any given day. The actual block schedule used, as shown above, is in the middle of the spectrum of one daily and multiple operations.

Appendix E. VBA Model Code

The following code was written in the VB editor within the Arena software. It provides the interface for the simulation models as well as the link between user input and model output. The first bit of code is found within 'This Document' and is described in more detail in section 6.1. This code was written to index the potential operating rooms a specific surgical procedure is capable of using.

ThisDocument:

```
Private Sub ModelLogic_RunBeginReplication()
Dim m As Model
Dim s As SIMAN
Set m = ThisDocument.Model
Set s = m.SIMAN
For i = 0 To 49
  If UserForm1.ListBox1.Selected(i) = True Then
  s.VariableArrayValue(s.SymbolNumber("Index", 1)) = s.VariableArrayValue(s.SymbolNumber("Index", 1)) + 1
  s.VariableArrayValue(s.SymbolNumber("PotentialRooms", 1, s.VariableArrayValue(s.SymbolNumber("Index",
1)))) = i + 1

  End If
Next
For i = 0 To 49
  If UserForm2.ListBox1.Selected(i) = True Then
  s.VariableArrayValue(s.SymbolNumber("Index", 2)) = s.VariableArrayValue(s.SymbolNumber("Index", 2)) + 1
  s.VariableArrayValue(s.SymbolNumber("PotentialRooms", 2, s.VariableArrayValue(s.SymbolNumber("Index",
2)))) = i + 1

  End If
```

The next portion of code is an example of the code needed to change resource allocation within the model. The text box within the VB UserForm is connected to the resource level within the simulation model. The second portion of code adds potential ORs selected by the user within the OR listbox for each surgical procedure.

Main Form UserForm:

```
Private Sub GetInfoFromOperationPercentages()
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(1)") = OperationPercentages.Orthopedic.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(2)") = OperationPercentages.General.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(3)") = OperationPercentages.Obstetrics.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(4)") = OperationPercentages.Ophthalmology.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(5)") = OperationPercentages.ENT.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(6)") = OperationPercentages.Oncology.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(7)") = OperationPercentages.Plastic.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(8)") = OperationPercentages.Urology.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(9)") = OperationPercentages.Cardiac.value
ThisDocument.Model.Modules(ThisDocument.Model.Modules.Find(smFindTag, "object.10736")).Data("Initial Value(10)") = OperationPercentages.Other.value
End Sub
```

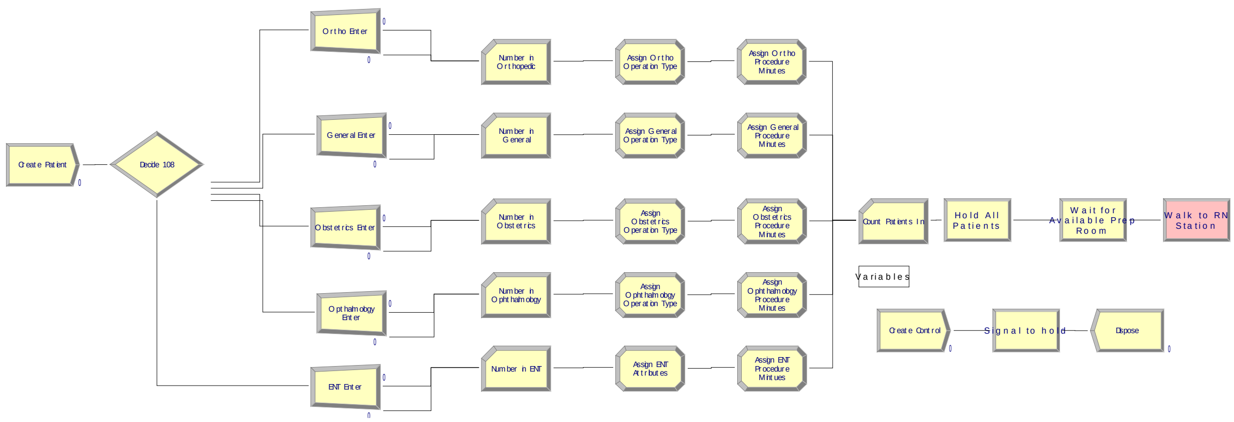
OR Selection:

```
Private Sub CommandButton1_Click()
ListBox1.AddItem "1"
ListBox1.AddItem "2"
ListBox1.AddItem "3"
ListBox1.AddItem "4"
ListBox1.AddItem "5"
ListBox1.AddItem "6"
ListBox1.AddItem "7"
ListBox1.AddItem "8"
ListBox1.AddItem "9"
ListBox1.AddItem "10" …

End Sub
```

Appendix F. Model 1: Suite without Variability, One Daily Operation

The first model runs on a daily block schedule and does not sort surgeries by their variability. Each model, one through four, is run for ten hours a day.



For each model described in the Appendices F through I, nine patients enter the system each day. Depending on which day it is, a different operation will be performed in Model 1. For example, If CalDayOfWeek(TNOW) = 1 (if it is a Monday) then nine orthopedic patients enter the system. Next, the operation type within that particular operation genre is selected based on a discrete distribution. The time in OR, inpatient/outpatient status, and genre type attributes are assigned and the patient is ready to travel through the surgical suite (model) following the flow described in section 4.1.

Model 1 was used to run the following treatment combinations in the design of experiments: ODR and OFR.

In each model, a control entity releases patients into the system, one at a time, in 40 minute intervals. This followed with the system employed by the hospital studied and can be

changed within the model window. For policies employing flexible operating rooms, the flexibility is set by the user within the interface. Hot keys are set to jump to each section within the model: patient arrival, ambulatory preparation, operating room, patient recovery, and non-value-added activities. The model was constructed in Rockwell Software's Arena 7.0 and can also be opened with Arena 10.0.

Appendix G. Model 2: Suite with Variability, One Daily Operation

Patients are given an operation genre in Model 2, as described in Appendix F, depending on which day of the week the model is simulating. After the patients are given all of their surgical attributes, they calculate a variance attribute which takes the longest possible time for surgery minus the shortest possible time for surgery to estimate the surgical variability.

Prior to any patient being admitted to the system, they are sorted in either decreasing or increasing order based on the surgery's operation variability. This must be done within the model window, not the interface. To do this, go to the Basic Process tab on the left-hand side of the screen. Select Queue and find the 'Hold All Patients' queue. For the Type associated with the Hold All Patients queue, select lowest attribute first to schedule patients with increasing variation or select highest attribute first to schedule patients with decreasing variation.

Model 2 was used to run the following treatment combinations in the design of experiments: OFD, ODI, OFI, and ODD.

Appendix H. Model 3: Suite without Variability, Multiple Daily Operations

Model 3 uses percentages defined by the user through the interface to determine how many patients of each type of operation will be entering the system each day. Attributes are assigned as described in Appendix F. All patients are held and admitted to the system one at a time in 40 minute intervals.

Model 3 was used to run the following treatment combinations in the design of experiments: MFR and MDR.

Appendix I. Model 4: Suite with Variability, Multiple Daily Operations

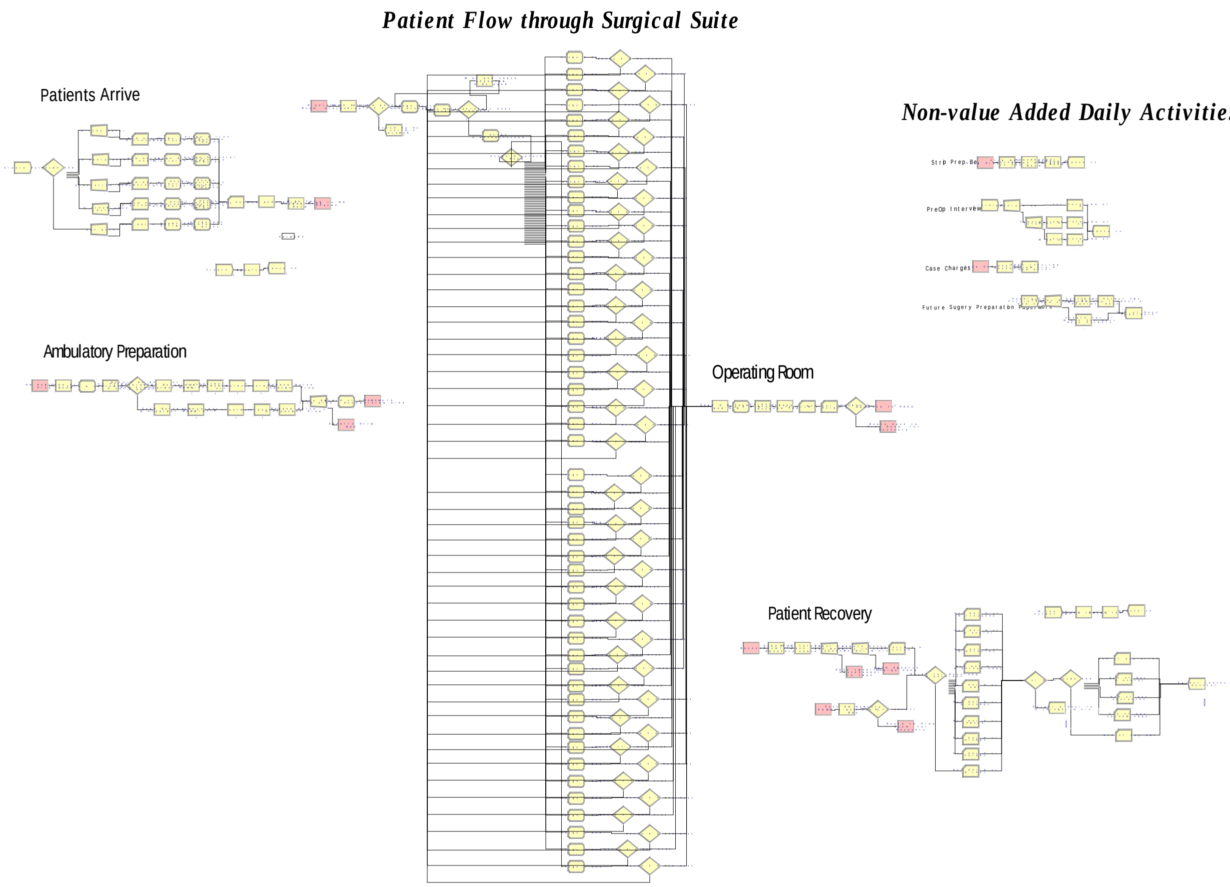
Model 4, like Model 3 uses user input to determine which operation types will be performed each day. Like Model 2, a variability attribute is defined, and prior to entering the system, patients are sorted by their surgery's operation variability.

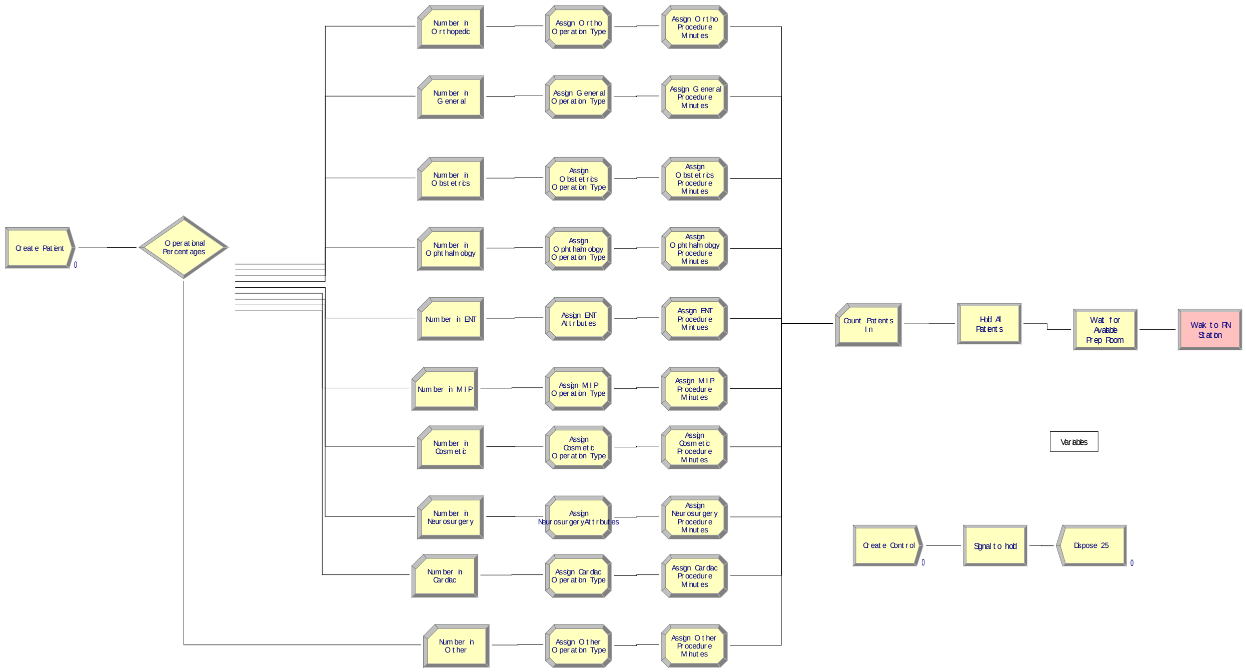
Model 4 was used to run the following treatment combinations in the design of experiments: MDD, MFI, MDI, and MFD.

Models 1 through 4 can be found on the attached disk.

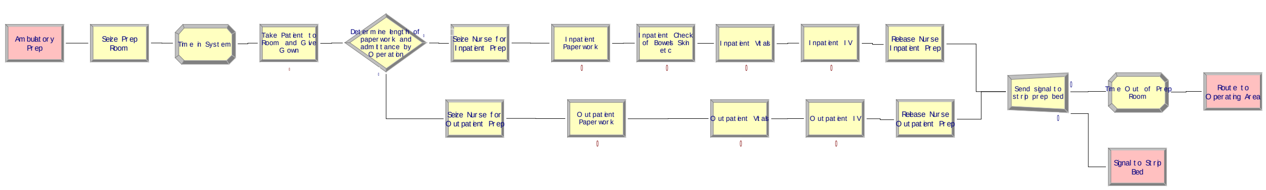
Appendix J. Process Layout

Below is a global template view for each model. If there are multiple operations being performed, the patient arrival section will look different. Besides patient arrival, the rest of the processes remain the same.



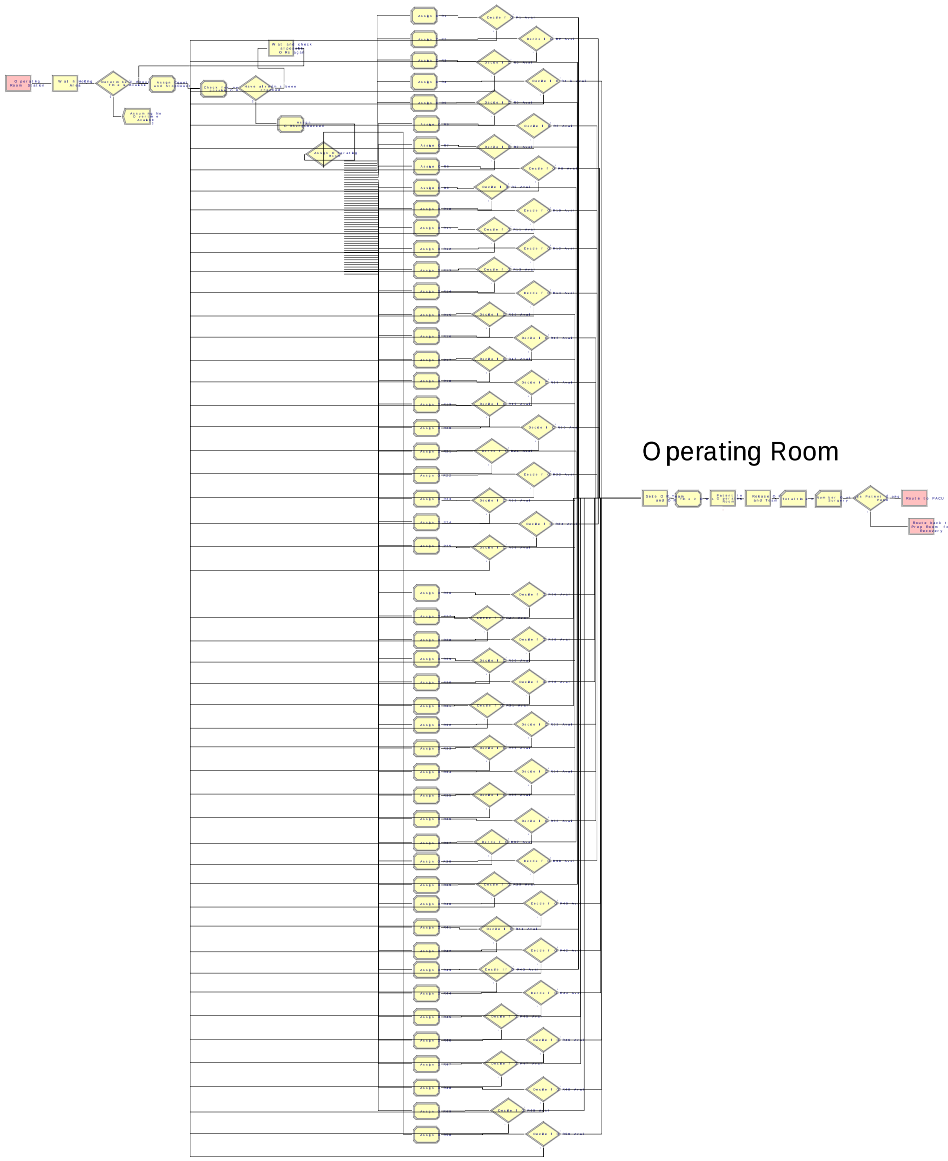


As entities are created, they are routed according to the percentages the user allocated to each operation genre. The number of patients for each genre is collected and attributes are assigned as before.

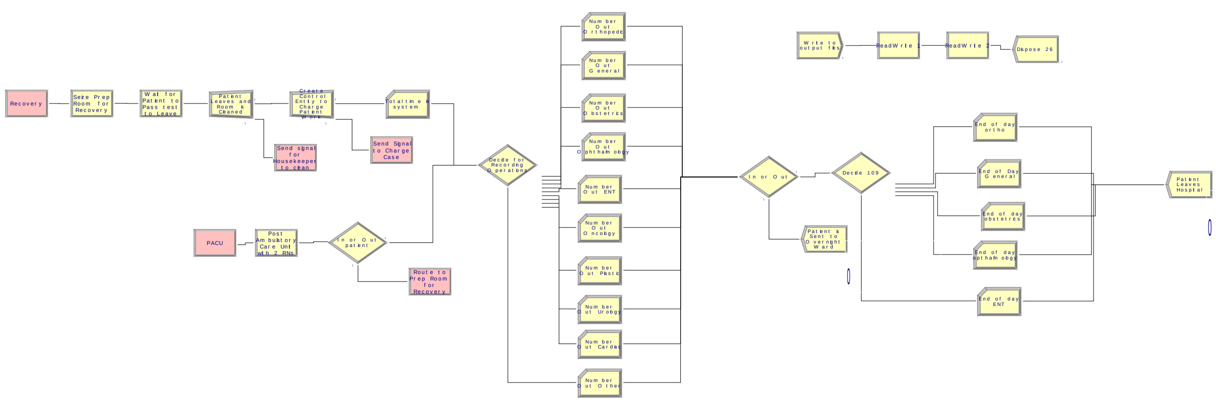


In the ambulatory preparation section, as soon as the patient is routed after being admitted, they seize a preparation room. Immediately afterwards, their time in system clock begins. The patient is given a few minutes to change into the surgical gown. A nurse is seized. Depending on whether they are an inpatient or outpatient, their treatment will be slightly different. The inpatient completes paperwork, the skin and bowels are checked by the nurse

along with vitals, and IV is administered. The outpatient does not require the skin and bowel check. All other operations for these two types of patients require similar time to process. The nurse is released and the patient is routed to the waiting section outside of the OR. A signal is sent to the non-value-added processes section to call a nurse to clean the released preparation room.



The operating room section on the previous page appears large because each OR, which is a separate resource, needed to be scanned by the model to determine if the resource was currently in use or available. The only way to scan the resource utilization was to have each OR modeled separately. The patient routed from the preparation room waits a few minutes or until the OR is cleaned and ready for occupation. The model checks to make sure there is enough time left in the day to complete the surgery without incurring overtime. If there is not enough time the entity is disposed of; if there is enough time, the patient goes through the following processes as outlined on page 42.



As the patient's surgery is complete, he or she is routed to either a preparation room for cataract operations or to PACU for all others. The patient in the preparation room will wait approximately 45 minutes before seizing a nurse for final clearance and paperwork. The patient routed to PACU will be observed for about 45 minutes by a nurse before being transferred back to the preparation room for final recovery and clearance. Records capture the ending time in system for patients in brackets corresponding to their operation genre. Output is written to Excel files and final performance measures are captured.