Improving the Scheduling of Operating Rooms at UMass Memorial Medical Center

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By:
Courtney Carroll (IE '14)
Meredith Juers (IE '14)
Sonja Kent (IE '14)

Advisor:
Professor Andrew Trapp, Ph.D.

Sponsor:
UMass Memorial Medical Center

Special Thanks:
Dr. Tze Chiam, Ph.D.
Taoye Chen
Natassia Taylor

Abstract

The goal of this project was to improve the scheduling of surgical cases at UMass Memorial Medical Center (UMMMC). Interviews, past surgical data, and observations were analyzed to evaluate the current state of surgical scheduling procedures. An optimization tool was developed in Excel that uses integer programming to increase the operating room utilization to be more competitive with industry standard. Recommendations were provided to more efficiently schedule surgical cases in the future to reduce overtime costs and maximize value-added time.

Acknowledgements

Authorship

This Major Qualifying Project Report was authored by Courtney Carroll, Meredith Juers, and Sonja Kent. Each section of this paper was written and edited by all three members of our team. The initial research was divided by topics. Courtney focused on heuristics, Meredith researched simulation, and Sonja explored optimization techniques. Sections of the rest of the paper were first drafted by individuals, but were then edited and reorganized resulting in a final paper representing a combined group effort. The abstract, acknowledgements, authorship, appendix and formatting were finalized as a group upon completion of the main sections of the paper. The optimization model was designed by Courtney, Meredith, and Sonja in collaboration with Professor Andrew Trapp. A majority of the VBA coding was done by Sonja.

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1. Introduction

UMass Memorial Medical Center (UMMMC) offers a wide range of specialized health services with the mission to improve the health of the people of central New England through excellence in clinical care, service, technique and research. To deliver on this promise, UMMMC aims to improve the quality and safety of the care delivered to their patients (UMass Memorial Medical Center, 2013). This level of quality for healthcare resources at medical centers such as UMMMC is essential to the general welfare of society. In order to tackle ever-increasing problems such as staffing shortages and rising costs, efficiency needs to be a priority across all campus-wide functions.

The UMass Memorial Medical Center campus, located in Worcester, Massachusetts, has 17 operating rooms that treat an average of almost 10,000 patients per year. In order to improve UMMMC's reputation as a private, charitable, non-profit hospital, efficiency should be emphasized in the scheduling of surgeries. The operating rooms are used by service lines such as cardiac, emergency trauma, and plastic surgery to name a few. Scheduling operations for the 28 service lines, 243 surgeons, and different groups within the hospital can be difficult, but it is important that scheduled OR time is used well in order to reduce costs and ensure the best patient care.

According to our liaison at UMMMC, Dr. Tze Chiam, Ph.D., the external benchmark for OR utilization is between 70 and 80%; UMMMC is currently operating at approximately 65% utilization for their operating rooms. The goal of this project is to increase utilization of operating room scheduling at UMMMC to a rate that is on par with industry standard. Through discussions with stakeholders, quantitative analysis, and modeling, we aim to provide enhanced scheduling recommendations to the surgery department at UMMMC. Our first objective is to analyze the current state of the operating room scheduling at UMMMC to better understand their current procedure and scheduling models. Our next objective is to develop a model that will allow us to determine an optimal schedule to provide the

best utilization of operating rooms. When possible, we will take into account factors such as surgeon and patient preferences for a more realistic implementation. Our final objective is to provide multiple scheduling recommendations to UMMMC that will lead to improved utilization rates for the operating rooms.

2. Background

In an effort to improve operating room scheduling at UMass Memorial Medical Center in Worcester, Massachusetts, we researched possible methods for improvement from the literature. Hospitals across the country are currently facing challenges such as rising costs (Bodenheimer, 2010), an aging population (Hellmich, 2008), inefficient hospital processes (New England Healthcare Institute, 2010) and staffing shortages (American Nurses Association, Inc., 2010), all of which play into the importance and necessity of this project. The purpose of this section is to provide an overview of techniques for OR scheduling improvement that may be applicable to UMMMC. Ranging from optimization, to simulation, to heuristics, this section explores the role these methods play in healthcare-related optimization today and the details involved in each process. Certain case studies will be highlighted and the effectiveness of each technique will be reported based on the results from these cases. Finally, a brief overview of the current state of the ORs at UMMMC will be described.

2.1 Optimization

Linear programming (LP) is a widespread tool in optimization that consists of three parts – the objective, decision variables, and constraints (Abrahamse, Bahl, & Mulholland, 2005). Linear programming is a technique that can optimize a linear objective, subject to some limitations (constraints) on the combinations of allowable variable values. The role of the variables in the model is that they are decisions reflecting what to do. The variables need to be determined in order to solve the problem. Constraints represent restrictions on the values of the variables and their allowable combinations. LP models in the healthcare domain may include considerations such as a mix of different financial objectives, amounts of constrained resources, various assumptions, and the volume of surgical procedures. One such application of linear programming is in determining a mix of patients that optimizes the financial outcome of both physicians and the hospital while taking into consideration

the consumption of resources by the intensive care unit (ICU), post-anesthesia care unit (PACU), surgical acute care unit (SACU), or other holding units (Beliën, Cardoen, & Demeulemeester, 2010). This is further exemplified in an article where a multi-objective integer programming model is used to minimize overtime and idle time in nurses' schedules (Mobasher, Lim, Bard, & Jordan, 2011).

Integer programming is related to linear programming and is a technique for finding the minimum or maximum value of a linear function in which at least some solution values must be integer. In the nurse scheduling study, solutions were derived based on the idea of a solution pool and modified goal programming, which resulted in an effective, 50% reduction in nurse idle- and over-time (Mobasher, Lim, Bard, & Jordan, 2011). The above example used goal programming, a type of multi-objective optimization, to handle multiple conflicting objective measures.

Constraints are a major factor in all linear programming models and can be divided into two different types: hard constraints and soft constraints. Constraints are frequently limited to hard constraints which are those that must be satisfied and are not allowed to be violated. Soft constraints may be violated, but at a cost. Soft constraints are not that common, but in the context of goal programming, they can be incorporated in the objective function (Beliën, Cardoen, & Demeulemeester, 2010). A list of common, important constraints in the context of operating room planning and scheduling can be seen below in Table 1.

Table 1: List of hard constraints (Beliën, Cardoen, & Demeulemeester, 2010)

Hard Constraint	Examples
Resource Constraints	Holding area, ward, ICU, PACU, SACU, equipment, surgical staff, budget, regular operating room time, operating room over/under time
Precedence Constraints/Time Lags	Time lag due to contamination risks (extended cleaning required), setting maximum allowed waiting time between two activities
Release/Due Date Constraints	Incorporating urgency deadlines for certain activities
Demand Constraints	Demand for operating room blocks, demand for surgery

Looking more specifically at the scheduling of ORs, one approach involves column generation. This method is best for problems with an exponential number of variables. Starting with a subset of the variables, additional variables can be produced and added to the model if they are useful (Beliën, Cardoen, & Demeulemeester, 2010). In this specific study, the researchers used this approach to minimize patient related costs and operating room utilization costs. One disadvantage is that column generation cannot force the decision variables to be integers; therefore the fractional outputs can then be used in constructive and improvement heuristics (Lamiri, Xie, & Zhang, 2008). Although not necessarily an optimal solution, heuristics often provide respectable solutions to these problems and typically do so quickly. Heuristics are described in more detail in Section 2.3. Another study created an integer programming model to schedule cases in a manner that minimized operating costs. This optimization model used branch-and-price, a method to solve optimization models with very large numbers of variables, to find a solution and had promising results especially with regards to solving large problems (Fe, Chu, Meskens, & Artiba, 2008).

2.2 Simulation

Simulating possible scheduling methods rather than immediately implementing them allows for the testing of many variables without economically threatening an OR with a schedule that may result in

a poor utilization. In addition to the cost savings of simulation, it also saves time. Two of the most commonly implemented simulation approaches include discrete-event and Monte-Carlo simulation (Beliën, Cardoen & Demeulemeester, 2010). The discrete-event simulation method illustrates systematic changes over time for a countable number of points and is therefore dynamic. In this study, discrete-event simulation is implemented to analyze operating room utilization, resource allocation, patient throughput and the number of patient deferrals (Beliën, Cardoen & Demeulemeester, 2010). Contrarily, the Monte-Carlo approach is a static method which illustrates a system's operation at a specific time. Monte-Carlo simulation is used to analyze and quantify impacts of procedures on patient wait time and utilization criteria. For instance, this study evaluated the impact of changing the master schedule and the order of performance criteria.

In order to analyze the effect of multiple scheduling techniques on operating room utilization, discrete-event simulation is used, since it involves dynamic changes. Arena is a software package specifically designed for discrete-event simulation. Arena allows processes to be linked by connector lines to demonstrate a systems flow and to indicate possible decisions and their resulting outcomes. This software allows analysts to imitate system behavior in the future based on past events, visualize the effect of variables on the system, and identify the best set of input values (Grinbergs, Kleins, Merkuryev & Teilans, 2008).   Arena will take into account data of operating room times with different variables to minimize the square error value of the distribution, which is a measure of the systems' quality (Chen, Pasquariello & Tyler, 2003).

One study that implemented a simulation model to improve OR utilization focused on determining the appropriate amount of block time to schedule as well as selecting the most effective days to schedule elective surgeries (Dexter, 1999). In this case, inputs into the model included methods which determine the time a patient will have surgery, case durations, patient wait times for surgeries,

hours of block time per day, and number of blocks per week (Dexter, 1999). One advantage of using simulation for this scenario is that it incorporates several parameters, determines unused OR time in each block and then computes the OR utilization based on the set parameters. For this study, analysts would require 100,000 years of OR scheduling data without the simulation. Instead, they were able to quickly run the simulation with different combinations of parameter values (Dexter, 1999).

Analysis of the simulation results illustrated that in order to fully optimize OR utilization, determining the date and time of a surgery must be completely in the control of the scheduler rather than the surgeon or patient (Dexter, 1999). Results also demonstrated that the parameter most affecting OR utilization is the length of time patients spend waiting before their surgery (Dexter, 1999). The longer patients wait, the less unused block time is left unutilized. In the schedule yielding the greatest OR utilization, block time was allocated based on the total predicted time of elective cases. Patients are scheduled into the first open block time on the next available date. If there is not a time within the next four weeks the patient is scheduled in overflow time which is scheduled separately outside the block time (Dexter, 1999).

Another study used a similar approach to simulation; however, the study focuses primarily on using simulation to determine a goal for OR utilization levels (Chen, Pasquariello & Tyler, 2003). The results of the simulation determined that the most efficient utilization for an OR is between 85% and 95% (Chen, Pasquariello & Tyler, 2003). When utilization was higher than this there were delays in other areas of the hospital and surgeon overtime was a common occurrence. It is important to determine the optimal value of utilization in order to create a specific objective for improvement.

2.3 Heuristics

Heuristics are exploratory problem-solving methods that often utilize self-educating techniques to improve performance. While heuristics can provide decent solutions to problems, they do not

guarantee an optimal solution. These methods may be used to provide multiple solutions from which the user can determine the best solution for their application.

A study built upon the foundation of previous research methods developed a new algorithm based on the open scheduling method (Fei, Chu, Meskens & Artiba, 2008; Fei, Meskens & Chu, 2010). The open scheduling strategy consists of assigning operations corresponding to each given surgeon into time slots, and operations that should be performed by different surgeons can be assigned to the same time slot (Liu, Chu & Wang 2011). For example, in Figure 1, operations of surgeons 1 and 3 are assigned to the same time slot. The objective of this particular model is to partition the set of operations into subsets and assign a timeslot to each subset to optimize the objective function using dynamic programming by aggregating states to avoid the explosion of the number of states (Liu, Chu & Wang, 2011).
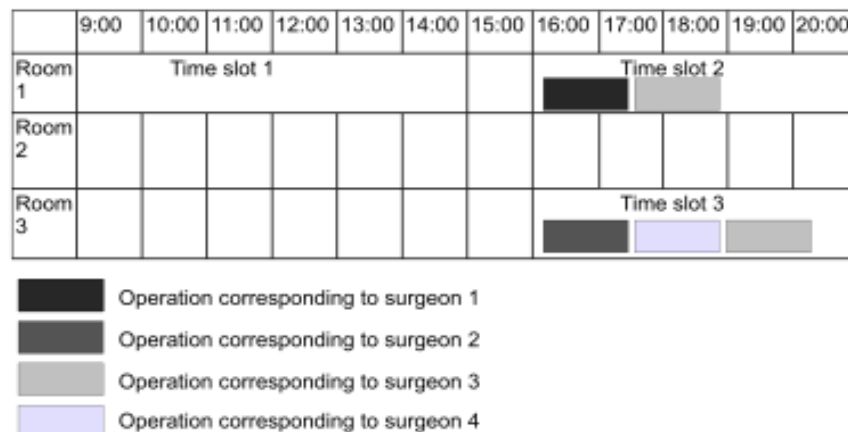
Figure 1: Open scheduling method using time slots (Liu, Chu, & Wang, 2010)

Heuristics can be a valuable tool for operating room scheduling. This method takes advantage of mathematical models as well as practical knowledge of the problem. In the case of operating room scheduling, there are many variables to be considered and hospitals may choose to place more importance on variables such as patient satisfaction or the level of utilization. The flexibility of a

heuristic approach allows for the user to develop a mathematical model or method that is most practical for their application, and not necessarily the model or method that provides an optimal solution.

2.4 Predictive Techniques

In addition to optimization, simulation and heuristic techniques, there are many predictive techniques that can be used to calculate or estimate future data. These techniques can consist of statistical models and computations based on past data from which conclusions can be made about future data.

One study explored the use of log-normal distribution method for predicting upper bound of surgical cases (Zhou & Dexter, 1998). For this method, case duration was defined as the time between when the patient enters and exits an operating room and surgeries with the same combination of scheduled procedures were considered to be the same surgery. The prediction bounds calculated using the two methods were tested using 48,847 surgical case data collected over 3 years (Zhou & Dexter, 1998).

Results indicated that prediction bounds classified by surgeon and procedure can accurately be calculated using the method that assumes that case durations follow a log-normal distribution. The prediction of bounds based on the log-normal distribution overestimated the desired value less often than the distribution free method (Zhou & Dexter, 1998).

In contrast to distribution models, in another study, a linear regression model is used to predict the time to complete a series of successive surgical cases in an operating room and minimize costs of staffing. These calculations take into account several independent and dependent variables such as categories of procedures, category of the case, the procedure completion time, number of turnovers, turnover time, and labor costs (including over-utilized and under-utilized time). The authors compare their linear regression model to the use of the sample mean of case times and turnover times for

operating room scheduling and its inability to take into consideration the labor costs associated with errors in case time predictions (Dexter, Traub & Qian, 1999). The objective of this function is to improve the operating room utilization while reducing the costs of under- and over-utilization and reducing unnecessary wait times for patients. The authors used a linear programming solver (COPLLP) obtained from the University of Iowa's Computational Optimization Laboratory to solve their linear programming model.

The theoretical advantage of this method is that it minimizes the cost function of interest. According to one article, the cost of under-utilization and over-utilization are approximately equal and is represented by the mean absolute error (Dexter, Traub & Qian, 1999). However, operating suites with full-time hourly employees with frequent overtime will cause the cost of over-utilization to be greater than the cost of under-utilization, so the mean absolute error is not an appropriate measure of the cost. The computational model developed in this study can be generalized to account for the additional over-utilization costs while the sample mean method cannot (Dexter, Traub & Qian, 1999). Additionally, the computational method minimizes the mean absolute error in terms of cost whereas the use of the sample means of previous case times and turnovers resulted in a lesser mean absolute error in calculating case times and turnover times (Dexter, Traub & Qian, 1999). So, while the computational method is preferred theoretically for its ability to minimize the cost function, the use of sample means is more effective and practical when calculating case times and turnover times.

Predictive techniques are especially useful in that they can be used within optimization, simulation and heuristics techniques as inputs or conclusions about trends in past data. For example, using predictive methods, conclusions drawn from past data can be incorporated into a simulation as an assumption that can help model the future state of a process.

2.5 Comparison of Methods

Table 2 illustrates the pros and cons of each method we researched to improve OR utilization.

Table 2: Comparison of analytical methods for improving OR schedules

	Pros	Cons
Optimization	• Can find optimal solution if one exists • Precise	• Limited flexibility • Solution cannot always be found • May have long run times
Simulation	• Easy to incorporate factors • Provides performance measures • More realistic output	• Requires software and programming knowledge • Can only determine the best output using the set of inputs provided
Heuristics	• More subjective • Usually provides good but not necessarily optimal solutions • Typically short run times	• Lack of optimality guarantee

2.6 OR Scheduling at UMMMC

The 17 operating rooms at UMMMC are currently scheduled using a block scheduling method. A block scheduling system assigns a block of operating room time to a service line, surgeon, or group based on demand. The blocks are scheduled on a monthly basis at UMMMC and each block is reserved for that owner's exclusive use. One of the challenges in developing the most efficient OR schedule is emergency surgeries. These emergency surgeries are a type of add-on case and are a volatile factor that must be incorporated into the schedule. Another major challenge facing the optimization of OR utilization is the unpredictability of the variety of surgeries and the surgeries going over or under the specific, scheduled time. Other challenges mentioned by liaison, Dr. Tze Chiam, include patient cancellations, surgeon cancellations, staffing issues, and cases that need rescheduling due to the previous case running overtime.

According to our contacts at UMMMC, ORs can be booked by three different parties – service lines, surgeons, or groups. These parties make a phone call to put in a request for a block on the OR schedule. The department scheduling the ORs generates a template at the beginning of each month, similar to the screenshot in Figure 2 below. Each block below is assigned to a specific party, open to be booked, or designated as a trauma block for emergencies or add-on cases.

		University Campus OR Schedule									
		Effective Date JANUARY 1, 2013									
Times*		(7:30-7:00)			(7:30-7:00)			(8:45-7:00)		(7:30-7:00)	(7:30-7:00)
Room #	WK	MONDAY	WK	TUESDAY		WK	WEDNESDAY	WK	THURSDAY	WK	FRIDAY
		AM 7:30-3:00 PM 3:00-7:00		AM 7:30-3 PM 3-5							
1	1	GEN███ Open	1	VAS Vascular Open		1	VAS Vascular (8:45-5:00)	1	GEN███ (7:30-5:00)	1	GEN███ (7:30-5:00)
	2	GEN███ Open	2	VAS Vascular Open		2	VAS Vascular (8:45-5:00)	2	GEN███ (7:30-5:00)	2	DOS ACS (7:30-5:00)
	3	GEN███ Open	3	VAS Vascular Open		3	VAS Vascular (8:45-5:00)	3	GEN███ (7:30-5:00)	3	GEN███ (7:30-5:00)
	4	GEN███ Open	4	VAS Vascular Open		4	VAS Vascular (8:45-5:00)	4	GEN███ (7:30-5:00)	4	DOS ACS (7:30-5:00)
	5	GEN███ Open	5	VAS Vascular		5	VAS Vascular (8:45-5:00)	5	GEN███ (7:30-5:00)	5	DOS ACS (7:30-5:00)
		AM 7:30-3:00 PM 3:00-7:00		AM 7:30-3							
2	1	VAS Vascular Open	1	TRAN Transplant (7:00-5:00)		1	DOS open (8:45-3:00)	1	VAS Vascular (7:30-5:00)	1	VAS Vascular (7:30-3:00)
	2	VAS Vascular Open	2	TRAN Transplant (7:00-5:00)		2	DOS open (8:45-3:00)	2	VAS Vascular (7:30-5:00)	2	VAS Vascular (7:30-3:00)
	3	VAS Vascular Open	3	TRAN Transplant (7:00-5:00)		3	DOS open (8:45-3:00)	3	VAS Vascular (7:30-5:00)	3	VAS Vascular (7:30-3:00)
	4	VAS Vascular Open	4	TRAN Transplant (7:00-5:00)		4	DOS open (8:45-3:00)	4	VAS Vascular (7:30-5:00)	4	VAS Vascular (7:30-3:00)
	5	VAS Vascular Open	5	TRAN Transplant (7:00-5:00)		5	DOS open (8:45-3:00)	5	VAS Vascular (7:30-5:00)	5	VAS Vascular (7:30-3:00)
3	1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (7:00-7:00)		1	CAR Cardiac (8:00-7:00)	1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (7:00-7:00)
	2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (7:00-7:00)		2	CAR Cardiac (8:00-7:00)	2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (7:00-7:00)
	3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (7:00-7:00)		3	CAR Cardiac (8:00-7:00)	3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (7:00-7:00)
	4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (7:00-7:00)		4	CAR Cardiac (8:00-7:00)	4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (7:00-7:00)
	5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (7:00-7:00)		5	CAR Cardiac (8:00-7:00)	5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (7:00-7:00)
4	1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (7:00-7:00)		1	CAR Cardiac (8:00-7:00)	1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (7:00-7:00)
	2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (7:00-7:00)		2	CAR Cardiac (8:00-7:00)	2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (7:00-7:00)
	3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (7:00-7:00)		3	CAR Cardiac (8:00-7:00)	3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (7:00-7:00)
	4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (7:00-7:00)		4	CAR Cardiac (8:00-7:00)	4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (7:00-7:00)
	5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (7:00-7:00)		5	CAR Cardiac (8:00-7:00)	5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (7:00-7:00)
		AM 7:30-3 PM 3:00-5:00		███████							
5	1	ORT███ Open	1	ORT FX		1	ORT███ (8:45-5:00)	1	ORT███ (7:30-5:00)	1	ORT███ (7:30-5:00)
	2	ORT███ Open	2	ORT FX		2	ORT███ (8:45-5:00)	2	ORT███ (7:30-5:00)	2	ORT███ (7:30-5:00)
	3	ORT███ Open	3	ORT FX		3	ORT███ (8:45-5:00)	3	ORT███ (7:30-5:00)	3	ORT███ (7:30-5:00)
	4	ORT███ Open	4	ORT FX		4	ORT███ (8:45-5:00)	4	ORT███ (7:30-5:00)	4	ORT███ (7:30-5:00)
	5	ORT███ Open	5	ORT FX		5	ORT███ (8:45-5:00)	5	ORT███ (7:30-5:00)	5	ORT███ (7:30-5:00)

Figure 2: Block scheduling template for ORs 1-5

In this OR suite, room 9 is the designated trauma room and is reserved for emergency cases. As mentioned previously, the OR utilization rate at UMMMC is calculated to be at around 65% compared to the external benchmark that is stated at 70-80%. One concern regarding utilization rate is that there are multiple methods to calculate this value and UMMMC does not have an established definition by which utilization can consistently be measured. The utilization rate measure we will work with for the purpose of this project will be an equation all stakeholders involved agree upon and implement. Given the

current process, UMMMC hopes to improve the OR utilization rate, block management, and add-on case management.

A research article on managing block time in operating rooms had a couple of useful recommendations regarding block scheduling (OR Manager, 2004). The main concepts from this research started with aiming for 80% of the OR time being blocked and always having at least two ORs open a day, regardless of the number of ORs in the suite. Looking specifically at the blocks that are scheduled, it is advised to avoid blocks shorter than eight hours long. Finally, in order to maintain a more efficient process as well as monitor OR functionality, it is advised to set utilization goals and measure it monthly (OR Manager, Inc., 2004). These recommendations are very applicable to the OR scheduling process at UMMMC since the hospital also uses a block scheduling method.

Equipped with a basic understanding of the current OR scheduling process and having discussed relevant techniques from the literature related to improving scheduling for OR optimizations, our next step was to develop a plan for the project's progression.

3. Methodology

3.1 Goals and Objectives

The primary goal of this project is to increase the utilization of operation rooms through improved scheduling at UMMMC. In order to achieve this goal our group has developed three main objectives:

1. Analyze the current state of operating room scheduling at UMMMC to better understand current procedure and schedules

2. Develop an analytical model that, with respect to our assumptions, generates operating room schedules that improve OR utilization

3. Provide recommendations to UMMMC for an improved scheduling procedure that will result in improved utilization rates for the operating rooms

3.2 Analysis of Current State

To improve the operating room scheduling at UMMMC, a thorough understanding of current processes used is crucial. In order to better our understanding, our team interviewed Dr. Tze Chiam, the Performance Improvement Specialist and our project liaison at UMMMC. From our interviews with Dr. Chiam, we were able to map out the process of operating room scheduling and operation procedures in UMass's surgical department. For this project, we will focus on two service lines: Ears, Nose, Throat (ENT), and Cardiac surgery. These service lines are common surgery areas and take up a significant portion of the current operating room schedule. That said, we also recognize the benefits of allowing for additional specialties to have improved scheduling options.

Dr. Chiam has developed a simulation shell that draws from patient records to simulate the current surgical operations of UMMMC This simulation shell could provide great insight into the effectiveness of our scheduling tool and may be used in the future in conjunction with our model. Variables such as patient flow, operating room location and service assignment provided by the simulation can enhance the usefulness of the model.

Working with Dr. Chiam is Taoye Chen, Data Analysis Intern at UMMMC, who has developed a prediction model to provide more accurate estimation of the room usage minutes for different types of surgical cases using a linear mixed-effect model. In developing our optimization model, we will use data from this prediction model to incorporate more accurate estimations of room minutes for different surgical cases. Additionally, Taoye compiled multiple months of data on surgical case durations for use in our model from which we will draw typical case durations, current utilization and the current block scheduling slots associated with each service line.

A significant factor in how operating rooms are scheduled has to do with the layout of the operating rooms at UMMMC and the flow of patients in and out of the PACU, operating rooms, and SACU. According to Dr. Chiam, there are currently 17 operating rooms in the UMass Medical Center's surgical department. Each operating room is typically assigned a certain type of surgery which is listed in Table 3.

Table 3: Typical OR service assignments at UMMMC

Operating Room	Typical Service Assignment
1	General / Transplant
2	Vascular / Transplant
3	Cardiac
4	Cardiac
5	Orthopedics
6	Orthopedics
7	Neurology
8	Neurology
9	Trauma
10	Endovascular (in transition) / GI Endoscopy
11	Overflow of General / Plastics
12	Trauma Eyes (exclusively)
13	Plastics
14	Ears, Nose, Throat (ENT)
15	Pediatrics / General / Plastics
16	Pediatrics
17	Hybrid / Endovascular

In an interview with Operating Room Control Desk Manager, Dawn Cotter, key factors vital to scheduling details such as patient conditions and case duration estimates were discussed. The importance of these factors to the surgeons was taken into consideration in the design of the final model. The details of this interview and operating suite tour can be found in Appendix A. Donna McLaughlin, the Director of Perioperative Information Systems at UMMMC was also interviewed to determine the specifics of the current scheduling system. The results of this interview can be found in Appendix B.

3.3 Develop Analytical Model

The ultimate objective of this project is to design an OR schedule that maximizes the utilization rate of the OR time by adjusting the scheduling of surgical cases. In the development of this schedule, we will focus on two service lines: Ears, Nose, Throat (ENT), and Cardiac (CAR) surgery. This is the

primary deliverable, but as discussed in the next section, there will be other scheduling options suggested. The OR schedule will be developed using a binary integer program which will result in a schedule that can be used as input in a related simulation model shell. The new schedule will then be evaluated with respect to its effect on OR utilization.

3.3.1 Incorporation of Linear Regression Model

One of the key components of improving the scheduling of surgical cases at UMMMC was to provide more accurate case duration estimations into the scheduling process. To do this, our team used a linear mixed-effects regression model developed by Taoye Chen at UMMMC. This model takes into account past surgical data Our optimization tool incorporates the regression model to predict surgical case duration in a more accurate manner than the previous method used by UMMMC.

As seen in the following table depicting the various procedure time estimation methods as well as the actual procedure time, the regression model is more accurate (Table 4). In the Cardiac service line, the surgeons total 1,043 minutes less than the actual procedure times over the course of the month while the regression model predicts only 91 minutes over. For ENT, the surgeons estimate the surgeries will take 643 minutes less than they actually do over the course of the month whereas the model estimates a total of 232 minutes over. This difference supports the accuracy of the regression model.

Table 4: Comparison of various procedure time estimation methods during February 2013

February 2013	Surgeon Predicted Minutes	Actual Procedure Minutes	Regression Model Predicted Minutes
Cardiac	13,008 (-7.42%)	14,051	14,142 (+0.65%)
ENT	7,340 (-8.05%)	7,983	8,215 (+2.91%)

This difference in times is depicted below in Figure 3. For both service lines it can clearly be seen that the regression model (in red) is much closer to the actual procedure minutes (in green).
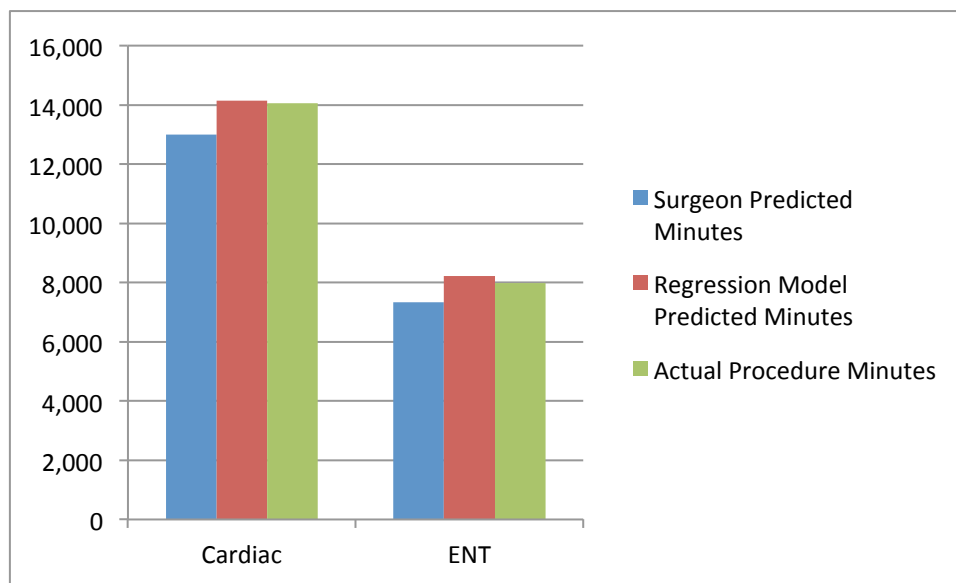
Figure 3: Comparison of predicted minute methods

3.3.2 Initial Schedule Design

The aim of the optimization model is to increase the utilization rate of the OR rooms to a rate on par with industry standard (currently estimated to average 70-80% between all service lines). We use the following equation, as defined by UMMMC, to calculate the utilization value:

$$Utilization = \frac{OR\ Time\ Utilized}{Available\ Block\ Time} \tag{1}$$

In this definition, the OR time utilized is defined as the room minutes plus a standard 30 minute setup and breakdown time for each procedure. It is essentially the amount of time the operating room is occupied. The available block time is the amount of time set in the predetermined block schedule. This denominator will remain constant for utilization calculation purposes of this project and the numerator will be adjusted in order to increase the utilization. The process of determining the designated block times will not be changed.

There were multiple methods to calculate the numerator which include room minutes, setup and breakdown minutes, or purely surgery minutes. Room minutes is the most accurate way to define the utilization since it is the amount of time an operating room is occupied, and therefore cannot be used for any other function. A setup and breakdown time is also included since this is a mandatory component of every procedure and definitely contributes to the overall utilization.

Based on Equation 1, the objective function for the optimization model is going to be to maximize the utilization without exceeding 100% utilization. Over 100% utilization would indicate the actual operating room times are exceeding the amount of time allocated to that surgery. This would then include undesired overtime expenses. The easiest way to translate this goal into a linear objective function for a practical model is to minimize the difference between the numerator (the actual OR time) and the denominator (the available block time). Testing a given schedule in the simulation, as described in the next subsection, will provide more clarity concerning the corresponding OR utilization. However, it is desirable that the block time and the actual time be as close to one another as possible.

The objective function for our model was designed with the goal of minimizing idle time. The detailed framework of the model will be explained in the section on model logistics. Defining constraints, variables, and the ultimate objective function involve discussions with UMMMC stakeholders, extensive literature research, and incorporation of real historical data from the operating rooms.

3.4 Project Flowchart
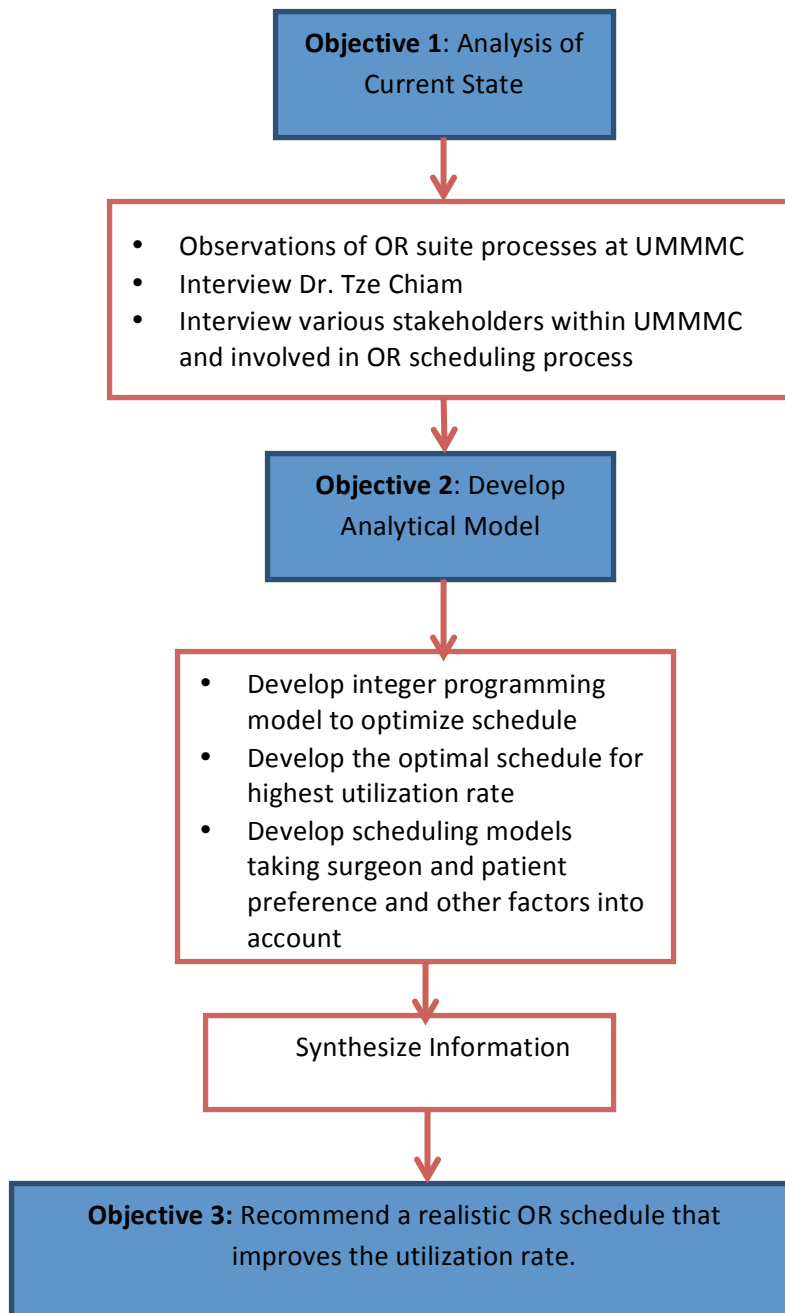
Figure 4: Project flowchart

4. Optimization Model

Our team developed an optimization model using binary integer programming to improve the utilization of ORs for UMMMC. The objective function for this model is to minimize the amount of slack time. Slack time is defined as the difference between the total block time available and the total time scheduled. By minimizing the amount of slack time within the schedule, the utilization of the operating rooms for each of the service lines will improve as the service lines are increasing the amount of surgical time per block while the amount of block time remains constant.

4.1. Model Details

For the purpose of this project, a snapshot of the February 2013 master block schedule and individual service line schedules will be used as a base model for the initial design. The 17 operating rooms are open every day, 5 days a week. The schedules are created on a five week basis; therefore there are 25 days for each scheduling period. This provides a challenge in designing the model since months to be scheduled do not consist of 25 work days. In February of 2013 for example, there are 20 days in which the ORs are open and we used the first 20 days for the first version of the block schedule template. For a given five-week period, Cardiac has 50 blocks reserved for its surgeries which totals 29,400 hours. There are two blocks each day for Cardiac surgeries (typically performed in Operating Rooms 3 and 4). ENT has 30 blocks set reserved for its surgeries within the 25 day period. These surgeries are typically performed in operating rooms 5 and 6 and over the course of the 5 weeks, totaling 10,140 hours of potential surgery time.

Notation

$$I = set\ of\ surgeries$$

$$J = set\ of\ blocks$$

$$B_j = Block\ time\ for\ all\ blocks\ j$$

$$S_i = Surgery\ time\ for\ surgery\ i$$

Assumptions

1. The constraints listed are all hard constraints and cannot be violated under any circumstances.

2. The model schedules the procedures as early as possible, so to leave the most amount of available block time later on in the month for further scheduling. This can be overridden by manually coding into the schedule where procedures can and cannot be scheduled (see section 4.3).

3. There is a constant break-down/setup time of 30 minutes for all surgeries, including the first and last surgery of the day.

4. We base our initial model data on values obtained from the February 2013 schedule, and we will base our initial utilization conclusions from these figures.

Variables

$$I_{car} = Set\ of\ surgeries\ for\ cardiac$$

$$J_{car} = Set\ of\ blocks\ available\ for\ cardiac$$

$$I_{ENT} = Set\ of\ surgeries\ for\ ENT$$

$$J_{ENT} = Set\ of\ blocks\ available\ for\ ENT$$

Decision Variables

Our aim is to determine which surgery should be assigned to which block. The corresponding decision variable is as follows:

Let $x_{ij} = 1, if\ surgery\ i\ is\ scheduled\ to\ block\ j$ (2)

           $= 0, otherwise.$

An example of the ENT and Cardiac service line-specific variables are detailed below.

$$|I_{Car}| = 16$$

$$|J_{Car}| = 2\ blocks * 25\ days = 50$$

Therefore, the total possible variables for Cardiac is (16 * 50) = 800.

$$|I_{ENT}| = 58$$

$$|J_{ENT}| = 30$$

The total possible variables for ENT is (58 * 30) = 1740.

Objective

The objective is to maximize the utilization. This can be done in an equivalent manner by minimizing the difference between the scheduled surgery times and the available block time subject to the given constraints. The total time available of the objective function is a constant; therefore, it does not affect the optimal solution resulting from the optimization. This is the formula used in the programming of the model:

$$Minimize: \Sigma_j (B_j - \Sigma_{i=1} S_i x_{ij}) \tag{3}$$

Constraints

1. Each surgical case cannot be scheduled more than once.

$$\Sigma_j x_{ij} \leq 1\ for\ all\ i \tag{4}$$
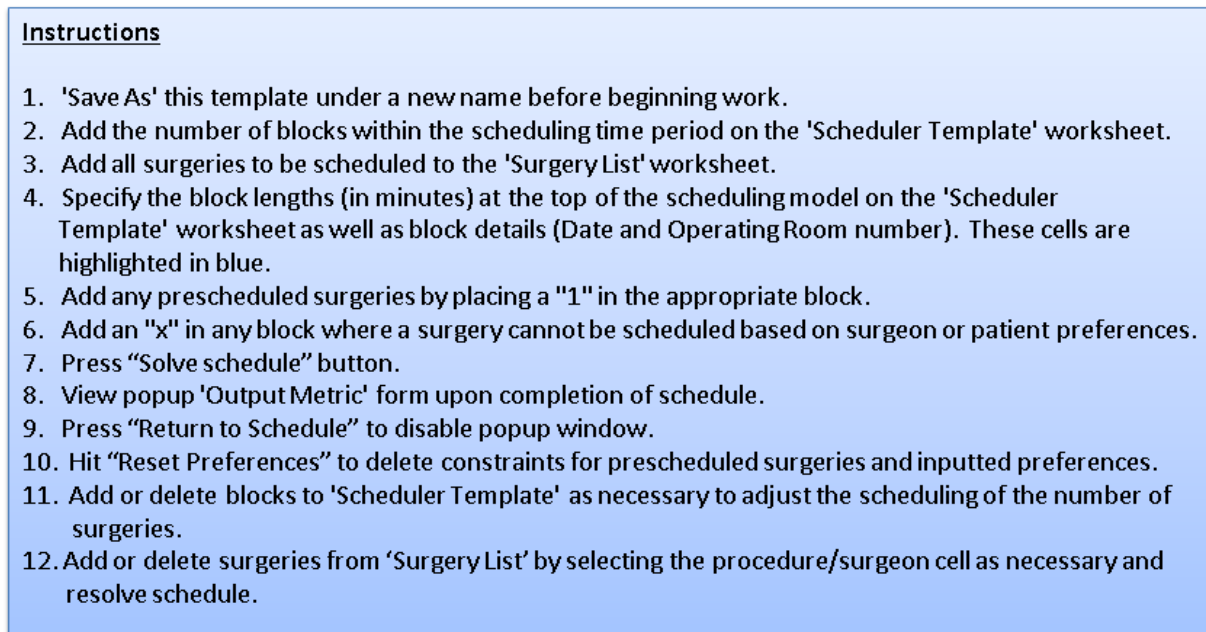
2. The sum of the surgical case times scheduled during a block cannot exceed the available block time.

$$\Sigma_i S_i x_{ij} \leq B_j \; for \; all \; j \tag{5}$$

Given the current operations and processes at the hospital, our model has three constraints. The first constraint is that each surgery can be scheduled at most once, so that there are no duplicate surgeries in the new schedule. The second constraint is that the total surgery time scheduled for a specific block cannot exceed its total block time. In order to avoid the costs of staffing operating rooms beyond normal operating hours, our model does not allow for overtime and the total surgery minutes for each block cannot exceed the total designated block time. The final restriction ensures that a procedure is either scheduled during block j (marked with a '1'), or not (marked with a '0'); that is, the scheduling decisions are binary.

4.2 Model Layout

The model was designed with a layout focusing on simplicity and ease of use. The first two worksheets in the Excel worksheet are used simply for reference for the scheduler and equations incorporated into the model. These worksheets do not require any use by the scheduler to run the model. The third worksheet in the Excel workbook is the *Instructions* tab that contains the information displayed in Figure 5. This provides step-by-step directions on how to use the scheduling tool and the multiple steps in effectively producing a final schedule. All three of these worksheets were made protected sheets with a password since they should not be altered unless updates are made to the model operation or layout in the future. For ease of use we made the password temporarily "password".

Instructions

1. 'Save As' this template under a new name before beginning work.
2. Add the number of blocks within the scheduling time period on the 'Scheduler Template' worksheet.
3. Add all surgeries to be scheduled to the 'Surgery List' worksheet.
4. Specify the block lengths (in minutes) at the top of the scheduling model on the 'Scheduler Template' worksheet as well as block details (Date and Operating Room number). These cells are highlighted in blue.
5. Add any prescheduled surgeries by placing a "1" in the appropriate block.
6. Add an "x" in any block where a surgery cannot be scheduled based on surgeon or patient preferences.
7. Press "Solve schedule" button.
8. View popup 'Output Metric' form upon completion of schedule.
9. Press "Return to Schedule" to disable popup window.
10. Hit "Reset Preferences" to delete constraints for prescheduled surgeries and inputted preferences.
11. Add or delete blocks to 'Scheduler Template' as necessary to adjust the scheduling of the number of surgeries.
12. Add or delete surgeries from 'Surgery List' by selecting the procedure/surgeon cell as necessary and resolve schedule.

Figure 5: User form displaying instructions for model use

As displayed in Figure 6, the second worksheet is the *Surgery List* tab calculates the predicted room minutes for the procedure. Significant factors on the procedure including surgeon, patient gender, scheduled duration, procedure number, ASA level, operation class, type, and laparoscopy are

recorded and the procedure minutes are calculated. Each column represents a different significant factor in the procedure duration calculation. Data can be input via drop-down menus when the specific cell is selected. All options, such as surgery and surgeon combinations for the first column, are available in the list. The surgery minutes automatically updates as data is submitted. It incorporates predicted surgical times based on the linear mixed-effects regression model developed by Leila Chen to calculate the estimated room minutes for each procedure.

Figure 6: Surgery list input worksheet

As depicted in Figure 7, the third worksheet is the SchedulerTemplate tab that enables the scheduling optimization. Along the left side of the table, the case names and durations are pulled in from the procedure input worksheet and displayed. This is the information used by the tool to schedule. Along the top highlighted in blue is the duration of the individual blocks in minutes; these durations can be adjusted by the scheduler based on the current block schedule to be filled. The four buttons are 'Add Block' and 'Delete Block' buttons as well as the 'Solve Schedule' and 'Reset Preferences' buttons. The number of blocks in the current schedule can be added to this worksheet to reflect the actual schedule. Blocks can easily be added or deleted to better fit in the number of cases to be scheduled. For instance, if a service line has two blocks per day in March the scheduler will add 62 blocks to schedule the month.

To solve the schedule, the 'Solve Schedule' button simply needs to be pressed. Any time input data or the number of blocks is changed, the scheduler should press the 'Reset Preferences' button and then resolve the schedule.

Utilization		#DIV/0!							
Solve Schedule									
Reset Preferences	Date								
	Operating Room Number								
Add Block	Block Minutes	200	45	202	202	202	400	202	200
Delete Block	Scheduled Minutes	0	0	0	0	0	0	0	0
	Block	1	2	3	4	5	6	7	8
Duration	Procedure								
142.30	ADENOIDECTOMY								
569.62	EXPLORATION WOUND								
186.52	MICRODISCECTOMY								
342.53	LAMINECTOMY CERVICAL								
285.45	REMOVAL HARDWARE								
159.62	VENTRICULOSTOMY								
134.05	ADENOIDECTOMY								

Utilization		80.02%							
Solve Schedule									
Reset Preferences	Date								
	Operating Room Number								
Add Block	Block Minutes	200	45	202	202	202	400	202	200
Delete Block	Scheduled Minutes	187	0	160	134	0	343	142	0
	Block	1	2	3	4	5	6	7	8
Duration	Procedure								
142.30	ADENOIDECTOMY	0	0	0	0	0	0	1	0
569.62	EXPLORATION WOUND	0	0	0	0	0	0	0	0
186.52	MICRODISCECTOMY	1	0	0	0	0	0	0	0
342.53	LAMINECTOMY CERVICAL	0	0	0	0	0	1	0	0
285.45	REMOVAL HARDWARE	0	0	0	0	0	0	0	0
159.62	VENTRICULOSTOMY	0	0	1	0	0	0	0	0
134.05	ADENOIDECTOMY	0	0	0	1	0	0	0	0

Model Output Metrics

Below are the output metrics for the given schedule. If all of the surgeries are scheduled, the last value will be 0. Blocks can be adjusted to change the utilization and other metrics.

Utilization (%):	80.02
Number of Surgeries Scheduled:	5
Total Number of Surgeries to be Scheduled:	7
Total Minutes Left to be Scheduled:	855

Return to Scheduler

Figure 7: Snapshots of Excel model user interface

In order to conduct the optimization of the binary integer program we used VBA coding to call OpenSolver. OpenSolver is an open source solver that is available under the Common Public License (CPL). This Microsoft Excel add-in solves linear and integer programming problems similar to the scheduling problem presented by this project. OpenSolver incorporates an objective function, constraints, and decision variables and uses formulas to output into user-designated cells. Directions on OpenSolver installation can be found in Appendix G. Microsoft Excel has a tool with similar capabilities called Solver. However, Solver has a limited capability for the number of variables that can be incorporated into the model so it was not sufficient for the purposes of this project.

Once a schedule has been created using OpenSolver, the results will appear in an output box. If a case is scheduled on a specific block it is color coded green, and if it is not scheduled the cell is coded grey to easily read the plan. For example, in Figure 7, the first procedure was scheduled for Block 2. The model automatically turns the cell green to make it easier for the scheduler to identify when each surgery has been scheduled. Additionally, any surgeries that were not scheduled are highlighted in yellow so the scheduler can easily see which surgeries are left to schedule.

4.3 Incorporating Preference Factors

There are many factors that can affect a surgical schedule. These factors include the surgeon schedule, surgeon room preference, surgeon case order preference, patient age and severity of a patient's condition. It can be difficult to accurately quantify these factors and incorporate them into a scheduling model, but they are crucial to creating a realistic model.

The schedules of surgeons can vary greatly between different service lines and at different times of the year. In addition, each surgeon takes vacation time at different points in the year, further affecting the OR scheduling. Rather than directly inputting each individual surgeon's schedule into the model, a feature has been incorporated to prevent certain surgeries from being scheduled in particular

block. For example, if a surgeon requests a specific day off from work, the scheduler can input an "x" into the cell for the corresponding block. By inputting an "x", the model will not schedule that surgery for blocks where there is an "x". Alternatively, if a surgeon and a patient have already agreed upon a certain block for surgery the scheduler can input a "1" into the corresponding block and the model will only allow the surgery to be scheduled in that particular block. An example of inputting preferences can be seen below in Figure 8.

		1	2	3	4	5	6	7	8
Utilization	66.58%								
Solve Schedule									
Reset Preferences	Date								
	Operating Room Number								
Add Block	Block Minutes	200	45	202	202	202	400	202	200
Delete Block	Scheduled Minutes	187	0	0	0	0	160	0	187
	Block	1	2	3	4	5	6	7	8
Duration	**Procedure**								
142.30	ADENOIDECTOMY								
569.62	EXPLORATION WOUND				x		x		
186.52	MICRODISCECTOMY	1			x		x		1
342.53	LAMINECTOMY CERVICAL				x				
285.45	REMOVAL HARDWARE								
159.62	VENTRICULOSTOMY						1		
134.05	ADENOIDECTOMY								

Figure 8: Model user interface with preferences added

In addition to fluctuating surgeon schedules, it is common practice at UMMMC for surgeons to schedule the order of procedures for the block according to preference. Patient factors such as age, severity of condition, availability, and personal preference can dictate when a surgeon will perform a surgery. For example, a surgeon might want to schedule a child, or a patient with a pre-existing medical condition such as diabetes, earlier in the morning, to prevent them from fasting for an entire day. Our model enables this freedom of choice for surgeons by only scheduling surgeries to a particular block, without assigning a specific order within each block. This allows surgeons to select the order in which they want to perform surgical cases.

5. Results

The comparison of utilization calculations for February 2013 is illustrated in Table 5.

Table 5: Summary of actual and predicted OR utilization and case durations versus utilization and case durations from optimization model

Row	February 2013	ENT	Cardiac	Formula/Explanation
1	**Allocated Block Time**	10,560	28,320	Total minutes of block time designated to the service line
2	**Surgeon Predicted OR Time**	7,340	13,008	Total surgery minutes as predicted by surgeons
3	**Actual OR Time**	8,215	14,051	Total surgery minutes that actually occurred
4	**Regression Model Predicted OR Time**	7,983	14,142	Total predicted surgery minutes using regression model
5	**Scheduled Utilization**	69.51%	45.93%	$\dfrac{Surgeon\ Predicted\ Times}{Allocated\ Block\ Time}$
6	**Actual Utilization**	77.79%	49.62%	$\dfrac{Actual\ Surgery\ Times}{Allocated\ Block\ Time}$
7	**Utilization from Optimization Model**	91.29%	62.19%	Optimized utilization using our tool and predicted surgery time from regression model

Table 5 includes summary metrics related to utilization, including the initial scheduled utilization, the actual utilization, and the model predicted utilization. It is important to note that the optimization model utilization is based on the underlying assumption that any case is able to be scheduled in any block. The first row of Table 5 denotes the total minutes of block time allocated to each service line by UMMMC. The second row of Table 5 denotes the surgeons' predicted duration for all of the surgical cases in February 2013, while row three denotes the actual duration of all the surgical cases for February 2013.

It can be seen in rows 2 and 3 that the surgeon predicted case duration is less than the actual case duration. This shows that there was some underestimation in scheduled case duration times. The underestimation can be due to many different factors that affect surgical case duration, including complications during surgery causing the case to take longer than expected. While these results are based on data from a single month of surgeries (February 2013), within two service lines (ENT and Cardiac), it can be seen that the utilization is significantly improved when scheduling with the Excel-based optimization model (further depicted in Figure 9).

The results of the optimization model are an increase in utilization as a result of more efficient scheduling of cases. The model is designed to optimize utilization using any case duration estimates, including the improved predictions resulting from the regression model. In the event that not all blocks are used in an optimized schedule, UMMMC has the ability to not open the corresponding operating room and save on operating costs or reallocate that time in the operating room to another service line. The optimized utilization metrics do not take into account these unused blocks in the calculation.

As can be seen in Table 5 and expanded upon in Figure 9, ENT saw an increase in utilization from 77.79% to 91.29%, an improvement of 13.5%. Cardiac saw a utilization improvement of 12.57%,

improving from 49.62% utilization to 62.19% (Figure 9). While both service lines saw an improvement of approximately 13% by using the optimization model, the utilization rate for Cardiac is still significantly lower than that of ENT. This is due to the difference in the case durations. ENT surgical cases are typically shorter than Cardiac, with an average case duration of 133 minutes in February 2013. In comparison, the average case duration of the Cardiac service line in February 2013 was 416 minutes, over three times as long as the average ENT case. Since Cardiac surgeries are significantly longer than ENT surgeries, fewer surgeries can be scheduled per block, with some blocks only able to fit one case. Due to this, the utilization for this service line is lower because it is more difficult to fit multiple, lengthy surgeries into one block. Given the differences in case duration, the improvement in utilization of the Cardiac service line is significant.
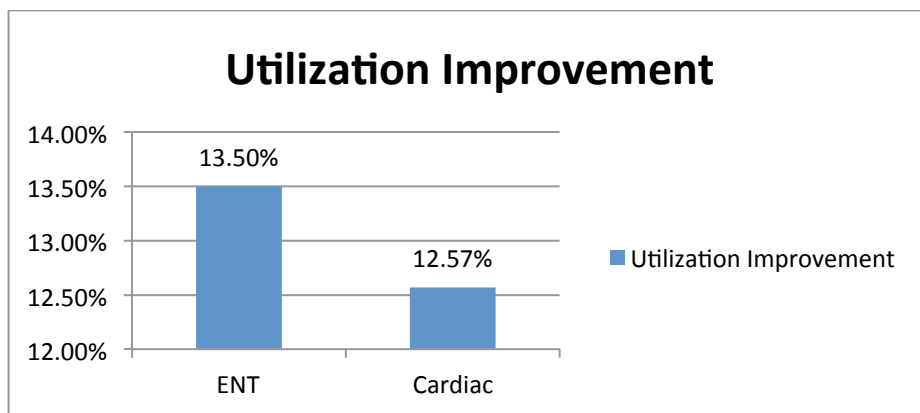
Figure 10: Utilization improvements with the implementation of scheduling tool

The improvements in utilization for the Cardiac and ENT service lines may lead to substantial savings for UMMMC, as OR time is very expensive. When operating rooms are left idle, the hospital is losing valuable income. According to a study of 100 hospitals, the average operating cost for an operating room was $62.19 per minute, with a range of responses from $22.80 to $133.12 per minute (Shippert, 2005). Including the average fee for an anesthesiologist, the average figure climbs to $66 per minute in operating costs. Adjusting these values to account for inflation, the values of operating costs for 2013 are $27.63, $79.92 and $156.81. The inflation values and calculations can be found in Appendix

F. Using these three costs as approximate figures for UMMMC, estimates can be obtained for three cases: low, average, and high operating room costs. Annual savings can be projected from these values, assuming that the utilization improvement and case load for each of the 12 months is constant (Tables 6 and 7).

Best case estimation of value of utilization increase for Cardiac service line

	Low Cost	Average Cost	High Cost
Allocated Block Time	10,560	10,560	10,560
1% of Block Time (min)	105.60	105.60	105.60
Value of 1% of Block Time	$2,917.73 (using $27.63/min)	$8,439.55 (using $79.92/min)	$16,559.14 (using $156.81/min)
Projected Increase in Utilization	13.5%	13.5%	13.5%
Value of Utilization Increase (Feb 2013)	$39,389.36	$113,933.92	$223,548.34
Projected Annual Value	$472,672.32	$1,367,207.00	$2,682,580.03

	Low Cost	Average Cost	High Cost
Allocated Block Time	28,320	28,320	28,320
1% of Block Time (min)	283.20	283.20	283.20
Value of 1% of Block Time	$7,824.82 (using $27.63/min)	$22,633.34 (using $79.92/min)	$44,408.59 (using $156.81/min)
Projected Increase in Utilization	12.57%	12.57%	12.57%
Value of Utilization Increase (Feb 2013)	$98,357.99	$284,501.08	$558,216.00
Projected Annual Value	$1,180,295.80	$3,414,012.90	$6,698,592.02

It is important to note that these estimates are made under the assumption of complete flexibility in scheduling surgical cases in Table 6 and Table 7. This assumption may limit the accuracy of these values because there are potential cases that require fixed assignments to a certain block. Assuming that there will be some pre-scheduled cases for UMMMC, additional estimations can be seen with a lower utilization rate increase in Tables 8 and Table 9.   A utilization rate increase of 6.75% for Cardiac and 6.285% for ENT was used, which is half of the increase produced from our model with complete scheduling flexibility. This represents a conservative estimate of potential money UMMMC could save by using the optimization tool.

Table 8: Conservative estimation of value of utilization increase for Cardiac service line

	Low Cost	Average Cost	High Cost
Allocated Block Time	10,560	10,560	10,560
1% of Block Time (min)	105.60	105.60	105.60
Value of 1% of Block Time	$2,917.73 (using $27.63/min)	$8,439.55 (using $79.92/min)	$16,559.14 (using $156.81/min)
Projected Increase in Utilization	6.75%	6.75%	6.75%
Value of Utilization Increase (Feb 2013)	$19,694.68	$56,966.96	$111,774.17
Projected Annual Value	$236,336.16	$683,603.52	$1,341,290.17

Table 9: Conservative estimation of value of utilization increase for ENT service line

	Low Cost	Average Cost	High Cost
Allocated Block Time	28,320	28,320	28,320
1% of Block Time (min)	283.20	283.20	283.20
Value of 1% of Block Time	$7,824.82 (using $27.63/min)	$22,633.34 (using $79.92/min)	$44,408.59 (using $156.81/min)
Projected Increase in Utilization	6.285%	6.285%	6.285%
Value of Utilization Increase (Feb 2013)	$49,178.99	$142,250.54	$279,108.00
Projected Annual Value	$590,147.88	$1,707,006.40	$3,349,296.01
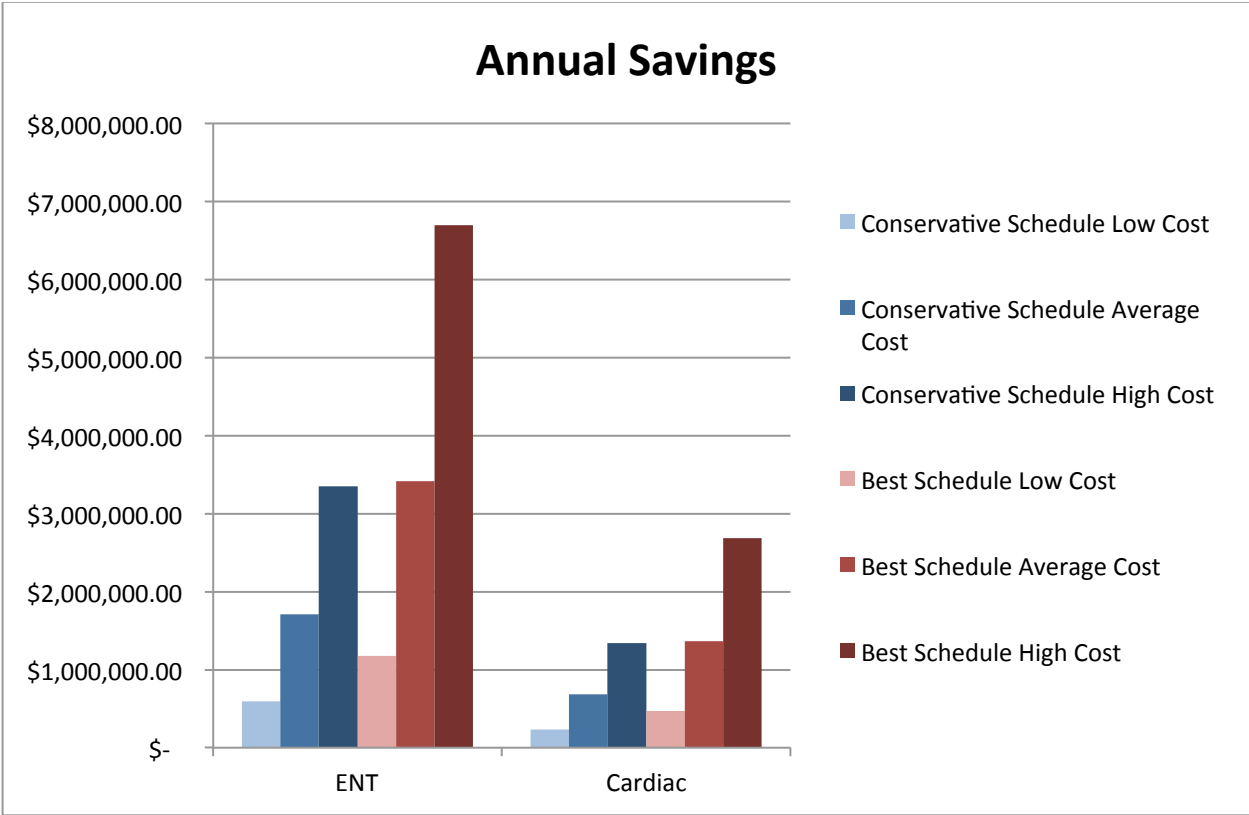
Figure 11: Annual savings for ENT and Cardiac with varying schedules and OR costs

As seen in Figure 11, the scheduling tool offers UMMMC the potential for substantial improvements even in the most conservative setting, based on the projected utilization and associated financial returns. It is also important to note that this project focused on just two service lines. UMMMC has the potential to see even greater utilization and financial benefits if adopted across additional service lines.

6. Conclusions

The optimization model developed in this project, in conjunction with more accurate surgical case duration times from the regression model, enabled us to generate a surgical case schedule for February 2013 with a utilization rate closer to the industry standard. The optimized schedule results in increased utilization rates of approximately 13% for both ENT and Cardiac service lines. Our first recommendation to UMMMC is to implement the scheduling tool our team has developed for future scheduling of surgical cases for any applicable service line.

Our team has incorporated multiple features that will help to improve the utilization of operating rooms in the future. Our tool incorporates a straightforward implementation of the regression model developed by Leila Chen, which enables more accurate case duration predictions. By incorporating these more accurate predictions, UMMMC can reduce the frequency of surgeries running over the allotted time. This will contribute to a reduction in the costs of paying staff for overtime and may also help keep the surgical departments on schedule.

Due to changing demand for different service lines at UMMMC, the block time allocations are reviewed and changed on a quarterly basis. To accommodate this, the scheduling tool is adaptable to meet these changing blocks. Users can easily add additional surgeries and blocks or remove blocks depending on the schedule for the service line.

The model was designed with respect to two different service lines, one with fewer, longer surgeries and one with more frequent, shorter surgeries. Also these two service lines had quite different operating room scenarios, one with two constant operating rooms and one with varying operating rooms. These differences enabled us to develop a scheduling tool designed to handle a variety of service lines with different surgical durations and OR block lengths.

In addition to scheduling for service line block time, this model can also be used to better schedule for open block time. Open block time is allotted time where any surgeon from any specialty can perform a procedure. Scheduling for this unassigned block can be difficult as there are many different cases that can be performed during this time. The developed scheduling tool can help to better fit as many procedures into this time as possible and ensure higher utilization rates for this time. By better utilizing open block time, UMMMC can better meet their growing surgery demand.

With a utilization increase ranging from 6.75% to 13.5% for the Cardiac service line, we can project a range of $472,672.32 to $2,682,580.03 in yearly savings for the best schedule. There is a potential range of $236,336.16 to $1,341,290.17 in yearly savings for a conservative schedule that takes preexisting schedule limitations into account and subsequently lowers the utilization rate. Regarding the ENT service line, we ranged the utilization increase from 6.285% to a high of 12.57% and for the best schedule, had potential annual savings of $1,180,295.80 to $6,698,592.02. Looking at a more conservative schedule, the savings were still significant, ranging from $590,147.88 to $3,349,296.01.

However, there are a few factors that the model does not take into consideration which may be seen as limitations. One of the constraints placed on the model is not allowing the sum of the scheduled surgeries to be greater than the block time. In some instances it may be beneficial to surpass the block time by short durations in order to fit in another surgery. If this is the case, the scheduler will have to manually change the block time in the model to allow for an overtime to occur. Another constraint placed on the model is that each surgery can only be scheduled once. It may be the case that the same surgeon is performing a particular surgery on more than one patient with the same predicted surgery length. The scheduler will have to list each of these surgeries separately in order for them both to be scheduled. Additionally, a limitation of the current model is that if the scheduler does not have a full list of surgeries, an accurate schedule will not be produced. In order to realize the main benefits of the

optimization tool, a list of the majority of surgeries will be necessary before running the model. The

model also assumes it is preferable to schedule surgeries earlier. If this is not desired, the scheduler will

have to input "x"s on earlier blocks to force the model to schedule the surgery later in the month.

Finally, an assumption that may limit model results is that the breakdown/setup times are set as a fixed

30 minute transition time for every procedure, including the first and the last. This is an estimate based

on the average, current transition time which may need to be altered in the future.

7. Future Work

7. 1 Incorporating Arena Simulation

In order to adapt our scheduling tool to meet future demand and changes for each service line at UMMMC, it will need to be compatible with simulation software, such as Arena Simulation Software. A simulation shell has been developed by Dr. Chiam at UMMMC. Using our scheduling tool and the simulation, UMMMC can better evaluate their evolving needs in terms of setting the blocks assigned to each service line based on the demand.
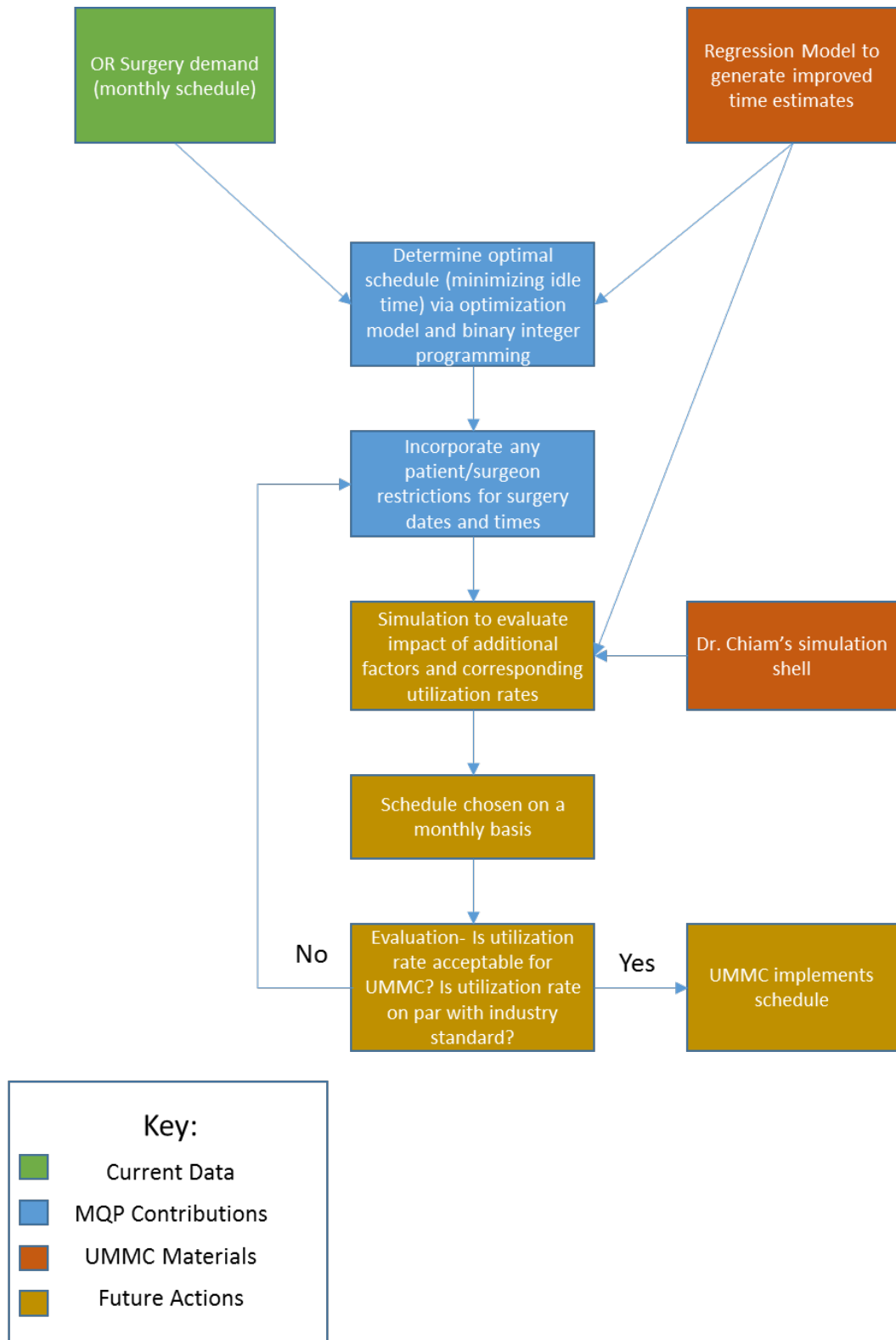
Figure 12: Flow chart illustrating future process

Figure 12 illustrates the combination of MQP and UMMMC contributions to the scheduling process as well as future actions to be taken. By incorporating data from the regression model, the new OR schedule can be tested in a simulation model. The flow chart depicts the cycle between inputting varying case data and different schedules in to the simulation shell and then reevaluating it based on a performance measures such as the OR utilization rate.

Thus, this evaluation of the OR schedule will ultimately be based off of the utilization rate. However, other key performance indicators may also be taken into account such as patient wait time and surgery overtime. When looking at multiple performance measures, they must be weighed for importance and value in the final decision to determine an improved schedule.

Another aspect of the process where improvements can potentially be made is the patient flow process. As mentioned by Dr. Chiam, there is no standardized patient flow process. This is modeled in the Arena simulation where patients may go through PACU and SACU before surgery, despite the fact that these units should be reserved for post-op patients only. If this process can be standardized and then modeled more efficiently in the Arena model, it would be a straightforward and simple way to increase efficiency in the overall process.

7.2 Documentation of Surgical Scheduling Procedure

While researching the current scheduling procedures at UMMMC, our team found that the different phases of scheduling are not documented in any one central location. In order to fully understand the different steps of the scheduling process, our team spoke with multiple UMMMC employees involved. Additionally, upon speaking to different UMMMC employees about the scheduling process, we found differing descriptions of procedures that would be more efficient if standardized.

In the future, it would be beneficial for complete scheduling process documentation to be available in one centralized location. Some elements that we suggest including are information on how a

surgery is scheduled: from the initial meeting with the patient, to the schedulers adding a surgery to the schedule for final approval. The approval process that the schedule undergoes should also be documented for a further understanding of how surgeries are ordered for each day based on patient factors. Based on our interviews with UMMMC employees, we recommend that UMMMC meet with both the scheduling employees and the operating room employees involved in the scheduling process to begin this documentation. Documentation of our interviews with these individuals can be found Appendices A and B of this report.

7.3 Utilization Comparison

After creating potential schedules, they should be compared to determine how and to what extent the addition of other factors impact the overall utilization rate. This will require external review of schedule quality and will need to be updated as necessary.

After schedules are selected, the hospital should look at the estimated utilization values and compare this calculation with other hospital utilization rates. This comparison will enable UMMMC to evaluate their potential position in the field if the recommended schedules are implemented. The hospital can determine whether the potential improvements will help UMMMC to catch up with other hospitals or if it will place the hospital on the forefront in terms of utilization maximization. This evaluation will help the hospital to decide on a future course of action and whether plans for further improvements will be necessary.

8. Design Reflection

The goal of this project was to design a tool that would assist UMass Memorial Medical Center in more efficiently scheduling their surgical cases to improve the utilization of their operating rooms. To accomplish this task, out group first analyzed the current process of scheduling surgical cases and the current utilization rates for UMMMC's operating rooms. For the purpose of this project, our group looked specifically at the Cardiac and ENT service lines. From the data provided by UMMMC, we were able to derive the utilization and actual room minutes for each of the surgical cases in February 2013.

To provide more accurate surgical room minute estimations into our model, we incorporated a linear mixed-effects regression model developed by Taoye Chen at UMMMC. This model takes into account past data for surgical cases as well as statistically significant patient factors that will affect the duration of a surgical case. Using the baseline of information from February 2013, our tool incorporates the regression model to predict surgical case duration in a more accurate manner than the previous method used by UMMMC.

Once the input data was constructed, our team created a grid of surgical cases and blocks to be scheduled. Within this grid, we developed a binary integer programming model in conjunction with the OpenSolver add-in to assign each combination of surgical cases and blocks with either a "0" or a "1" value, with "1" indicating that a particular surgery was scheduled on a given day.

Our model is designed to be used by the surgical scheduling staff at UMMMC. Keeping in mind the users of this tool, our team created a user interface that is easy to use but provides enough features and options for the schedulers to be able to take into account many different scenarios. First we color coded the results of the model so that the "1" values, which indicate scheduled surgeries, are highlighted in green while the "0" values are colored in gray. We also incorporated buttons and pop-up

forms that allow the user to more easily execute the scheduler tool and input parameters without having to adjust any coding or formulas.

The scheduling process at UMMMC is very complex and involves multiple stages, reviews and employees that come together to make a surgical schedule. Due to this complexity, there were some constraints that we had to work with to create a functional and realistic model.

As discussed in Chapter 4 of this report, our team had to work under many constraints and assumptions. We assumed all surgical cases have equal priority and there is no order they have to be scheduled in, but at the same time the model assumes the earlier a procedure is scheduled the better. In order to maximize the utilization, the known procedures are automatically scheduled in the earlier days in order to leave as much availability later on in the month for additional procedures to be scheduled. However, this can be adjusted manually. Also, a constant value of thirty minutes for cleanup/set up for each surgery is assumed. We developed our model based on these assumptions of the current processes in place at UMMMC.

One of the greatest challenges we faced was difficulties working with an outside group off of the WPI campus. This was a great opportunity to face real-life obstacles encountered in the workplace when collaborating with off-site partners. The 7-week term-based academic schedule at WPI is quite different than the schedule at UMass. Also, as students, this project is a major aspect of our curriculum, while the employees at UMass still have their daily tasks, work, and other business projects. Given this, we had to be flexible regarding meeting times and locations as well as the transfer of data and documents. We learned to effectively use email and conference calls as well as physical meetings. The methods for best communication with an outside organization that we learned will prove to be valuable in the future. Having the opportunity to work with the hospital is unique for a college student and the lessons we learned would not have been attained through regular coursework.

From the beginning we had to use effective communication to establish objectives and major components for the project. One of the first components that needed to be standardized for the purpose of our work as well as UMass moving forward was how to calculate the utilization rate. After some research, it was determined that there was no defined utilization equation being used and previous utilization values come from a third party vendor that receives UMass OR data and calculates utilization values. The specific methods and equations for these calculations are unknown though.

As stated in the OR Block Scheduling and Management Policy, the utilization was defined in Equation 6.

$$\frac{Total\ Patient\ In\ to\ Patient\ Out + Turnover\ Time\ During\ Allocated\ Block\ Hours}{Total\ Allocated\ Block\ Time - Surrendered\ Block\ Time} * 100 \qquad (6)$$

Although defined, this equation is not promoted and many employees are unaware of a standardized utilization equation. After discovering this, it was used as the basis of our utilization equation. Given that surrendered block time can only be known within days of the surgery day in question, it was decided not to be incorporated in our equation. Since our project is focused on scheduling significantly in advance, surrendered block time will not be known and does not affect the calculations for our purposes. Establishing this equation was a key component in setting the foundation of our project and pushed us to research and communicate closely with UMass.

Throughout the course of our project with UMass, we observed periodic operational changes. In the beginning of our project, Leila Chen was working alongside Dr. Tze Chiam as a sponsor for our MQP project. After A-term, Leila was moved to another area of the hospital and Natassia Taylor took over her responsibilities. Additionally, our presentation to the surgeons planned for the beginning of C-term had to be rescheduled due to a large reorganization at the hospital. We observed how these changes affected our project, hospital employees' roles, and hospital operations. It was valuable to

witness these changes and how frequently they occur in the workplace. Throughout the course of this project, we discovered the importance of change management. The stakeholders of our project included Dr. Margaret Hudlin, the UMMMC Chief Medical Officer, and Dr. Tze Chiam, our project sponsor, as well as the surgeons who will be affected by the implementation of our model. We worked carefully to consider the goals of each of these stakeholders and to incorporate them into our scheduling process. We believe our model is successful in this aspect because it increases the overall utilization, while still allowing for flexibility and surgeon preferences.

Our project relied heavily on our ability to code Visual Basic in order to develop our optimization model in Microsoft Excel. Unfortunately, we had minimal experience with coding in VBA. Developing the model required research as well as trial and error with different coding conventions. Understanding and writing code was one of the biggest skills we developed in the course of the project that will likely be used in the future.

Optimization is a common tool used by many companies in order to improve the efficiency of their processes and ultimately save money. The skills we have developed in creating the optimization model will likely be applicable to projects we will encounter in our engineering careers. In order to continue the learning endeavor, it is important to keep up with the latest software and coding standards. It is also important to adapt knowledge to apply to the constant evolution of these tools. Our experience with these tools and creating optimization models will continue to develop.

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10. Appendix

A. Operating Room Tour

In order to further our understanding of OR procedures at UMMMC we scheduled a tour of the facility with Operating Room Control Desk Manager, Dawn Cotter. She brought us through the department and explained the layout of the rooms and the flow of patients through the system. We began by walking through the preoperative area comprising of 25 beds and then walked through the new section of the hospital which consisted of operating rooms 1 through 10. Since these rooms are new, spacious, and have the most modern technology these rooms are generally preferred by surgeons. We then walked through the old wing of the OR where rooms 11 through 17 are located. Lastly, we walked through the postoperative area to continue following a typical OR patient's path through the department.

Following our tour, we spoke to Dawn about standard OR practice and specifics for our model. She confirmed with us that turnover time should be incorporated into our model as a fixed 30 minute value between all surgeries. Dawn also explained that scheduling is decentralized, meaning that each service line schedules differently. Surgeons in each service line change the schedule based on their preferences and specific patient characteristics. For instance, many surgeons aim to schedule children, diabetics, and patients with mental disabilities earliest within a block. Within 24 hours of the block the schedule is considered finalized and any leftover block time may be allocated to other service lines. At 10pm the schedule is posted on a whiteboard for the next day. Each room is listed down the side of the board with an index card listing patient name, procedure type, and surgeon placed at the appropriate time which is listed across the top of the board. While this system is considered out of date, it allows for surgeries to be easily moved in the schedule as necessary.

According to Dawn the main problem facing the OR is that surgeons book the rooms for an inaccurate amount of time. For example, a surgeon may book a two hour block for a surgery that ultimately consumes five hours of block time. This puts the OR behind schedule for the rest of the day and results in overtime and patient dissatisfaction. Another problem is that surgeries may need to be canceled at the last minute due to circumstances such as patient illness, surgeon emergency, no show patients, or error in patient profile on necessary procedures. However, this problem is more difficult to prevent since it cannot easily be predicted and accounted for in a model.

B. Phone Call with Donna McLaughlin

In order to better understand the scheduling process our group met with Donna McLaughlin, Director Perioperative Information Systems at UMMMC. From our meetings with Mrs. McLaughlin, we were able to gather information on how blocks are scheduled for each service line, how surgeries are scheduled within the blocks for each service line and what the process is for filling unused blocks.

At the beginning of every year, a board of chairs from each of the surgical departments meets to determine what the projected demand will for each of the service lines in UMMMC's surgical department for the upcoming year. These chairs weigh other factors such as the demand for each individual surgeon and the average case time for each surgeon in order to allocate blocks to each service line. Once the initial block schedule is complete, this board reconvenes every three months to review the utilization of each service line and make adjustments based on the utilization and demand for each service line.

Once the block schedule is solidified, each service line can begin scheduling cases. The scheduling of individual cases starts with a meeting between the surgeon and the patient, during which time the procedure and procedure date are determined. Once the date is selected the surgeon will send this information to the administrator for their service line who will put in a scheduling request for each of the surgical cases with information including the date of surgery, procedure, surgeon, the amount of time the surgeon estimates the surgery will take and an operating room.

Once submitted the scheduling request is sent to the scheduling department where six to seven schedulers work to fill the blocks allocated to each service line. When a request is received the schedulers will go to the date of surgery and fill that day with cases from the beginning of the day to the end in a first come, first scheduled basis. So, if a scheduler receives a request for a particular day, which has no previously scheduled surgeries on that day, the requested surgery will be scheduled as the first

one for that day. When another request for that day comes in, the scheduler will allot 30 minutes in between surgeries for clean-up and set up (also known as turnover time) and then schedule the next surgery after the first surgery for that day.

In order to calculate a case duration time for each of the surgical cases in the schedule, the scheduling department uses a software system called Perioperative Solutions. This program calculates the estimated surgical case duration by drawing from twelve previous cases, disregarding the highest and lowest durations of the twelve and then averaging the ten remaining cases. If there is a discrepancy between a surgeon's requested time and the time generated by the software, the schedulers will consult the chair of the service line and they will clarify any discrepancy. One issue with this process is that the software does not take into account patient factors, so it is difficult to get an accurate surgical case duration. For example, Coronary Artery Bypass Graft procedures (known as CABG) can be performed on more one or more vessels and the amount of time to complete the procedure on one vessel is much less than the amount of time it takes to perform the procedure on three vessels. Because there is no distinction between the one vessel procedure and the three vessel procedure in the scheduling software, the data can be skewed.

Two days before the date of surgery, the schedule compiled by the scheduling department is sent out to all of the surgeons and staff involved in the execution of surgical procedures. Surgeons can then adjust the order of their surgeries based on their preference and patient factors such as age or medical condition. Because patients must fast before having surgery, the staff at UMMMC tries to schedule children and patients with medical conditions such as insulin-dependent diabetics earlier in the morning, as it is difficult for these patients to fast for long periods of time. Finally, by 11:00 am the day before surgery, the schedule is finalized and sent out to all the areas involved in the surgical process.

Additionally patients are contacted at this time and are provided with a time for arrival and surgery for the following day.

Occasionally, the surgical blocks for each service line are not completely filled with surgical cases for that service line. UMMMC has a procedure for filling these extra spaces outlined in the UMMMC Policy Manual. According to the OR Block Scheduling and Management Policy, when this time is released, surgeons from any service line can schedule cases in these times.

University Campus OR Schedule
Effective Date FEBRUARY 1, 2013

Times*		(7:30-7:00)		(7:30-7:00)		(8:45-7:00)		(7:30-7:00)		(7:30-7:00)
Room #	WK	MONDAY	WK	TUESDAY	WK	WEDNESDAY	WK	THURSDAY	WK	FRIDAY

Room 1

WK	MONDAY AM 7:30-3:00 / PM 3:00-7:00	WK	TUESDAY AM 7:30-3 / PM 3-5	WK	WEDNESDAY	WK	THURSDAY	WK	FRIDAY
1	GEN ▮ Open	1	VAS Vascular Open	1	VAS Vascular (8:45-5:00)	1	GEN ▮ (7:30-5:00)	1	GEN ▮ (7:30-5:00)
2	GEN ▮ Open	2	VAS Vascular Open	2	VAS Vascular (8:45-5:00)	2	GEN ▮ (7:30-5:00)	2	DOS ACS (7:30-5:00)
3	GEN ▮ Open	3	VAS Vascular Open	3	VAS Vascular (8:45-5:00)	3	GEN ▮ (7:30-5:00)	3	GEN ▮ (7:30-5:00)
4	GEN ▮ Open	4	VAS Vascular Open	4	VAS Vascular (8:45-5:00)	4	GEN ▮ (7:30-5:00)	4	DOS ACS (7:30-5:00)
5	GEN ▮ Open	5	VAS Vascular Open	5	VAS Vascular (8:45-5:00)	5	GEN ▮ (7:30-5:00)	5	DOS ACS (7:30-5:00)

Room 2

WK	MONDAY AM 7:30-3:00 / PM 3:00-7:00	WK	TUESDAY	WK	WEDNESDAY	WK	THURSDAY	WK	FRIDAY
1	VAS Vascular Open	1	TRAN Transplant (7:00-5:00)	1	DOS open (8:45-3:00)	1	VAS Vascular (7:30-5:00)	1	VAS Vascular (7:30-3:00)
2	VAS Vascular Open	2	TRAN Transplant (7:00-5:00)	2	DOS open (8:45-3:00)	2	VAS Vascular (7:30-5:00)	2	VAS Vascular (7:30-3:00)
3	VAS Vascular Open	3	TRAN Transplant (7:00-5:00)	3	DOS open (8:45-3:00)	3	VAS Vascular (7:30-5:00)	3	VAS Vascular (7:30-3:00)
4	VAS Vascular Open	4	TRAN Transplant (7:00-5:00)	4	DOS open (8:45-3:00)	4	VAS Vascular (7:30-5:00)	4	VAS Vascular (7:30-3:00)
5	VAS Vascular Open	5	TRAN Transplant (7:00-5:00)	5	DOS open (8:45-3:00)	5	VAS Vascular (7:30-5:00)	5	VAS Vascular (7:30-3:00)

Room 3

WK	MONDAY	WK	TUESDAY	WK	WEDNESDAY	WK	THURSDAY	WK	FRIDAY
1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (8:00-7:00)	1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (7:00-7:00)
2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (8:00-7:00)	2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (7:00-7:00)
3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (8:00-7:00)	3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (7:00-7:00)
4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (8:00-7:00)	4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (7:00-7:00)
5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (8:00-7:00)	5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (7:00-7:00)

Room 4

WK	MONDAY	WK	TUESDAY	WK	WEDNESDAY	WK	THURSDAY	WK	FRIDAY
1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (8:00-7:00)	1	CAR Cardiac (7:00-7:00)	1	CAR Cardiac (7:00-7:00)
2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (8:00-7:00)	2	CAR Cardiac (7:00-7:00)	2	CAR Cardiac (7:00-7:00)
3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (8:00-7:00)	3	CAR Cardiac (7:00-7:00)	3	CAR Cardiac (7:00-7:00)
4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (8:00-7:00)	4	CAR Cardiac (7:00-7:00)	4	CAR Cardiac (7:00-7:00)
5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (8:00-7:00)	5	CAR Cardiac (7:00-7:00)	5	CAR Cardiac (7:00-7:00)

Room 5

WK	MONDAY AM 7:30-3 / PM 3:00-5:00	WK	TUESDAY	WK	WEDNESDAY	WK	THURSDAY	WK	FRIDAY
1	ORT ▮ Open	1	ORT FX	1	ORT ▮ (8:45-5:00)	1	ORT ▮ (7:30-5:00)	1	ORT ▮ (7:30-5:00)
2	ORT ▮ Open	2	ORT FX	2	ORT ▮ (8:45-5:00)	2	ORT ▮ (7:30-5:00)	2	ORT ▮ (7:30-5:00)
3	ORT ▮ Open	3	ORT FX	3	ORT ▮ (8:45-5:00)	3	ORT ▮ (7:30-5:00)	3	ORT ▮ (7:30-5:00)
4	ORT ▮ Open	4	ORT FX	4	ORT ▮ (8:45-5:00)	4	ORT ▮ (7:30-5:00)	4	ORT ▮ (7:30-5:00)
5	ORT ▮ Open	5	ORT FX	5	ORT ▮ (8:45-5:00)	5	ORT ▮ (7:30-5:00)	5	ORT ▮ (7:30-5:00)

Room 6

WK	MONDAY *Siegal	WK	TUESDAY AM 7:30-3:00 / PM 3-5:00	WK	WEDNESDAY *Kraus	WK	THURSDAY *Leclair	WK	FRIDAY *Rotating
1	ORT FX	1	ORT ▮ Open	1	ORT FX	1	ORT FX	1	ORT FX
2	ORT FX	2	ORT ▮ Open	2	ORT FX	2	ORT FX	2	ORT FX
3	ORT FX	3	ORT ▮ Open	3	ORT FX	3	ORT FX	3	ORT FX
4	ORT FX	4	ORT ▮ Open	4	ORT FX	4	ORT FX	4	ORT FX
5	ORT FX	5	ORT ▮ Open	5	ORT FX	5	ORT FX	5	ORT FX

Room 7

WK	MONDAY	WK	TUESDAY	WK	WEDNESDAY	WK	THURSDAY AM 7:30-5 / PM 5:00-7:00	WK	FRIDAY AM 7:30-3:00 / PM 3:00-7:00
1	NEU ▮ (7:30-5:00)	1	ORT ▮ (7:30-5:00)	1	NEU ▮ (8:45-5:00)	1	NEU ▮ Open	1	VAS Vascular Open
2	NEU ▮ (7:30-5:00)	2	ORT ▮ (7:30-5:00)	2	NEU ▮ (8:45-5:00)	2	NEU ▮ Open	2	PLAS Plastics Open
3	NEU ▮ (7:30-5:00)	3	ORT ▮ (7:30-5:00)	3	NEU ▮ (8:45-5:00)	3	NEU ▮ Open	3	VAS Vascular Open
4	NEU ▮ (7:30-5:00)	4	ORT ▮ (7:30-5:00)	4	NEU ▮ (8:45-5:00)	4	NEU ▮ Open	4	PLAS Plastics Open
5	NEU ▮ (7:30-5:00)	5	ORT ▮ (7:30-5:00)	5	OPEN (8:45-5:00)	5	NEU ▮ Open	5	PLAS Plastics Open

Room 8

WK	MONDAY AM 7:30-3 / PM 3:00-5:00	WK	TUESDAY AM 7:30-3:00 / PM 3:00-7:00	WK	WEDNESDAY AM 8:45-5:00 / PM 5:00-7:00	WK	THURSDAY AM 7:30-11:30 / PM 11:30-7:00	WK	FRIDAY AM 7:30-3 / PM 3:00-5:00
1	ORT ▮ Open	1	VAS Vascular Open	1	NEU ▮ Open	1	NEU ▮ (7:30-5:00)	1	ORT ▮
2	ORT ▮ Open	2	VAS Vascular Open	2	NEU ▮ Open	2	Open (7:30-5:00)	2	ORT ▮ Open
3	ORT ▮ Open	3	VAS Vascular Open	3	NEU ▮ Open	3	NEU ▮ (7:30-5:00)	3	ORT ▮
4	ORT ▮ Open	4	VAS Vascular Open	4	NEU ▮ Open	4	URO ▮ OPEN	4	ORT ▮ Open
5	ORT ▮ Open	5	VAS Vascular Open	5	Open Open	5	Open (7:30-5:00)	5	ORT ▮

	#	Day 1	Day 2	Day 3	Day 4	Day 5
9	1	TRAUMA	TRAUMA	TRAUMA	TRAUMA	TRAUMA
	2	TRAUMA	TRAUMA	TRAUMA	TRAUMA	TRAUMA
	3	TRAUMA	TRAUMA	TRAUMA	TRAUMA	TRAUMA
	4	TRAUMA	TRAUMA	TRAUMA	TRAUMA	TRAUMA
	5	TRAUMA	TRAUMA	TRAUMA	TRAUMA	TRAUMA
11	1	VAS Vascular 7:30-5:00	Add-on	Add-on	ORT ■ (7:30-5:00)	Add-on
	2	VAS Vascular 7:30-5:00	Add-on	Add-on	ORT ■ (7:30-5:00)	Add-on
	3	VAS Vascular 7:30-5:00	Add-on	Add-on	ORT ■ (7:30-5:00)	Add-on
	4	VAS Vascular 7:30-5:00	Add-on	Add-on	ORT ■ (7:30-5:00)	Add-on
	5	VAS Vascular 7:30-5:00	Add-on	Add-on	ORT ■ (7:30-5:00)	Add-on
13	1	PED 730-1130 DOS ACS1130-3:0	PED 730-1130 DOS ACS1130-3:00	PLAS Plastics ■ (8:45-5pm)	PLAS Plastics (7:30-5:00)	PLAS Plastics (7:30-5:00)
	2	URO ■ (7:30-3:00)	PED 730-1130 DOS ACS1130-5:00	PLAS Plastics ■ (8:45-5pm)	PLAS Plastics (7:30-5:00)	PLAS Plastics (7:30-5:00)
	3	PED 730-1130 DOS ACS1130-3:0	PED 730-1130 DOS ACS1130-5:00	PLAS Plastics ■ (8:45-5pm)	PLAS Plastics (7:30-5:00)	PLAS Plastics (7:30-5:00)
	4	NEU ■ (7:30-3:00)	PED 730-1130 DOS ACS1130-3:00	PLAS Plastics ■ (8:45-5pm)	PLAS Plastics (7:30-5:00)	PLAS Plastics (7:30-5:00)
	5	PED 730-1130 DOS ACS1130-3:0	PED 730-1130 DOS ACS1130-5:00	PLAS Plastics ■ (8:45-5pm)	PLAS Plastics (7:30-5:00)	PLAS Plastics (7:30-5:00)
14		AM 7:30-12:00 / PM 12:00-5:00			AM 7:30-12:30 PM 12:30-7:00	
	1	ENT ■	ENT |OPEN (3:00-5:00)	ENT ■ (8:45-5:00)	DOS ACS ENT ■	ENT ■ (7:30-5:00)
	2	ENT ■	ENT (7:30-3:00)	ENT ■ (8:45-5:00)	DOS ACS ENT ■	ENT ■ (7:30-5:00)
	3	ENT ■	ENT (7:30-3:00)	ENT ■ (8:45-5:00)	DOS ACS ENT ■	ENT ■ (7:30-5:00)
	4	ENT ■	ENT |OPEN (3:00-5:00)	ENT ■ (8:45-5:00)	DOS ACS ENT ■	ENT ■ (7:30-5:00)
	5	ENT ■	ENT (7:30-3:00)	ENT ■ (8:45-5:00)	DOS ACS ENT ■	ENT ■ (7:30-5:00)
15			AM 7:30-3:00 PM 3:00-7:00			Am 7:30-3:00 PM 3:00-7:00
	1	Add-on	DOS Open Open	DOS ACS (8:45-5:00)	Add-on	PED Pediatrics Open
	2	Add-on	DOS Open Open	DOS ACS (8:45-5:00)	Add-on	PED Pediatrics Open
	3	Add-on	SURGONC ■	DOS ACS (8:45-5:00)	Add-on	PED Pediatrics Open
	4	Add-on	DOS Open Open	DOS ACS (8:45-5:00)	Add-on	PED Pediatrics Open
	5	Add-on	DOS Open Open	DOS ACS (8:45-5:00)	Add-on	PED Pediatrics Open
16		AM 7:00-3:00 PM 3:00-5:00		AM 8:45-5:00 PM 5:00-7:00		
	1	NEU ■ 7:30-5:00	GEN ■ (7:30-5:00)	ORT ■ Open	ENT ■ (7:30-3:00)	DOS ACS (7:30-5:00)
	2	NEU ■ 7:30-5:00	GEN ■ (7:30-5:00)	ORT ■ Open	ENT ■ (7:30-3:00)	PEDI surg
	3	NEU ■ 7:30-5:00	GEN ■ (7:30-5:00)	ORT ■ Open	ENT ■ (7:30-3:00)	DOS ACS (7:30-5:00)
	4	GEN ■ 7:30 - 5:00	GEN ■ (7:30-5:00)	ORT ■ Open	ENT ■ (7:30-3:00)	PEDI surg
	5	NEU ■ 7:30-5:00	GEN ■ (7:30-5:00)	ORT ■ Open	ENT ■ (7:30-3:00)	VAS Vascular (7:30-3:0 OPEN

D. February 2013 Scheduled Surgical Cases

Date	Proc#	Operation Class	Surgeon	Sched Duration	Payment Authorization	Service	Rm Minutes	Surgery Minutes	ASA	Procedure
2/1/13	2	ADDON		360	U INPATIENT	CARD	418	351	4	BYPASS GRAFT CORONARY ARTERY AORTIC VALVE REPLACE
2/1/13	2	SCHEDULED		360	U INPATIENT	CARD	528	375	4	REPLACEMENT MITRAL VALVE
2/1/13	1	ADDON		360	U INPATIENT	CARD	370	266	3	REPLACEMENT MITRAL VALVE
2/2/13	3	ADDON		409	U INPATIENT	CARD	460	327	4E	BYPASS GRAFT CORONARY ARTERY OFF PUMP
2/3/13	1	ADDON		70	U INPATIENT	CARD	154	79	3E	CREATION PERICARDIAL WINDOW
2/4/13	1	SCHEDULED		240	U INPATIENT	ENT	255	190	2	DISSECTION NECK RADICAL
2/4/13	1	SCHEDULED		360	U INPATIENT	CARD	330	147	3	REPLACEMENT AORTIC VALVE
2/4/13	2	ADDON		360	U INPATIENT	CARD	327	240	4	STERNOTOMY MEDIAN
2/4/13	2	ADDON		360	U INPATIENT	CARD	247	116	4	STERNOTOMY MEDIAN
2/5/13	1	SCHEDULED		120	U OUTPATIENT	ENT	154	104	1	DECOMPRESSION ENDOLYMPHATIC SAC
2/5/13	1	SCHEDULED		240	U OUTPATIENT	ENT	212	152	2	INSERTION COCHLEAR IMPLANT
2/5/13	1	SCHEDULED		30	U OUTPATIENT	ENT	38	12	1	MYRINGOTOMY TUBE INSERTION
2/5/13	4	ADDON		360	U INPATIENT	CARD	639	505	3	BYPASS GRAFT CORONARY ARTERY
2/5/13	2	SCHEDULED		360	U INPATIENT	CARD	426	327	3	BYPASS GRAFT CORONARY ARTERY
2/6/13	1	SCHEDULED		60	U OUTPATIENT	ENT	93	63	2	EXCISION MASS NECK
2/6/13	1	SCHEDULED		150	U OUTPATIENT	ENT	113	72	2	THYROID LOBECTOMY
2/6/13	1	SCHEDULED		60	U OUTPATIENT	ENT	61	25	2	MICROLARYNGOSCOPY LASER
2/6/13	1	SCHEDULED		195	U INPATIENT	ENT	214	148	2	THYROIDECTOMY
2/6/13	1	SCHEDULED		360	U INPATIENT	CARD	326	248	4	REPLACEMENT AORTIC VALVE
2/6/13	3	SCHEDULED		360	U INPATIENT	CARD	441	329	3	BYPASS GRAFT CORONARY ARTERY
2/7/13	1	SCHEDULED		90	U OUTPATIENT	ENT	118	86	1	EXCISION MASS NECK
2/7/13	1	SCHEDULED		60	U OUTPATIENT	ENT	73	40	1	TONSILLECTOMY ADENOIDECTOMY
2/7/13	1	SCHEDULED		60	U OUTPATIENT	ENT	52	23	2	EXCISION MASS NECK
2/7/13	1	SCHEDULED		60	U OUTPATIENT	ENT	80	42	1	TONSILLECTOMY ADENOIDECTOMY
2/7/13	2	SCHEDULED		60	U OUTPATIENT	ENT	31	6	2	LARYNGOSCOPY DIRECT
2/7/13	1	SCHEDULED		45	U OUTPATIENT	ENT	52	19	2	TONSILLECTOMY
2/7/13	2	SCHEDULED		60	U OUTPATIENT	ENT	88	47	2	TONSILLECTOMY ADENOIDECTOMY
2/7/13	2	SCHEDULED		360	U INPATIENT	CARD	554	421	3	REPLACEMENT AORTIC VALVE
2/11/13	2	SCHEDULED		360	U INPATIENT	CARD	405	312	3	BYPASS GRAFT CORONARY ARTERY
2/11/13	2	SCHEDULED		15	U OUTPATIENT	ENT	38	20	2	EXAMINATION UNDER ANESTHESIA EAR MICROSCOPIC
2/11/13	1	SCHEDULED		60	U OUTPATIENT	ENT	79	37	2	MICROLARYNGOSCOPY
2/11/13	2	SCHEDULED		60	U OUTPATIENT	ENT	135	66	2	TONSILLECTOMY ADENOIDECTOMY
2/11/13	1	SCHEDULED		120	U OUTPATIENT	ENT	156	111	1	ENDOSCOPIC FUNCTIONAL SINUS SURGERY FESS
2/11/13	3	ADDON		360	U INPATIENT	CARD	294	201	3	BYPASS GRAFT CORONARY ARTERY
2/12/13	3	ADDON		405	U INPATIENT	CARD	376	294	3	BYPASS GRAFT CORONARY ARTERY
2/12/13	2	SCHEDULED		360	U INPATIENT	CARD	344	258	4	BYPASS GRAFT CORONARY ARTERY
2/12/13	3	SCHEDULED		360	U INPATIENT	CARD	621	501	4	REPLACEMENT MITRAL VALVE
2/12/13	1	SCHEDULED		210	U OUTPATIENT	ENT	216	148	2	TYMPANOMASTOIDECTOMY
2/12/13	2	SCHEDULED		60	U INPATIENT	ENT	65	28	2	TONSILLECTOMY ADENOIDECTOMY
2/12/13	1	SCHEDULED		60	U INPATIENT	ENT	104	29	2	TONSILLECTOMY ADENOIDECTOMY
2/13/13	2	SCHEDULED		60	U OUTPATIENT	ENT	122	77	2	EXPLORATION NECK
2/13/13	1	SCHEDULED		120	U OUTPATIENT	ENT	191	133	3	PAROTIDECTOMY
2/13/13	1	SCHEDULED		150	U OUTPATIENT	ENT	142	93	2	THYROID LOBECTOMY
2/13/13	1	ADDON		80	U INPATIENT	ENT	101	55	4E	TRACHEOSTOMY
2/13/13	2	SCHEDULED		360	U INPATIENT	CARD	382	282	3	BYPASS GRAFT CORONARY ARTERY

Date		Status		Min	Type	Service				Procedure
2/13/13	2	SCHEDULED		360	U INPATIENT	CARD	397	298	3	BYPASS GRAFT CORONARY ARTERY AORTIC VALVE REPLACE
2/14/13	2	SCHEDULED		60	U OUTPATIENT	ENT	44	7	3	ESOPHAGOSCOPY RIGID
2/14/13	1	SCHEDULED		90	U OUTPATIENT	ENT	74	35	2	ENDOSCOPIC FUNCTIONAL SINUS SURGERY FESS
2/14/13	2	SCHEDULED		60	U OUTPATIENT	ENT	75	44	2	ADENOIDECTOMY
2/14/13	1	SCHEDULED		75	U INPATIENT	ENT	52	23	2	TONSILLECTOMY ADENOIDECTOMY
2/14/13	2	SCHEDULED		60	U OUTPATIENT	ENT	64	40	1	TONSILLECTOMY ADENOIDECTOMY
2/14/13	1	SCHEDULED		60	U OUTPATIENT	ENT	67	36	2	TONSILLECTOMY ADENOIDECTOMY
2/14/13	1	SCHEDULED		60	U OUTPATIENT	ENT	66	43	2	TONSILLECTOMY ADENOIDECTOMY
2/14/13	2	SCHEDULED		360	U INPATIENT	CARD	482	361	4	REPLACEMENT AORTIC VALVE
2/15/13	1	SCHEDULED		360	U INPATIENT	CARD	263	165	3	REPLACEMENT AORTIC VALVE
2/15/13	3	SCHEDULED		360	U INPATIENT	CARD	370	237	3	BYPASS GRAFT CORONARY ARTERY
2/15/13	1	SCHEDULED		90	U OUTPATIENT	ENT	90	49	3	ENDOSCOPIC FUNCTIONAL SINUS SURGERY FESS
2/15/13	1	SCHEDULED		90	U OUTPATIENT	ENT	58	27	2	SEPTOPLASTY
2/15/13	2	SCHEDULED		60	U INPATIENT	ENT	79	35	1	MYRINGOTOMY TUBE INSERTION
2/15/13	1	SCHEDULED		30	U OUTPATIENT	ENT	30	7	2	MYRINGOTOMY TUBE INSERTION
2/15/13	1	SCHEDULED		45	U INPATIENT	ENT	70	17	1	TONSILLECTOMY ADENOIDECTOMY
2/19/13	1	ADD ON		388	U INPATIENT	CARD	186	116	5E	INSERTION VASCULAR ACCESS CATHETER
2/19/13	1	SCHEDULED		180	U OUTPATIENT	ENT	149	96	2	TYMPANOMASTOIDECTOMY
2/19/13	1	SCHEDULED		180	U INPATIENT	ENT	196	138	2	THYROIDECTOMY
2/19/13	2	SCHEDULED		60	U OUTPATIENT	ENT	72	31	2	ADENOIDECTOMY
2/19/13	3	SCHEDULED		360	U INPATIENT	CARD	404	257	3	BYPASS GRAFT CORONARY ARTERY
2/19/13	1	SCHEDULED		360	U INPATIENT	CARD	315	207	3	REPLACEMENT AORTIC VALVE
2/20/13	2	SCHEDULED		90	U OUTPATIENT	ENT	108	90	1	SEPTOPLASTY
2/20/13	1	SCHEDULED		120	U INPATIENT	ENT	210	168	2	THYROIDECTOMY
2/20/13	1	SCHEDULED		150	U OUTPATIENT	ENT	162	91	2	THYROIDECTOMY
2/20/13	3	SCHEDULED		360	U INPATIENT	CARD	188	67	4	BYPASS GRAFT CORONARY ARTERY AORTIC VALVE REPLACE
2/21/13	1	SCHEDULED		60	U OUTPATIENT	ENT	50	18	2	MICROLARYNGOSCOPY LASER
2/21/13	1	SCHEDULED		90	U INPATIENT	ENT	63	23	2	CAUTERIZATION NASAL TURBINATES
2/21/13	1	SCHEDULED		60	U OUTPATIENT	ENT	74	23	2	MICROLARYNGOSCOPY LASER
2/21/13	1	SCHEDULED		60	U OUTPATIENT	ENT	55	36	3	MICROLARYNGOSCOPY LASER
2/21/13	3	SCHEDULED		360	U INPATIENT	CARD	349	230	3	BYPASS GRAFT CORONARY ARTERY
2/22/13	2	SCHEDULED		360	U INPATIENT	CARD	240	143	4	BYPASS GRAFT CORONARY ARTERY
2/22/13	1	SCHEDULED		60	U OUTPATIENT	ENT	53	18	3	MICROLARYNGOSCOPY
2/22/13	1	SCHEDULED		90	U OUTPATIENT	ENT	127	78	3	MASTOIDECTOMY
2/22/13	3	ADD ON		261	U INPATIENT	CARD	407	269	4	BYPASS GRAFT CORONARY ARTERY
2/25/13	1	ADD ON		360	U INPATIENT	CARD	471	325	3	REPLACEMENT AORTIC VALVE
2/25/13	1	SCHEDULED		60	U OUTPATIENT	ENT	66	32	2	MICROLARYNGOSCOPY LASER
2/25/13	1	SCHEDULED		150	U INPATIENT	ENT	195	114	2	THYROIDECTOMY
2/26/13	1	SCHEDULED		360	U INPATIENT	CARD	390	254	4	REPLACEMENT AORTIC VALVE
2/26/13	3	SCHEDULED		360	U INPATIENT	CARD	475	364	4	BYPASS GRAFT CORONARY ARTERY
2/26/13	1	SCHEDULED		120	U OUTPATIENT	ENT	141	100	1	EXCISION MASS HEAD
2/26/13	1	SCHEDULED		60	U OUTPATIENT	ENT	23	2	2	EXAMINATION UNDER ANESTHESIA EAR MICROSCOPIC
2/27/13	1	SCHEDULED		180	U INPATIENT	ENT	240	185	2	THYROIDECTOMY
2/27/13	1	SCHEDULED		120	U OUTPATIENT	ENT	215	155	3	PAROTIDECTOMY
2/27/13	1	SCHEDULED		165	U INPATIENT	ENT	175	130	2	THYROIDECTOMY
2/28/13	2	ADD ON		375	U INPATIENT	CARD	452	370	3	BYPASS GRAFT CORONARY ARTERY OFF PUMP
2/28/13	1	SCHEDULED		60	U OUTPATIENT	ENT	83	34	2	TONSILLECTOMY ADENOIDECTOMY
2/28/13	2	SCHEDULED		60	U OUTPATIENT	ENT	100	58	2	TONSILLECTOMY ADENOIDECTOMY
2/28/13	1	SCHEDULED		60	U OUTPATIENT	ENT	106	62	1	EXCISION LESION HEAD

E. VBA Code

Output Form:

```
Private Sub UserForm_Initialize()


Dim Label8Value As Integer
Label8Value = Sheets("SchedulerTemplate").Range("C2") - Sheets("SchedulerTemplate").Range("C3")

Dim UtilizationAsPercent As Currency
UtilizationAsPercent = Sheets("SchedulerTemplate").Range("C1")
UtilizationAsPercent = UtilizationAsPercent * 100

Label5.Caption = UtilizationAsPercent
Label4.Caption = Sheets("SchedulerTemplate").Range("$A$4").Value
Label7.Caption = Sheets("SchedulerTemplate").Range("$A$6").Value
Label8.Caption = Label8Value

End Sub
```

Adding Row Function:

```
Sub Add_Row()
'
' Add_Row Macro

    Rows("3:3").Select
    Selection.Insert Shift:=xlDown, CopyOrigin:=xlFormatFromLeftOrAbove
    Range("I2:J2").Select
    Selection.AutoFill Destination:=Range("I2:J3"), Type:=xlFillDefault
    Range("I2:J3").Select
    Range("A3").Select

' Add_Procedure2 Macro

    Sheets("SchedulerTemplate").Select

    Rows("12:12").Select
    Selection.Insert Shift:=xlDown, CopyOrigin:=xlFormatFromLeftOrAbove
    Range("H11").Select
    Selection.AutoFill Destination:=Range("H11:H12"), Type:=xlFillDefault
    Range("H11:H12").Select
    Range("I11").Select
    Selection.AutoFill Destination:=Range("I11:I12"), Type:=xlFillDefault
    Range("I11:I12").Select
```

```vba
    Range("J11").Select
    Selection.AutoFill Destination:=Range("J11:J12"), Type:=xlFillDefault
    Range("J11:J12").Select

' CopyValues Macro

    Range("B12").Select
    ActiveCell.FormulaR1C1 = "='Surgery List'!R[-9]C[8]"
    Range("C12").Select
    ActiveCell.FormulaR1C1 = "='Surgery List'!R[-9]C[-2]"
    Range("C13").Select

    Worksheets("Surgery List").Activate
End Sub
```

Add Block Function:
```vba
Sub Add_Block_Scheduler()

' Add_Block_Scheduler Macro

    Columns("F:F").Select
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
    Range("E9").Select
    Selection.AutoFill Destination:=Range("E9:F9"), Type:=xlFillDefault
    Range("D5:D8").Select
    Selection.AutoFill Destination:=Range("D5:F8"), Type:=xlFillDefault
    Range("D14").Select

' CopyFormula Macro

    'Range("E5").Select
    'Selection.AutoFill Destination:=Range("E5:F5"), Type:=xlFillDefault
    'Range("E5:F5").Select

End Sub
```

Calculate Optimized Schedule Function:
```vba
Sub FinalCode()

Application.ScreenUpdating = False

'Determine the number of days to schedule

    Dim FurthestPoint As Integer
    FurthestPoint = 3

        For c = 4 To 100
            If Not Cells(9, c).Value = "" Then
```

```vba
            FurthestPoint = FurthestPoint + 1
            Else
            FurthestPoint = FurthestPoint + 0
            End If
        Next


    Dim FurthestPointRow As Integer
    FurthestPointRow = 10

        For r = 11 To 200
            If Not Cells(r, 3).Value = "" Then
            FurthestPointRow = FurthestPointRow + 1
            Else
            FurthestPointRow = FurthestPointRow + 0
            End If
        Next


'Adding constraints based on these preferences

    For r = 11 To FurthestPointRow
        For c = 4 To FurthestPoint
            If Cells(r, c).Value = 1 Then
            SolverAdd cellRef:=Cells(r, c).Address, relation:=2, formulatext:="=1"
            End If
            If Cells(r, c).Value = "x" Then
            SolverAdd cellRef:=Cells(r, c).Address, relation:=2, formulatext:="=0"
            End If
        Next
    Next

'Perform OpenSolver

'Error Catching

Dim ReturnValue As OpenSolverResult
ReturnValue = RunOpenSolver(False, True)

If ReturnValue > 0 Then
MsgBox ("Error has occurred. Check to make sure a procedure is not scheduled twice, or a pre-
scheduled procedure does not exceed block minutes.")
Else:
RunOpenSolver False

'Changing the colors of the cells
For r = 11 To FurthestPointRow
    For c = 4 To FurthestPoint
        If Cells(r, c).Value = 1 Then
        Cells(r, c).Interior.ColorIndex = 43
```

```vba
      Else: Cells(r, c).Interior.ColorIndex = 48
         End If
      Next
Next

'If a surgery is not scheduled, turn it yellow
Dim iloveyellow As Integer
iloveyellow = 5

   For c = 4 To 100
      If Not Cells(9, c).Value = "" Then
      iloveyellow = iloveyellow + 1
      Else
      iloveyellow = iloveyellow + 0
      End If
   Next

For r = 11 To FurthestPointRow
   If Cells(r, iloveyellow).Value = 0 Then
   Cells(r, 3).Interior.ColorIndex = 6
   End If
Next

'After it solves - if the utilization is 0

If Range("C8") = 0 Then
MsgBox ("No surgeries can be scheduled with these preferences or block times.")
Else: UserForm1.Show
End If

End If

End Sub
```

Delete Block Function:
```vba
Sub DeleteRow()

' DeleteRow Macro

   Columns("F:F").Select
   Selection.Delete Shift:=xlToLeft
End Sub
```

Original	22.8	
	Monetary	Inflation %
2005	0.7752	0.034
2006	0.7296	0.032
2007	0.6384	0.028
2008	0.8664	0.038
2009	-0.0912	-0.004
2010	0.3648	0.016
2011	0.7296	0.032
2012	0.4788	0.021
2013	0.342	0.015
Today's Value	27.6336	

Original	66	
	Monetary	Inflation %
2005	2.244	0.034
2006	2.112	0.032
2007	1.848	0.028
2008	2.508	0.038
2009	-0.264	-0.004
2010	1.056	0.016
2011	2.112	0.032
2012	1.386	0.021
2013	0.99	0.015
Today's Value	77.748	

Original	133.12	
	Monetary	Inflation %
2005	4.52608	0.034
2006	4.25984	0.032
2007	3.72736	0.028
2008	5.05856	0.038
2009	-0.53248	-0.004
2010	2.12992	0.016
2011	4.25984	0.032
2012	2.79552	0.021
2013	1.9968	0.015
Today's Value	156.81536	

G. Installation of OpenSolver in Excel

- Download OpenSovler from http://opensolver.org/installing-opensolver/
- Extract the files from the OpenSolver21 file

cbc	Application
CPL License	Text Document
GNU GPL License	Text Document
OpenSolver	Microsoft Excel Add-In
OpenSolver ChangeLog	Microsoft Excel Worksheet
ReadMe	Text Document

- Execute the 'cbc.exe' file. When prompted, run the file.

Compressed (zipped) Folders

This application may depend on other compressed files in this folder.

For the application to run properly, it is recommended that you first extract all files.

[Extract all] [Run] [Cancel]
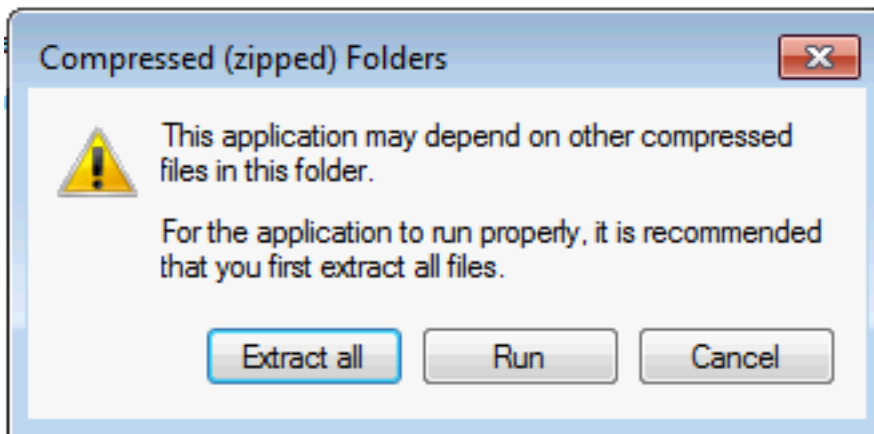
- Open the OpenSolver.xlam file
- In Microsoft Excel load the Solver add-in File > Options > Add-Ins.

Save & Send

Help

Options

Exit

Add-Ins available:

- Analysis ToolPak
- Analysis ToolPak - VBA
- Euro Currency Tools
- PrecisionTree 6.0
- ☑ Solver Add-in
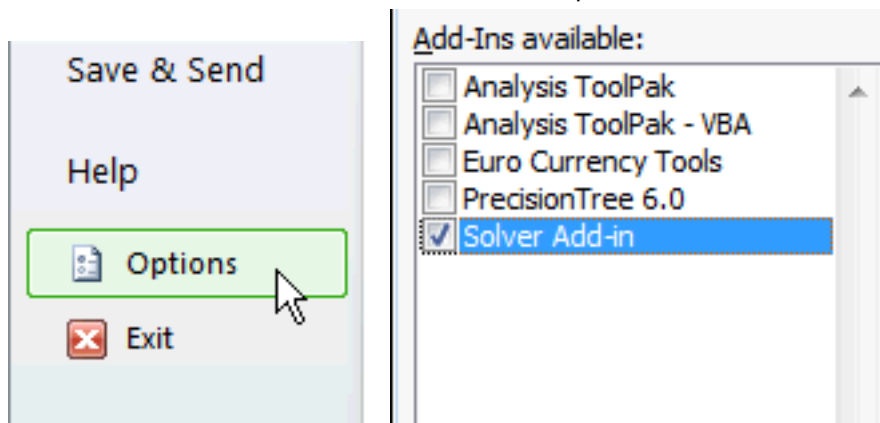
- OpenSolver will appear under the 'Data' tab in Excel

min z
x ≤ y
x = 2
Model   Solve   Show/Hide Model
                  Quick Solve
                  OpenSolver

OpenSolver