Optimization of an Operating Room Surgical Schedule

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Abstract:

Operating room surgical schedules often present logistical difficulties in terms of assigning doctors to specific operating rooms. Due to a wide variety of factors such as room availability, working hours in a week, doctor preferences, and operating room capabilities, surgical scheduling can prove to be challenging. Specifically at Boone Hospital Center in Columbia, MO, administrators utilize a static schedule and manually modify the assignments on a case-by-case basis. In this senior design project, we work to transform this static schedule into a working dynamic model which can be programmed to incorporate different scenarios within the hospital based on specific hospital parameters. By implementing a mixed linear integer program to minimize the difference between a surgical group's target and allocated time within an operating room, we demonstrate the advantages of using this model to optimize surgical assignments on a weekly basis at Boone.

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1. General Background

In the United States, hospitals must operate in a way that allows them to provide effective medical services to their patients while utilizing the space available in the most efficient way at the lowest possible cost. All of these objectives must be addressed when hospital administration makes scheduling assignments for its practicing doctors.

Scheduling procedures in hospitals often present logistical difficulties due to a wide range of variables such as doctor availability, doctor preference, operating hours, and functionality of rooms. With many moving parts and many factors to consider, creating an optimal surgical schedule is not an easy task. Having an optimal, or close to optimal, surgical schedule can improve the efficiency in the hospital by helping to reduce hospital and patient costs, to reduce patient waiting time, and to increase the utilization of the operating rooms.

Boone Hospital Center, where we will conduct our study, is a 400-bed full service hospital located in Columbia, MO. According to the hospital center's website, it "provides progressive healthcare programs, services, and technology to people in 26 mid-Missouri counties" [1].

The hospital is full service, but especially excels in cardiology, neurology, oncology, surgical, obstetrical services. The hospital maintains a 24-hour emergency center with hospital-based ambulance service and a helipad for incoming emergency air transportation. The hospital employs 350 physicians on the medical staff and over 2000 people in total, and serves over 60,000 patients each year.

As is common practice in this industry, Boone Hospital Center employs a block-scheduling system to schedule its surgeries. According to Irem Ozkarahan's *Allocation of Surgeries to Operating Rooms by Goal Programming* [2], a block-scheduling system assigns a block of operating room (OR) time to each practicing doctor or group of doctors per a particular period of time (typically, on a weekly basis). The block is reserved for the owner's exclusive use and when unused, the OR time is made available to other doctors.

2. Problem Definition

In this project, we analyze surgical scheduling procedures that have already been established, consider the successes and opportunities for growth of each, and formulate our own approach for an optimal surgical schedule. In particular, we look to optimize the operating room surgical schedule for Boone Hospital Center in Colombia, MO. The hospital has 22 operating rooms and currently uses a fixed block schedule that has not been adjusted or analyzed in terms of optimality in recent years. Our goal is to use operations research and optimization techniques to improve on the schedule. An additional motivation for the project is to create a dynamic model which can be adjusted to fit differing scenarios within the hospital. In practice, a static surgical schedule cannot account for the variability in weekly schedule including, but not limited to, changing doctor preferences for or against a certain day of the week, number of hours allocated to a particular group of doctors, varying shift lengths, and availability of a particular operating room. Our senior design project looks to address these issues and to provide Boone Hospital Center with an improved scheduling model.

3. Current Block Schedule at Boone

To begin our project, we obtained the current block schedule for the operating rooms in Boone Hospital Center. As it stands, this schedule does not schedule all of the surgical groups, but instead leaves gaps for the schedule to be modified manually on a per week basis. In general, the schedule presents a large amount of unutilized time, with a total utilization of only 64.6% (See Appendix E for a copy for the current schedule modified in a format we will use throughout the project). After examining this schedule, we decided as part of our objectives to schedule as many surgical groups as possible while staying close to a target allocation time for each group to increase the overall utilization. We also wanted to improve the readability of the Boone OR block schedule as the current schedule presented to us was organized in an unclear format.

4. Background Research

The topic of optimizing an operating room schedule is a common problem in scheduling surgeons in hospitals. Since the problem is so widespread, many operations research studies have been conducted with varying objective function formulations. One such method was performed by Kuo, Schroeder, et.al. in *Optimization of Operating Room Allocation Using Linear Programming Techniques* [3], which attempts maximize the financial return of a particular hospital. By looking at operating room times, procedure times, and costs of the OR usage (including equipment and doctors' fees), Kuo uses Excel Solver to maximize the hospital's revenue.

Another approach, used by Blake, Dexter, and Donaldin *Operating Room Managers' Use of Integer Programming for Assigning Block Time to Surgical Groups: A Case Study* [4], uses a block scheduling approach to develop a consistent weekly schedule that minimizes the difference between each group's target allocation (predetermined by desired OR utilization or performance contribution) and the actual assignment of OR time.

Finally, in *A Mixed Integer Programming Approach for Allocating Operating Room Capacity* [5], the authors focused on minimizing patients' length of stay. Because the costs associated with a patient's hospital stay are one of the most significant expenditures for the hospital, it is in its best interest to decrease the patient's total length of stay, which in turn means optimizing the utilization of the available space.

Since the data we were able to obtain from Boone Hospital Center did not include any cost or revenue information, we chose to focus our objectives on utilization of the operating rooms. The data lends itself to an approach most similar to Dr. Blake's, where we use a combination of historical data to come up with weekly target allocations for surgical groups and a mixed integer linear program to optimize the number of blocks assigned weekly to each group.

5. Starting Point*: Operating Room Managers' Use of Integer Programming for Assigning Block Time to Surgical Groups: A Case Study*

In *Operating Room Managers' Use of Integer Programming for Assigning Block Time to Surgical Groups: A Case Study*, Dr. John T. Blake identifies that a common problem at hospitals with fixed amounts of available operating room time is determining a fair method of distributing time between surgical groups. Typically, a hospital determines a surgical group's share of available block time using formulas based on OR utilization, contribution margin, or some other performance metric. Once each group's share of time has been calculated, a method is found for fitting each group's allocated OR time into the surgical master schedule. In this study, the authors examined how to assign specific ORs on specific days of the week to specific surgical groups under the assumption that the target number of hours of OR time to be allocated to each surgical group had already been chosen.

6. Small Trial Problem Formulation

Based on the information given in Blake's article, we attempted to formulate a simplified version of the problem presented in it. To create this initial trial formulation, we followed the objective function as well as an adjusted set of constraints similar to those listed in the article. For the full problem formulation from the article, please see Appendix A.

We used the target allocations for each surgical group as they were given in the article, and made some assumptions regarding operating room types as this data was not given explicitly in the article.

6.1 Decision Variables:

For this initial trial, we made the assumption that there were three operating room types in this particular hospital based on a sample weekly schedule given in the article. The paper also listed five operating days per week as well as five total surgical groups that needed to be allocated time in the master schedule. This gave us a total of 75 decisions variables, x_{ijk}, where

x_{ijk} = integer variable representing the number of operating rooms of type $i = \{0, 1, 2\}$ assigned to surgical group $j = \{0, 1, 2, 3, 4\}$ on the k^{th} day of the week, where $k = \{0, 1, 2, 3, 4\}$.

The index *i* specifies the OR type which allows us to differentiate between ORs that are specialized to perform only certain types of procedures. Since the breakdown of the OR type was not provided within the paper, we made the following classifications:

0	Surgery and Gynecology
1	Otolaryngology, Surgery, and Gynecology
2	Oral, Gynecology, and Ophthalmology

The *j* index specifies a particular surgical group. Each doctor who works in the operating rooms is associated with a particular surgical group, and for our purposes, all doctors in a particular surgical group are interchangeable. The following groups were provided by the article:

0	Surgery
1	Gynecology
2	Ophthalmology
3	Otolaryngology
4	Oral Surgery

The index *k* simply corresponds to the day of the week. We used the following indices:

0	Monday
1	Tuesday
2	Wednesday
3	Thursday
4	Friday

6.2 Objective Function:

The objective is to minimize the percentage difference between the target and allocated hours for all surgical groups per week. Specific to this formulation, we minimize

$$\sum_{j=0}^{4} \frac{\max(0, t_j - \sum_{i=0}^{2} \sum_{k=0}^{4} d_{ik} x_{ijk})}{t_j}$$

Where,

- t_j is the target allocation hours per week for each surgical group, *j*
- d_{ik} is the number of operating hours of the i^{th} type of operating room staffed on the k^{th} day of the week

Our weekly target allocation hours per surgical group (given in the article) are as follows:

t_j: target allocation for group *j*	
t_0	189.0
t_1	117.4
t_2	39.4
t_3	26.3
t_4	19.9

Each OR's daily operating hours were also given in the article. For this particular example, the operating hours for all ORs varied from 6.5 hours to 9 hours per day.

During the formulation of this objective function, we discussed the possibility of having the objective function simply be the difference between the target hours and the actual allocation across each of the surgical groups. In order to discourage an allocation greater than the target value, we took the maximum of this difference and zero. We decided, also, that since the different surgical groups vary greatly in size and in the number of target hours allocated to them that the objective function should provide a level of fairness across the surgical groups by minimizing the percentage difference between the target and the allocated hours rather than the simple difference.

6.3 Constraints:

1. The number of operating rooms of type *i* assigned to all groups on the k^{th} day must be less than or equal to the total number of operating rooms of that type (a_{ik})

$$\sum_{j=0}^{4} x_{ijk} \leq a_{ik}$$

2. The number of ORs of all types assigned to the j^{th} group on the k^{th} day of the week must not exceed the number of doctors in that group (p_{jk})

$$x_{ijk} \leq p_{jk}$$

We were not given the values for number of operating rooms of type *i* (a_{ik}) or for the number of doctors in each group (p_{jk}), so we chose values that we felt were reasonable for the purposes of our trial model. Our chosen a_{ik} and p_{jk} values are outlined below:

a_{ik}: total number of ORs of type *i* on day *k*	
a_{0k}	6
a_{1k}	1
a_{2k}	3

p_{jk}: total number of doctors in group *j* on day *k*	
p_{0k}	5
p_{1k}	1
p_{2k}	4
p_{3k}	2
p_{4k}	3

The final set up for this trial simulation can be found in Appendix B.1.

6.4 Results:

Running the formulation using the standard Excel Solver Add-In, we obtained the following results: the objective function value was 0.625212947, the total weekly hours allocated for all surgical groups in a given week was 331, and the utilization (dividing the allocated hours by the total capacity of 392.5 hours) was 84.3%. Once we obtained these values, we wanted to validate the optimization by seeing the results in a visual format. We drafted a sample schedule, with days of the week in the rows, OR types in the columns (color-coded according to the indices we discussed above), and the associated number of hours within each shift in the body of the table. We used the values of our decision variables to fill in the schedule according to which surgical group was scheduled in which type of operating room on which day of the week. Again, every operating room of a particular type is interchangeable, so we arbitrarily filled in the schedule starting at the left and moving to the right. The resulting schedule is below:

	1	2	3	4	5	6	7	8	9	10	OPS 1	OPS 1
Mon	Surgery	Surgery	Surgery	Gynecology		Otolaryngol	ogy					
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Tues	Surgery	Surgery	Surgery	Surgery	Gynecology	Otolaryngol	ogy					
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 15:30	8:00 - 16:00
Wed	Surgery	Surgery	Surgery	Surgery	Gynecology	Surgery		Ophthalmol	ogy		Ophthalmol	Oral Surgery
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Thu	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmol	ogy		Ophthalmol	Oral Surgery
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Fri	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmol	ogy		Ophthalmol	Oral Surgery
	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	Not staffed	Not staffed	9:00 - 15:30	9:00 - 16:00

Figure 1: Small Formulation Schedule

Overall, we believe that the schedule looks reasonable. Since all of the constraints are satisfied, none of the shifts are overlapping, and all of the OR types correspond to the type of surgical group assigned to it, we can assume that the problem is correctly formulated and that this particular solution is valid. This trial formulation was the basis for our larger model of the

OR schedule at Boone Hospital Center. We used the assumptions, objectives, and constraints from the trial model to expand and optimize the more intricate operating schedule.

7. The Large Formulation

7.1 Data Collection:

We obtained raw data regarding 6 months of operation from January 1, 2011 to June 30, 2011 at Boone Hospital Center. The data included information regarding all procedures that had been completed in the hospital over those 6 months, including which doctor did the procedure, the start and end time for each procedure, what date it was completed on, and which operating room it was completed in. We also had access to the current weekly block schedule. Boone Hospital Center has 22 operating rooms, 3 of which are specialized for specific procedures and the rest of which can handle all types of surgical procedures. In general, the operating hours of these rooms are Monday through Saturday during the hours of 8:00 AM and 3:30 PM. Each working day is broken up into 2 shifts, morning and afternoon. The final piece of background data enumerated the 87 doctors that perform procedures within these operating rooms and their affiliations to 24 distinct surgical groups.

7.2 Data Analysis

We decided to only use the data associated with the doctors that had performed 10 or more procedures within the 6-month time period. There were 87 doctors listed initially, and we removed data for 12, leaving us with 75 doctors, belonging to 24 separate surgical groups.

Since our formulation calls for shifts assigned per day of the week, the next step in formulating the data into a format that we could use was to go through the original data spreadsheet and assign the proper day of the week to each date as was listed in the original document. We then used the start and end times for each procedure to find the time it took to complete each procedure. In this process we assumed that the listed procedure times include prep time, actual procedure time, and clean up time so that procedures can be scheduled back to back.

Once we calculated the procedure times and narrowed down our list of doctors, we used pivot tables in Excel to calculate the historical weekly allocation of hours per surgical group.To do this, we assigned the day of the week into each column and the surgical group in each row further subdivided into each doctor within that group. The body of the table included the sum of the procedure times for each doctor within each group for each day of the week. This allowed us to find the total number of historical hours used over the 6-month span across each surgical group. Since there were 26 weeks from January 1 to June 30, we divided each of those totals by 26 to obtain the average number of hours that each surgical group used on a weekly basis. These historical averages became the weekly target allocations for each surgical group within our final formulation. Once we completed the data analysis, we were ready to start the formulation of the problem in Excel.

7.3 Preparation for Problem Formulation

7.3.1Expanding from the Small Trial Problem

We began our formulation with 4 specialized operating room types, 24 surgical groups (A through X), and 12 shifts (morning and afternoon per operating day over 6 days a week) leading to a total of 1152 decisions variables. We then addressed the issue of specializations of ORs. Based on information provided to us from Boone Hospital Center, we determined that 19 of the 22 ORs have the ability to serve doctors performing any type of procedure. This makes these 19 rooms interchangeable in terms of our formulation, and we assigned them as "Type 1." The other 3 rooms can only provide service to specific surgical groups. Specifically, OR 12 can only serve

Surgical Group R, OR 16 serves Surgical Group U, and OR 17 serves only Surgical Group F. We assigned these rooms as Types 2, 3, and 4 respectively. In the case of Boone Hospital Center, only one surgical group was assigned to a specialized OR, however, our formulation allows for the possibility of a specialized OR serving multiple surgical groups.

These assignments of specializations led to one operating room type that serves all 24 groups on each of the 12 shifts, and three operating room types that only serve one specific surgical group on each of the 12 shifts ultimately resulting in $24 \times 12 + 3 \times 12 = 324$ decision variables.

7.3.2 Software

Since the standard Excel Solver Add-In only allows for a maximum of 200 decision variables, we needed to find another method or software to run our formulation. After researching a few different possibilities, we found a free online trial version of Excel Premium Solver Platform which can run up to 2000 decision variables. This program automatically detects the appropriate solution method based on the given objectives and constraints. For the duration of the project, we used Premium Solver Platform to run our optimizations. Because our original formulation had a "maximum" component to the objective function, our model was considered a "non-smooth problem." Premium Solver Platform was able to transform our non-smooth problem by adding new integer and continuous variables and constraints to the model (both internally and temporarily) that have the same effect as our MAX function into a linear mixed-integer problem. It then uses what is called the "LP/Quadratic Solver" to solve the problem much more efficiently than it would a non-smooth problem. It uses the Branch and Bound Method to find the best integer solution that satisfied each of the constraints.

7.3.3 Adjusting Capacity

Before moving forward with the formulation, there was one more concern to address. The historical data for total procedure times shows high under-utilization on the hospital ORs compared with the total number of hours available for use. We set up pivot tables in Excel to find the average historical number of hours per week that each surgical group uses, and we found that the total number of hours per week across all surgical groups is on average 478.32 hours. Based on the current surgical schedule that we obtained from Boone, we made the assumption that all 22 ORs have an operating time of 7.5 hours per day for the 6 days of the week. This leads to a total capacity of 990 hours per week across all ORs. This also means that under the current schedule, the hospital's overall OR utilization is at only 48.3%.

Since this utilization is disturbingly below 100% and that the hospital OR capacity is significantly greater than the demand for the ORs, we needed to make an adjustment that brought the hospital capacity and OR demand closer together. Any solutions that we would have found given the unadjusted capacity and demand information would have been arbitrary since there would be an infinite number of possible solutions. Later in the process, we did run a trial where the capacity greatly exceeded the demand in order to be able to make comparisons between the current block schedule and our formulation. For this discussion, see section 10.1. Therefore, we worked to scale down the capacity within reason to obtain more meaningful results.

We first decided to assign three of the ORs for emergency procedures, effectively eliminating these capacities from our formulation. This was a reasonable assumption to make due to the variability of scheduling emergency procedures in hospitals. This also allowed the possibility of those doctors that we initially eliminated due to small numbers of procedures to practice in one of the operating rooms not assigned to a surgical group in our formulation. We also cut down the number of hours in each working shift. For Monday-Friday, we reduced each morning shift from 5 hours to 2.5 hours and each afternoon shift from 2.5 hours to 2 hours for a total of 4.5 hours for each working day. For Saturdays, we reduced the morning shift to 1.5 hours and the afternoon shift to just one hour. This gave us a total weekly capacity across all ORs of 475 total hours (versus the total weekly target demand of 478.32 hours). We realize that it is probably not realistic to assume that a hospital OR has only a 4.5 hour operating day, however we wanted the simulation to have a demand that slightly exceeded the hospital's capacity, and this assumption was necessary to move forward with the formulation and ultimately a meaningful schedule.

7.4 Final Problem Formulation

From this point, we were ready to formulate an optimization problem that included the actual data from Boone Hospital Center. We worked with 324 decision variables, x_{ijk}, where

x_{ijk} = integer variable representing the number of operating rooms of type $i = \{1, 2, 3, 4\}$ assigned to surgical group $j = \{1, 2, \ldots, 24\}$ on the k^{th} shift, where $k = \{1, 2, \ldots, 12\}$.

The index *i* specifies an OR type which allows us to differentiate between ORs that are specialized to perform only certain types of procedures. In our formulation, room type 1 (General) signifies an operating room type that can handle any type of procedure, and thus can cater to the needs of any of the surgical groups. Room type 2 is specialized to perform only a certain type of procedure, and in the case of Boone Hospital Center, it can only provide service to Surgical Group R. Similarly, room types 3 and 4 can only serve groups U and F, respectively.

1	General*
2	R (OR 12)

3	U(OR 16)
4	F (OR 17)

The *j* index specifies a particular surgical group. Each doctor who works in the operating rooms is associated with a particular surgical group, and for our purposes, all doctors in a particular surgical group are interchangeable. In the case of Boone Hospital Center, there were 24 surgical groups that performed procedures in Boone's operating rooms. *For the purposes of hospital privacy and non-disclosure, we have blinded the names of the surgical groups.* Our $j = \{1, 2, \ldots, 24\}$ corresponding to surgical groups A through X

The index *k* simply corresponds to a particular shift. For the Boone formulation, we used 12 different shifts: one in the morning and one in the afternoon for Monday-Saturday. We used the following indices:

1	Monday Morning
2	Monday Afternoon
3	Tuesday Morning
4	Tuesday Afternoon
5	Wednesday Morning
6	Wednesday Afternoon
7	Thursday Morning
8	Thursday Afternoon
9	Friday Morning
10	Friday Afternoon
11	Saturday Morning
12	Saturday Afternoon

As in our smaller formulation, the objective is to minimize the percentage difference between the target and allocated hours for all surgical groups per week. Specific to this formulation, we minimize

$$\sum_{j=1}^{24} \frac{\max(0, t_j - \sum_{i=1}^{4} \sum_{k=1}^{12} d_{ik} x_{ijk})}{t_j}$$

Where,

- t_j is the target allocation hours per week for each surgical group, *j*
- d_{ik} is the number of operating hours of the i^{th} type of operating room staffed on the k^{th} shift

Our weekly target allocation hours per surgical group (as derived from the historical data from Boone Hospital Center) are as follows:

t_j: target values for group *j*			
t_A	2.693589744	t_M	7.950641026
t_B	2.183333333	t_N	24.87051282
t_C	4.585897436	t_O	3.967307692
t_D	1.533333333	t_P	52.16282051
t_E	163.95	t_Q	1.991025641
t_F	103.3423077	t_R	6.860897436
t_G	0.526282051	t_S	14.61602564
t_H	0.928205128	t_T	2.896794872
t_I	12.3775641	t_U	34.46410256
t_J	1.731410256	t_V	6.755769231
t_K	0.958974359	t_W	23.39358974
t_L	1.762179487	t_X	1.814102564

We used the same set of constraints as in the small formulation, just increased to include the increased number of decision variables. Also, for our larger formulation, we did not have to guess at the values for number of operating rooms of type *i* (a_{ik}) or for the number of doctors in each group (p_{jk}), as these were provided for us by our contact at Boone. The a_{ik} values give are:

a_{ik}: total number of ORs of type *i* on shift *k*		
a_{1k}	16*	* Assuming 3 emergency rooms
a_{2k}	1	
a_{3k}	1	
a_{4k}	1	

And the p_{jk} values for our formulation are:

p_{jk}: total number of doctors in group *j* on shift *k*	
p_{1k}, p_{4k}, p_{7k}, p_{8k}, p_{9k}, p_{10k}, p_{11k}, p_{12k}, p_{13k}, p_{17k}, p_{19k}, p_{20}, p_{22}, p_{24}	1
p_{2k}, p_{14k}, p_{15k}, p_{16k}, p_{18k}	2
p_{3k}	3
p_{5k}	19
p_{6k}	10
p_{21}	7
p_{23}	13

The final set up for this simulation can be found in Appendix B.2.

7.5 Results

Running this formulation, we obtained the following results: the objective function value was 0.19059, the total weekly hours allocated for all surgical groups in a given week was 459.5, and the utilization (dividing the allocated hours by the total capacity of 475 hours) was 96.7%. We used the values of our decision variables to fill in an example schedule according to which surgical group was scheduled in which type of operating room on which day of the week. Again, every operating room of a particular type is interchangeable, so we arbitrarily filled in the schedule starting at the left and moving to the right. The resulting schedule is below:

																				Emergency		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Mon	E	E	E	E	E	E	E	E	E	E	E	R	P	P	U	F	S	V	W	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	I	J	M	N	O	P	R	P	S	U	F	V	W	W	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Tues	C	C	E	E	E	E	E	E	E	E	E		I	N	U	F	N	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	I	N	N	O	P	P	Q	S	W	W	R	W	W	U	F	W	W	W	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Wed	E	E	E	E	F	F	F	F	F	F	F		F	F	U	F	M	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	F	F	F	F	F	F	F	I	N	R	N	P	U	F	P	S	X	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Thurs	B	E	F	F	F	F	F	F	F	F	F		N	N	U	F	P	P	S	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	F	F	F	F	F	F	F	F	F	I	L		N	P	U	F	P	S		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Fri	E	E	E	E	E	E	E	E	E	E	E		E	E	U	F	E	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	D	E	E	E	E	E	E	E	E	I	M		P	P	U	F	S	T		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Sat	E	E	E	E	F	M	N	N	P	P	U		U	U	U	F	U	U	V			
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	E	E	G	H	K	P	R	P	T	U	F	U	U	V			
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

Figure 2: Large Formulation Schedule

Here, as in our small trial formulation, the schedule meets our expectations. No shifts overlap, all specialized rooms serve the surgical group that they are able to serve, and the emergency rooms remain unassigned. A larger schedule and a summary of the results can be found in Appendix D.1. In addition, a table comparing this schedule to the current block schedule including time allocated to each surgical group and distributions of hours per day is available in Appendix G.

8. Modified Small Trial Formulation

8.1 Adding Friday Penalties

While creating the schedule of the Small Trial Formulation, we noticed that solver obtained an optimal solution which scheduled fairly evenly across the 5 days of the week. In practice, however, Fridays are generally considered less desirable as compared to the rest of the working week. This idea was confirmed by our contact at Boone Hospital who informed us that if possible, doctors want to avoid being scheduled on Fridays. For this reason, we decided to alter the original objective function to include penalty weights for the Friday shifts. This allows the solver to still schedule shifts on Friday if necessary, but it discourages the Friday shifts from being assigned as often.

To implement these penalty weights, we first separated our 5 surgical groups into 2 categories, large target allocation and small target allocation, to make the penalties more balanced relative to the size of the surgical group. Our large target allocation group includes Surgical Groups 0 and 1 while the small target allocation group includes Surgical Groups 2, 3, and 4, and are assigned constant weights of C_1 and C_2 respectively. The new objective function formulation minimizes the following:

$$\sum_{j=0}^{4} \frac{\max(0, t_j - \sum_{i=0}^{2} \sum_{k=0}^{4} d_{ik} x_{ijk})}{t_j} + C_1 \left[\sum_{j=0}^{1} \sum_{i=0}^{2} \frac{x_{ij4}}{t_j} \right] + C_2 \left[\sum_{j=2}^{4} \sum_{i=0}^{2} \frac{x_{ij4}}{t_j} \right]$$

where C_1 and C_2 are weights that can be modified depending on how much we want to discourage scheduling of a shift on Friday. For our specific trial, we used C_1=1 and C_2 = 2.To make these penalties are fair as possible between the surgical groups, we also divided the sum of the appropriate decision variables by the target of that particular surgical group to make penalties a percentage of the target allocation of time. Aside from the change in the objective function, all of the assumptions and formulas that we used in the earlier Small Trial Formulation remained the same.

After modifying the objective function to include penalty weights against assigning shifts to Fridays, solver found an optimal solution with only 2 assignments on Friday which validates our process of adding weights to the objective function to simulate preferences for or against certain shifts. The resulting schedule is shown below:

	1	2	3	4	5	6	7	8	9	10	OPS 1	OPS 1
Mon	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Oral Surgery			Oral Surgery	
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Tues	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Oral Surgery				
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 15:30	8:00 - 16:00
Wed	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Ophthalmol
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Thu	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Ophthalmol
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Fri	Surgery	Gynecology				Surgery						
	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	Not staffed	Not staffed	9:00 - 15:30	9:00 - 16:00

Figure 3: Small Formulation with Friday Penalties

The schedule emphasizes the fact that scheduling a surgical group to perform a procedure on a Friday is highly discouraged which forces most of the shifts to be assigned on Monday through Thursday.

Another important topic of discussion is the objective function value for this modified formulation with penalty weights. The objective function value for this new formulation is slightly larger than our original small formulation (0.644312845 versus 0.625212947, respectively). This pattern can be validated by the fact that the problem is more constrained against choosing Friday for the schedule making the overall solution more difficult to obtain. With this new formulation, the OR schedule now shows a utilization of 85.9%.

8.2 Modified Objective Function

During the analysis of the results from the previous smaller formulations, we decided to evaluate not only the overall utilization but also the percentage difference between each of the target and allocated values within each surgical group. The following table shows a summary of those values:

Small Formulation Original:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
0	189.0	191.5	-2.5	2.5	1%
1	117.4	44	73.4	73.4	63%
2	39.4	44	-4.6	4.6	12%
3	26.3	29.5	-3.2	3.2	12%
4	19.9	22	-2.1	2.1	11%
Total	--	--	--	85.8	--

Small Formulation with Friday Penalties:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
0	189.0	195	-6.0	6	3%
1	117.4	44	73.4	73.4	63%
2	39.4	45	-5.6	5.6	14%
3	26.3	30	-3.7	3.7	14%
4	19.9	23	-3.1	3.1	16%
Total	--	--	--	91.8	--

The absolute percentage difference for the individual surgical groups for both of the above trials was much higher than we were expecting to see, especially for surgical group 2 which showed a percentage difference between the target allocation and the actual allocation of 63%. Since the purpose of the objective function was to minimize the percentage difference between target and allocated hours, we found these large differences to be a bit concerning. For this reason, we decided to reevaluate the objective function formula.

The original objective function, as taken from Blake's article, uses the maximum function in Excel which chooses the greater of 0 and the difference between the target and the allocated values. The purpose of this maximum function is to discourage the allocation of hours that go above the target value. However, this can cause some limitations for the optimal solution because it does not penalize an extremely low allocation, i.e. a very large negative difference between the target allocation and the actual allocation. To resolve this issue, we developed an alternative objective function which removed the maximum function and instead used the absolute value of the target and the actual allocation. This places an equal emphasis on both under and over allocating the schedule compared to the target. The new objective function minimizes the following:

$$\sum_{j=0}^{4} \frac{\text{abs}(t_j - \sum_{i=0}^{2} \sum_{k=0}^{4} d_{ik} x_{ijk})}{t_j}$$

Using this objective function (every other part of the formulation remained as before), we obtained the following results:

<u>Small Formulation with Absolute Value in Objective Function:</u>

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
0	189.0	191.5	-2.5	2.5	1%

1	117.4	42.5	74.9	74.9	64%
2	39.4	38.5	0.9	0.9	2%
3	26.3	-29.5	-3.2	3.2	12%
4	19.9	21.5	-1.6	1.6	8%
Total	--	--	--	83.1	--

As expected, the absolute difference across all groups decreased (from 91.8 total hours to 83.1 total hours), and the absolute percentage difference was either very close to or below the formulation with the original objective function. This decrease in the absolute difference, however, did not come without a cost. With this new objective function formulation, our final objective function value increased to 0.876134945 (up from 0.625212947), our total number of allocated hours decreased to 323.5 from 331, and our total OR utilization decreased to 82.4% (from 84.3%). We present the schedule that results from this formulation below:

	1	2	3	4	5	6	7	8	9	10	OPS 1	OPS 1
Mon	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology					
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Tues	Surgery	Gynecology				Surgery		Ophthalmology			Ophthalmol	Ophthalmol
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 15:30	8:00 - 16:00
Wed	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology				
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Thu	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngology		Gynecology			Oral Surgery	
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Fri	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Oral Surgery	Oral Surgery
	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	Not staffed	Not staffed	9:00 - 15:30	9:00 - 16:00

Figure 4: Small Formulation with Absolute Value in Objective Function

8.3 Modified Objective Function with Friday Penalties

Finally, we ran one more formulation, including the penalties for Friday assignments and using the absolute value in the objective function to see how the combination of these would affect the OR schedule. The final objective function formula took on the following form:

$$\sum_{j=0}^{4} \frac{\text{abs}(t_j - \sum_{i=0}^{2} \sum_{k=0}^{4} d_{ik} x_{ijk})}{t_j} + C_1 \left[\sum_{j=0}^{1} \sum_{i=0}^{2} \frac{x_{ij4}}{t_j} \right] + C_2 \left[\sum_{j=2}^{4} \sum_{i=0}^{2} \frac{x_{ij4}}{t_j} \right]$$

The results of this formulation are outlined below:

Small Formulation with Absolute Value in Objective Function with Friday Penalties:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
0	189.0	188	1.0	1	1%
1	117.4	44	73.4	73.4	63%
2	39.4	39	0.4	0.4	1%
3	26.3	30	-3.7	3.7	14%
4	19.9	22.5	-2.6	2.6	13%
Total	--	--	--	81.1	--

With this final objective function formulation, our final objective function value increased to 0.925802807, our total number of allocated hours stayed at 323.5, and our total OR utilization remained at 82.4%. Though the utilization remained the same as the one without the Friday penalties, it reduced the total absolute difference across surgical groups. The final schedule appears below:

	1	2	3	4	5	6	7	8	9	10	OPS 1	OPS 1
Mon	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Oral Surgery
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Tues	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Ophthalmol
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 15:30	8:00 - 16:00
Wed	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Oral Surgery			Oral Surgery	
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Thu	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology					
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Fri	Surgery	Gynecology										
	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	Not staffed	Not staffed	9:00 - 15:30	9:00 - 16:00

Figure 5: Small Formulation with Absolute Value in Objective Function and Friday Penalties

Both of the two types of objective functions (with the maximum and absolute value functions within them) present viable options for a surgical scheduling process, each with their strengths and weaknesses. The maximum version allows for a higher utilization of existing operating rooms, and the absolute value version decreases the difference between target and allocation for each surgical group, effectively leveling the allocations of each group. Depending on whether the person who is making the master surgical schedule for a hospital places more importance on one objective over another, he or she could choose which process makes more sense for the given scenario.

9. Modified Large Formulation

9.1 Modification of Formulation

We then altered the original objective function in our large formulation to include penalty weights for the both the Saturday and Friday shifts to discourage our model from schedule blocks into the undesirable weekend and Friday shifts. To implement these penalty weights, we first separated our 24 surgical groups into three categories, large target allocation (those that had allocations of 100 hours per week or more), medium target allocation (those that had a target of between 10 and 99 hours per week), and small target allocation (those with targets less than 10 hours a week), to make the penalties more balanced relative to the size of the surgical group. Our corresponding penalty values C_1, C_2 and C_3 can be modified depending on how much we want to discourage scheduling of a shift on Friday. For our specific trial, we used C_1=2, C_2 = 5 and C_3 = 10. Otherwise, the objective function formula and all of the assumptions and formulas that we used in the earlier Large Formulation remained the same. For a summary of the formulation of this scenario, see Appendix D.2. The resulting block is detailed below:

																				Emergency		
	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	21	22	23
Mon	B	I	N	P	P	U	U	U	U	U	V	R	W	W	U	F	W	W	W	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	D	E	I	M	N	O	O	P	P	U	R	U	W	U	F	W	W		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Tues	E	F	F	F	F	F	F	F	F	F	N	R	P	P	U	F	W	W		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	E	E	E	G	I	J	K	M	P	R	P	Q	U	F	T	X		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Wed	C	C	F	F	F	F	F	F	F	F	F	R	N	N	U	F	P	P		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	F	I	L	M	N	N	R	P	P	U	F	T	V		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Thurs	F	F	F	F	F	F	F	F	F	I	N	R	N	P	U	F	P	V		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	F	F	F	F	F	F	F	F	H	I	M	R	N	N	U	F	P	P		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Fri	E	E	E	E	E	E	E	E	E	E	E		E	E			E	E	E	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	E	E	E	E	E	E	E	E	E		E	E			E	E	E	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Sat																						
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

Figure 6: Large Formulation with Weekend Penalties

9.2 Results and Discussion

Again, this formulation greatly reduces the number of shifts allocated to surgical groups on Saturday, however, due to a large demand for operating rooms, scheduling on Fridays cannot be avoided. For this trial, our objective function value is 1.12382, the number of total allocated hours is 414, and the utilization is 87.2%. As before, we see that there is a trade-off between decreasing the number of undesirable weekend shifts and total utilization. This scenario results in less total utilization and a higher objective function value than in the original.

We also ran trials with the substitution of the absolute value instead of the maximum function in the objective function formula, and for our set of parameters, the results were identical to the trials with the maximum in the objective function. For more details on each of these formulations, see Appendix D.

10. Conclusion

Based on our results, we feel confident that the model works and can be utilized as a tool for more efficient scheduling in a hospital setting. Furthermore, the model is set up in a way that allows hospital management to adjust parameters (like room specializations, room number changes, i.e. due to equipment maintenance, and personnel changes, i.e. the acquisition of new surgical groups into the hospital system). The model provides an opportunity for hospital administration to easily adjust the number of target hours per group, should they need to be modified based on changes in customer preferences, as well as the number of hours in each shift.

10. 1 Revisiting the Current Block Schedule

Having done all of the above analysis, we were interested in comparing the current block schedule utilized at Boone Hospital Center to a formulation of the same scope. In order to do this, we ran a version of our large formulation model with the original capacities in the operating rooms (7.5 hour shifts, Monday through Friday). The resulting schedule is in Appendix F. This can be directly compared to Boone's current block schedule, found in Appendix E. We matched the assigned shifts in this schedule to the current one as closely as possible. We realize, however, that because the capacity exceeds demand, this optimal solution found by Premium Solver Platform is only one of several optimal solutions.

With all this in mind, we discuss some limitations of our model and possible steps one could take in order to expand on our analysis below.

10. 2 Limitations

As expected with a project of this magnitude, we ran into and had to address a few road blocks. The first of these was an issue with the problem's magnitude. As previously mentioned, the standard Excel Solver Add-In is very limited as far as the size of the formulation it can handle, with a maximum of 200 decision variables and 100 constraints. Expanding our initial trial formulation into one that was meaningful for an actual hospital's operations required us to seek out other software. We sought to find software that could handle the magnitude we required and one that did not require us to learn the intricacies of a new program that we had no familiarity with. We found the solution in the free trial version of Excel Premium Solver Platform, which allowed us to formulate our problem in the familiar format of regular Excel and was able to handle the multitude of our decision variables and constraints.

Another limitation to our formulation was the fairly limited data that we were able to obtain from Boone. We had to come up with the target allocation values for each surgical group on our own, based on the last 6 months of procedures done in the hospital. While we feel that this was a valid method for obtaining these numbers, we also acknowledge that there is probably more information that we did not have access to that would affect the optimal target allocation values.

Another consideration we would have liked to be able to take into account is doctor's preferences regarding particular shifts. We know that, in general, all doctors prefer not to work on weekends or on Fridays (and we included this in our formulation), but we know there are also instances where doctors are either unable or unwilling to practice on other days of the week due to other professional commitments. If we had information regarding doctors' individual preferences, we would add them into our current set of constraints, by reducing the number of doctors that are able to work in parallel on a given shift during the week.

In a more comprehensive model, we would have also liked to include constraints dealing with the number of secondary hospital personnel available during each shift. We believe that depending on the hospital organization, there could be constraints on the number of nurses and anesthesiologists that are available to aid doctors during their procedures. Unfortunately, we were unable to obtain this information from Boone Hospital Center.

We approached our formulation from the utilization perspective, but an equally compelling option would have been to analyze the problem from a cost perspective. Had we been provided with cost information for Boone, including wages, waiting costs, and hourly operating costs for rooms and equipment, it would have been interesting to see how cost information would have affected the results we obtained. Our objective function, in this case, would be to minimize the total cost of the hospital's weekly operation. However, we were also unable to obtain any cost information from Boone, due to privacy reasons.

10.3 Further Analysis and Recommendations

Having completed all of the above analysis, we want to consider some possible next steps in expanding on our methodologies for exploring a model for more efficient hospital block scheduling. Our first step would be to look more thoroughly into the underutilization of the available OR hours. According to the data provided, the hospital is operating at less than 50% utilization. We would be interested in a further discussion of possibly restructuring a few of the ORs for other purposes in the hospital or closing them down to cut operating costs.

We would then consider a more thorough exploration of the penalties against weekends and Fridays. In our formulation, we used arbitrary numbers for these penalties (ones that had the desired effect of lowering the number of shifts schedules on the weekend) in the objective function. In order to make these weights less arbitrary, we would have to do more research to determine how preferable each shift is over another in a more quantitative manner. Likely, there would be a scale of penalties relating each day to the other. Also, in our formulations, we had only 2 or 3 categories of surgical groups (based on size), and these categories determined which penalty that group would be assigned to. It would be interesting to see if a more optimal solution could be found by having a larger number of smaller categories of surgical groups each associated with a separate penalty.

In our analysis, we also used the same number of hours for each day's morning and afternoon shifts (except for Saturday).We would be interested to see how changing the number of hours in each shift would affect the optimal solution. This analysis would be especially compelling when done in conjunction with differing penalties across different days or with an examination of the formulation from the cost perspective.

Our current formulation is a good first step to address the dynamic nature of hospital scheduling, but we recognize that there are also a significant number of parameters that would have a significant impact on our results that we were unable to include.

Finally, we recommend that Boone Hospital Center reevaluates their current block schedule to increase utilization. Based on our analysis, we have concluded that it is possible to achieve an optimal operating room schedule within the current hospital constraints, with a reduction of total operating hours, which could save the hospital money or allow them to schedule more procedures with greater flexibility.

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APPENDIX A: Problem Formulation (as described in Operating Room Managers' Use of Integer Programming for Assigning Block Time to Surgical Groups: A Case Study

Decision variables:

x_{ijk} = integer variable representing the number of operating rooms of type i = {0, 1, … , N_{types} - 1} assigned to surgical group j = {0, 1,…,N_{group} - 1} on the k^{th} day of the week, where k = {0, 1, 2, 3, 4, 5, 6}.

Objective Function:

The objective is to minimize the percentage difference between the target and allocated hours for all surgical groups per week.

Min

$$\sum_{j=0}^{N_{group}-1} \frac{\max(0, t_j - \sum_{i=0}^{N_{types}-1} \sum_{k=0}^{6} d_{ik} x_{ijk})}{t_j}$$

Where,

- t_j is the target allocation hours per week for each surgical group, *j*
- d_{ik} is the number of hours of the i^{th} type of operating room staffed on the k^{th} day of the week

Constraints:

1. The number of operating rooms of type *i* assigned to all groups on the k^{th} day must equal the total number of operating rooms of that type (a_{ik})

$$\sum_{j=0}^{N_{group}-1} x_{ijk} = a_{ik}$$

**Note: we used <= instead of = in our formulation*

2. The number of operating rooms of all types assigned to the j^{th} surgical group on the k^{th} day of the week must be at least $LDAll_{jk}$ and at most $UDAll_{jk}$

$$LDAll_{jk} \leq x_{ijk} \leq UDAll_{jk}$$

3. The number of operating rooms of the i^{th} type assigned to the j^{th} group on the k^{th} day must be at least $LDType_{ijk}$ and at most $UDType_{ijk}$

$$LDType_{ijk} \leq x_{ijk} \leq UDType_{ijk}$$

4. The number of operating rooms of the i^{th} type assigned to the j^{th} group each week must be at least $LWeek_{ij}$ and at most $UWeek_{ij}$

$$LWeek_{ij} \leq \sum_{k=0}^{6} x_{ijk} \leq UWeek_{ij}$$

*Note: the constraints for our formulations look slightly different than the ones listed above. See **Problem Formulation** starting on page 5 for a discussion of how we set up our problem.*

APPENDIX B: Problem Set-Ups

B.1 Small Formulation Set-Up

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1					a_ik: total number of ORs of type I on day j				p_jk: total number of doctors in group j on day k				t_j: target allocation for group j				difference				
2					a_0k	6			p_0k	5			t_0	189.0			12.5	7%	0.066		
3					a_1k	1			p_1k	1			t_1	117.4			73.4	63%	0.625		
4					a_2k	3			p_2k	4			t_2	39.4			-4.6	-12%	0.117		
5									p_3k	2			t_3	26.3			-3.2	-12%	0.122		
6									p_4k	3			t_4	19.9			-2.1	-11%	0.106		
7																			1.035		
8	Dec. Var.				x000	x001	x002	x003	x004	x010	x011	x012	x013	x014	x100	x101	x102	x103	x104	x110	x111
9					3	4	4	5	5	1	1	1	1	1	0	0	1	0	0	0	0
10	Obj. Function	(min)	0.62521295		9	9	9	9	8	9	9	9	9	8	7.5	7.5	7.5	7.5	7	7.5	7.5
11	Total Weekly Hours		331																		
12	Total Capacity		392.5																		
13	Utilization		0.8433121																		
14																					
15	Constraints	Sum	Type	RHS																	
16	*Number of ORs of type i assigned to all groups on the k th day must be <= the total number of ORs of that type*																				
17	Type 0, Mon	4	<=	6	1					1											
18	Type 1, Mon	1	<=	1											1					1	
19	Type, 2 Mon	0	<=	3																	
20	Type 0, Tues	5	<=	6		1					1										
21	Type 1, Tues	1	<=	1												1					1
22	Type 2, Tues	0	<=	3																	
23	Type 0, Wed	5	<=	6			1					1									
24	Type 1, Wed	1	<=	1													1				
25	Type 2, Wed	3	<=	3																	
26	Type 0, Thurs	6	<=	6				1					1								
27	Type 1, Thurs	1	<=	1														1			
28	Type 2, Thurs	3	<=	3																	
29	Type 0, Fri	6	<=	6					1					1							
30	Type 1, Fri	1	<=	1															1		
31	Type 2, Fri	3	<=	3																	
32	*Number of ORs of all types assigned to the j th group on the k th day of the week must not exceed the number of doctors in that group*																				

B.2 Large Formulation Set-Up

Target Values for gro		Allocated	Difference	Absolute Difference	Absolute Percentage Difference
A	2.693589744	3	-0.306410256	0.306410256	11.38%
B	2.183333333	2.5	-0.316666667	0.316666667	14.50%
C	4.585897436	5	-0.414102564	0.414102564	9.03%
D	1.533333333	2	-0.466666667	0.466666667	30.43%
E	163.95	139.5	24.45	24.45	14.91%
F	103.3423077	103.5	-0.157692308	0.157692308	0.15%
G	0.526282051	1	-0.473717949	0.473717949	90.01%
H	0.928205128	1	-0.071794872	0.071794872	7.73%
I	12.3775641	12.5	-0.122435897	0.122435897	0.99%
J	1.731410256	2	-0.268589744	0.268589744	15.51%
K	0.958974359	1	-0.041025641	0.041025641	4.28%
L	1.762179487	2	-0.237820513	0.237820513	13.50%
M	7.950641026	8	-0.049358974	0.049358974	0.62%
N	24.87051282	25	-0.129487179	0.129487179	0.52%
O	3.967307692	4	-0.032692308	0.032692308	0.82%
P	52.16282051	50	2.162820513	2.162820513	4.15%
Q	1.991025641	2	-0.008974359	0.008974359	0.45%
R	6.860897436	9.5	-2.639102564	2.639102564	38.47%
S	14.61602564	15	-0.383974359	0.383974359	2.63%
T	2.896794872	3	-0.103205128	0.103205128	3.56%
U	34.46410256	34.5	-0.035897436	0.035897436	0.10%
V	6.755769231	7	-0.244230769	0.244230769	3.62%
W	23.39358974	24.5	-1.106410256	1.106410256	4.73%
X	1.814102564	2	-0.185897436	0.185897436	10.25%
	478.3166667			**34.40897436**	

a_ik: total number of ORs of type i on shift k

a_1k	16	* Assuming 3 emergency rooms (19-3)
a_2k	1	
a_3k	1	
a_4k	1	

p_jk: total number of doctors in group j on shift k

p_1k	1
p_2k	2
p_3k	3
p_4k	1
p_5k	19
p_6k	10
p_7k	1
p_8k	1

	Mon AM	Mon PM	Tues AM	Tues PM	Wed AM	Wed PM	Thur AM	Thur PM	Fri AM	Fri PM	Sat AM	Sat PM
Hours	2.5	2	2.5	2	2.5	2	2.5	2	2.5	2	1.5	1

Decision Variables

01.01.01	01.01.02	01.01.03	01.01.04	01.01.05	01.01.06	01.01.07	01.01.08	01.01.09	01.01.10	01.01.11	01.01.12	01.02
0	1	0	0	0	0	0	0	0	0	0	1	0

Obj. Func.	(Min)	0.19059
Total Weekly Hours		459.5
Total Capacity		475
Utilization		0.967368

Number of ORs of type i assigned to all groups on the k^{th} day must be <= the total number of ORs of that type

Constraints	**Sum**	**Type**	**RHS**	01.01.01	01.01.02	01.01.03	01.01.04	01.01.05	01.01.06	01.01.07	01.01.08	01.01.09	01.01.10	01.01.11	01.01.12
Type 1, Mon AM	16	<=	16	1	0	0	0	0	0	0	0	0	0	0	0
Type 1, Mon PM	16	<=	16	0	1	0	0	0	0	0	0	0	0	0	0
Type 2, Mon AM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 2, Mon PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 3, Mon AM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 3, Mon PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 4, Mon AM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 4, Mon PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 1, Tues AM	16	<=	16	0	0	1	0	0	0	0	0	0	0	0	0
Type 1, Tues PM	16	<=	16	0	0	0	1	0	0	0	0	0	0	0	0
Type 2, Tues AM	0	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 2, Tues PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 3, Tues AM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 3, Tues PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 4, Tues AM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 4, Tues PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 1, Wed AM	16	<=	16	0	0	0	0	1	0	0	0	0	0	0	0
Type 1, Wed PM	16	<=	16	0	0	0	0	0	1	0	0	0	0	0	0
Type 2, Wed AM	0	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 2, Wed PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 3, Wed AM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 3, Wed PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 4, Wed AM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 4, Wed PM	1	<=	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 1, Thurs AM	16	<=	16	0	0	0	0	0	0	1	0	0	0	0	0
Type 1, Thurs PM	16	<=	16	0	0	0	0	0	0	0	1	0	0	0	0

APPENDIX C: Summaries of Small Formulations

C.1 Small Formulation Original

Objective Function: $\sum_{j=0}^{4} \frac{\max(0, t_j - \sum_{i=0}^{2} \sum_{k=0}^{4} d_{ik} x_{ijk})}{t_j}$

Objective Function Value: 0.625212947

Total Weekly Allocated Hours: 331

Total Capacity Hours: 392.5

Utilization: 0.843312102

Schedule:

	1	2	3	4	5	6	7	8	9	10	OPS 1	OPS 1
Mon	Surgery	Surgery	Surgery	Gynecology		Otolaryngology						
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Tues	Surgery	Surgery	Surgery	Surgery	Gynecology	Otolaryngology						
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 15:30	8:00 - 16:00
Wed	Surgery	Surgery	Surgery	Surgery	Gynecology	Surgery		Ophthalmology			Ophthalmol	Oral Surgery
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Thu	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Oral Surgery
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Fri	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Oral Surgery
	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	Not staffed	Not staffed	9:00 - 15:30	9:00 - 16:00

Individual Surgical Group Allocation Summary:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
0	189.0	191.5	-2.5	2.5	1%
1	117.4	44	73.4	73.4	63%
2	39.4	44	-4.6	4.6	12%
3	26.3	29.5	-3.2	3.2	12%
4	19.9	22	-2.1	2.1	11%
Total	--	--	--	85.8	--

C.2 Small Formulation with Friday Penalties

Objective Function: $\sum_{j=0}^{4} \frac{\max(0, t_j - \sum_{i=0}^{2} \sum_{k=0}^{4} d_{ik} x_{ijk})}{t_j} + C_1 \left[\sum_{j=0}^{1} \sum_{i=0}^{2} \frac{x_{ij4}}{t_j} \right] + C_2 \left[\sum_{j=2}^{4} \sum_{i=0}^{2} \frac{x_{ij4}}{t_j} \right]$

Objective Function Value: 0.644312845

Total Weekly Allocated Hours: 337

Total Capacity Hours: 392.5

Utilization: 0.858598726

Schedule:

	1	2	3	4	5	6	7	8	9	10	OPS 1	OPS 1
Mon	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Oral Surgery			Oral Surgery	
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Tues	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Oral Surgery				
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 15:30	8:00 - 16:00
Wed	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Ophthalmol
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Thu	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Ophthalmol
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Fri	Surgery	Gynecology				Surgery						
	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	Not staffed	Not staffed	9:00 - 15:30	9:00 - 16:00

Individual Surgical Group Allocation Summary:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
0	189.0	195	-6.0	6	3%
1	117.4	44	73.4	73.4	63%
2	39.4	45	-5.6	5.6	14%
3	26.3	30	-3.7	3.7	14%
4	19.9	23	-3.1	3.1	16%
Total	--	--	--	91.8	--

Day Preference Weights (C_1, C_2)

$C_1 = 1$ Large: Includes t_0, t_1

$C_2 = 2$ Small: Includes t_2, t_3, t_4

C.3 Small Formulation with Absolute Value in Objective Function

Objective Function: $\sum_{j=0}^{4} \frac{\text{abs}(t_j - \sum_{i=0}^{2} \sum_{k=0}^{4} d_{ik} x_{ijk})}{t_j}$

Objective Function Value: 0.876134945

Total Weekly Allocated Hours: 323.5

Total Capacity Hours: 392.5

Utilization: 0.824203822

Schedule:

	1	2	3	4	5	6	7	8	9	10	OPS 1	OPS 1
Mon	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology					
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Tues	Surgery	Gynecology				Surgery		Ophthalmology			Ophthalmol	Ophthalmol
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 15:30	8:00 - 16:00
Wed	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology				
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Thu	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngology		Gynecology			Oral Surgery	
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Fri	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Oral Surgery	Oral Surgery
	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	Not staffed	Not staffed	9:00 - 15:30	9:00 - 16:00

Individual Surgical Group Allocation Summary:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
0	189.0	191.5	-2.5	2.5	1%
1	117.4	42.5	74.9	74.9	64%
2	39.4	38.5	0.9	0.9	2%
3	26.3	-29.5	-3.2	3.2	12%
4	19.9	21.5	-1.6	1.6	8%
Total	--	--	--	83.1	--

C.4 Small Formulation with Absolute Value in Objective Function with Friday Penalties

Objective Function: $\sum_{j=0}^{4} \frac{\text{abs}(t_j - \sum_{i=0}^{2} \sum_{k=0}^{4} d_{ik} x_{ijk})}{t_j} + C_1 \left[\sum_{j=0}^{1} \sum_{i=0}^{2} \frac{x_{ij4}}{t_j} \right] + C_2 \left[\sum_{j=2}^{4} \sum_{i=0}^{2} \frac{x_{ij4}}{t_j} \right]$

Objective Function Value: 0.925802807

Total Weekly Allocated Hours: 323.5

Total Capacity Hours: 392.5

Utilization: 0.824203822

Schedule:

	1	2	3	4	5	6	7	8	9	10	OPS 1	OPS 1
Mon	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Oral Surgery
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Tues	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Ophthalmology			Ophthalmol	Ophthalmol
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 15:30	8:00 - 16:00
Wed	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology	Oral Surgery			Oral Surgery	
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Thu	Surgery	Surgery	Surgery	Surgery	Surgery	Otolaryngol	Gynecology					
	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 17:00	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	8:00 - 15:30	Not staffed	Not staffed	8:00 - 16:00	8:00 - 15:30
Fri	Surgery	Gynecology										
	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 17:00	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	9:00 - 15:30	Not staffed	Not staffed	9:00 - 15:30	9:00 - 16:00

Individual Surgical Group Allocation Summary:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
0	189.0	188	1.0	1	1%
1	117.4	44	73.4	73.4	63%
2	39.4	39	0.4	0.4	1%
3	26.3	30	-3.7	3.7	14%
4	19.9	22.5	-2.6	2.6	13%
Total	--	--	--	81.1	--

Day Preference Weights (C_1, C_2)

$C_1 = 1$ Large: Includes t_0, t_1

$C_2 = 2$ Small: Includes t_2, t_3, t_4

APPENDIX D: Summaries of Large Formulations

D.1 Large Formulation Original

Objective Function: $\sum_{j=1}^{24} \frac{\max(0, t_j - \sum_{i=1}^{4} \sum_{k=1}^{12} d_{ik} x_{ijk})}{t_j}$

Objective Function Value: 0.19059

Total Weekly Allocated Hours: 459.5

Total Capacity Hours: 475

Utilization: 0.967368421

Individual Surgical Group Allocation Summary:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
A	2.693589744	3	-0.306410256	0.306410256	11.38%
B	2.183333333	2.5	-0.316666667	0.316666667	14.50%
C	4.585897436	5	-0.414102564	0.414102564	9.03%
D	1.533333333	2	-0.466666667	0.466666667	30.43%
E	163.95	139.5	24.45	24.45	14.91%
F	103.3423077	103.5	-0.157692308	0.157692308	0.15%
G	0.526282051	1	-0.473717949	0.473717949	90.01%
H	0.928205128	1	-0.071794872	0.071794872	7.73%
I	12.3775641	12.5	-0.122435897	0.122435897	0.99%
J	1.731410256	2	-0.268589744	0.268589744	15.51%
K	0.958974359	1	-0.041025641	0.041025641	4.28%
L	1.762179487	2	-0.237820513	0.237820513	13.50%
M	7.950641026	8	-0.049358974	0.049358974	0.62%
N	24.87051282	25	-0.129487179	0.129487179	0.52%
O	3.967307692	4	-0.032692308	0.032692308	0.82%
P	52.16282051	50	2.162820513	2.162820513	4.15%
Q	1.991025641	2	-0.008974359	0.008974359	0.45%
R	6.860897436	9.5	-2.639102564	2.639102564	38.47%
S	14.61602564	15	-0.383974359	0.383974359	2.63%
T	2.896794872	3	-0.103205128	0.103205128	3.56%
U	34.46410256	34.5	-0.035897436	0.035897436	0.10%
V	6.755769231	7	-0.244230769	0.244230769	3.62%
W	23.39358974	24.5	-1.106410256	1.106410256	4.73%
X	1.814102564	2	-0.185897436	0.185897436	10.25%
Total	--	--	--	**34.40897436**	--

Schedule for Large Formulation Original:

																				Emergency		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Mon	E	E	E	E	E	E	E	E	E	E	E	R	P	P	U	F	S	V	W	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	I	J	M	N	O	P	R	P	S	U	F	V	W	W	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Tues	C	C	E	E	E	E	E	E	E	E	E		I	N	U	F	N	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	I	N	N	O	P	P	Q	S	W	W	R	W	W	U	F	W	W	W	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Wed	E	E	E	E	F	F	F	F	F	F	F		F	F	U	F	M	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	F	F	F	F	F	F	F	I	N	R	N	P	U	F	P	S	X	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Thurs	B	E	F	F	F	F	F	F	F	F	F		N	N	U	F	P	P	S	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	F	F	F	F	F	F	F	F	F	I	L		N	P	U	F	P	S	W	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Fri	E	E	E	E	E	E	E	E	E	E	E		E	E	U	F	E	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	D	E	E	E	E	E	E	E	E	I	M		P	P	U	F	S	T	W	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Sat	E	E	E	E	F	M	N	N	P	P	U		U	U	U	F	U	U	V			
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	E	E	G	H	K	P	R	P	T	U	F	U	U	V			
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

D.2 Large Formulation with Friday Penalties

Objective Function:

$$\sum_{j=1}^{24} \frac{\max(0, t_j - \sum_{i=1}^{4}\sum_{k=1}^{12} d_{ik}x_{ijk})}{t_j} + C_1\left[\sum\sum_{i=1}^{4}\frac{\sum_{k=9}^{12} x_{ijk}}{t_j}\right] + C_2\left[\sum\sum_{i=1}^{4}\frac{\sum_{k=9}^{12} x_{ijk}}{t_j}\right] + C_3\left[\sum\sum_{i=1}^{4}\frac{\sum_{k=9}^{12} x_{ijk}}{t_j}\right]$$

*Note: The first summation following each C represents the summation of large, medium, and small surgical groups, respectively.

Objective Function Value: 1.12382

Total Weekly Allocated Hours: 414

Total Capacity Hours: 475

Utilization: 0.871578947

Individual Surgical Group Allocation Summary:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
A	2.693589744	4	-1.306410256	1.306410256	48.50%
B	2.183333333	2.5	-0.316666667	0.316666667	14.50%
C	4.585897436	5	-0.414102564	0.414102564	9.03%
D	1.533333333	2	-0.466666667	0.466666667	30.43%
E	163.95	94.5	69.45	69.45	42.36%
F	103.3423077	103.5	-0.157692308	0.157692308	0.15%
G	0.526282051	2	-1.473717949	1.473717949	280.02%
H	0.928205128	2	-1.071794872	1.071794872	115.47%
I	12.3775641	13	-0.622435897	0.622435897	5.03%
J	1.731410256	2	-0.268589744	0.268589744	15.51%
K	0.958974359	2	-1.041025641	1.041025641	108.56%
L	1.762179487	2	-0.237820513	0.237820513	13.50%
M	7.950641026	8	-0.049358974	0.049358974	0.62%
N	24.87051282	25	-0.129487179	0.129487179	0.52%
O	3.967307692	4	-0.032692308	0.032692308	0.82%
P	52.16282051	36	16.16282051	16.16282051	30.99%
Q	1.991025641	2	-0.008974359	0.008974359	0.45%
R	6.860897436	18	-11.13910256	11.13910256	162.36%
S	14.61602564	15.5	-0.883974359	0.883974359	6.05%
T	2.896794872	4	-1.103205128	1.103205128	38.08%
U	34.46410256	34.5	-0.035897436	0.035897436	0.10%
V	6.755769231	7	-0.244230769	0.244230769	3.62%
W	23.39358974	23.5	-0.106410256	0.106410256	0.45%
X	1.814102564	2	-0.185897436	0.185897436	10.25%
Total	--	--	--	**106.9089744**	--

Day Preference Weights (C_1, C_2, C_3)

$C_1 = 2$ large (Target Values > 100 Hours)

$C_2 = 5$ medium (10 Hours < Target Values < 99)

$C_3 = 10$ small (Target Values < 10)

Schedule for Large Formulation with Friday Penalties:

																				Emergency		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Mon	B	I	N	P	P	U	U	U	U	U	V	R	W	W	U	F	W	W	W	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	D	E	I	M	N	O	O	P	P	U	R	U	W	U	F	W	W		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Tues	E	F	F	F	F	F	F	F	F	F	N	R	P	P	U	F	W	W		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	E	E	E	G	I	J	K	M	P	R	P	Q	U	F	T	X		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Wed	C	C	F	F	F	F	F	F	F	F	F	R	N	N	U	F	P	P		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	F	I	L	M	N	N	R	P	P	U	F	T	V		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Thurs	F	F	F	F	F	F	F	F	F	I	N	R	N	P	U	F	P	V		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	F	F	F	F	F	F	F	F	H	I	M	R	N	N	U	F	P	P		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Fri	E	E	E	E	E	E	E	E	E	E	E		E	E			E	E	E	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	E	E	E	E	E	E	E	E	E		E	E			E	E	E	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Sat																						
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

D.3 Large Formulation with Absolute Value in Objective Function

Objective Function: $\sum_{j=1}^{24} \frac{\text{abs}(t_j - \sum_{i=1}^{4} \sum_{k=1}^{12} d_{ik} x_{ijk})}{t_j}$

Objective Function Value: 2.82347

Total Weekly Allocated Hours: 459.5

Total Capacity Hours: 475

Utilization: 0.967368421

Individual Surgical Group Allocation Summary:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
A	2.693589744	3	-0.306410256	0.306410256	11.38%
B	2.183333333	2.5	-0.316666667	0.316666667	14.50%
C	4.585897436	5	-0.414102564	0.414102564	9.03%
D	1.533333333	2	-0.466666667	0.466666667	30.43%
E	163.95	139.5	24.45	24.45	14.91%
F	103.3423077	103.5	-0.157692308	0.157692308	0.15%
G	0.526282051	1	-0.473717949	0.473717949	90.01%
H	0.928205128	1	-0.071794872	0.071794872	7.73%
I	12.3775641	12.5	-0.122435897	0.122435897	0.99%
J	1.731410256	2	-0.268589744	0.268589744	15.51%
K	0.958974359	1	-0.041025641	0.041025641	4.28%
L	1.762179487	2	-0.237820513	0.237820513	13.50%
M	7.950641026	8	-0.049358974	0.049358974	0.62%
N	24.87051282	25	-0.129487179	0.129487179	0.52%
O	3.967307692	4	-0.032692308	0.032692308	0.82%
P	52.16282051	50	2.162820513	2.162820513	4.15%
Q	1.991025641	2	-0.008974359	0.008974359	0.45%
R	6.860897436	9.5	-2.639102564	2.639102564	38.47%
S	14.61602564	15	-0.383974359	0.383974359	2.63%
T	2.896794872	3	-0.103205128	0.103205128	3.56%
U	34.46410256	34.5	-0.035897436	0.035897436	0.10%
V	6.755769231	7	-0.244230769	0.244230769	3.62%
W	23.39358974	24.5	-1.106410256	1.106410256	4.73%
X	1.814102564	2	-0.185897436	0.185897436	10.25%
Total	--	--	--	**34.40897436**	--

Schedule for Large Formulation with Absolute Value in Objective Function:

																				Emergency		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Mon	E	E	E	E	E	E	E	E	E	E	E	R	P	P	U	F	S	V	W	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	I	J	M	N	O	P	R	P	S	U	F	V	W	W	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Tues	C	C	E	E	E	E	E	E	E	E	E		I	N	U	F	N	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	I	N	N	O	P	P	Q	S	W	W	R	W	W	U	F	W	W	W	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Wed	E	E	E	E	F	F	F	F	F	F	F		F	F	U	F	M	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	F	F	F	F	F	F	F	I	N	R	N	P	U	F	P	S	X	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Thurs	B	E	F	F	F	F	F	F	F	F	F		N	N	U	F	P	P	S	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	F	F	F	F	F	F	F	F	F	I	L		N	P	U	F	P	S		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Fri	E	E	E	E	E	E	E	E	E	E	E		E	E	U	F	E	P	P	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	D	E	E	E	E	E	E	E	E	I	M		P	P	U	F	S	T		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Sat	E	E	E	E	F	M	N	N	P	P	U		U	U	U	F	U	U	V			
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	E	E	G	H	K	P	R	P	T	U	F	U	U	V			
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

*Note: This is schedule is identical to the schedule in Appendix D.1.

D.4 Large Formulation with Absolute Value in Objective Function with Friday Penalties

Objective Function:

$$\sum_{j=1}^{24} \frac{\mathrm{abs}(t_j - \sum_{i=1}^{4}\sum_{k=1}^{12} d_{ik}x_{ijk})}{t_j} + C_1\left[\sum\sum_{i=1}^{4}\frac{\sum_{k=9}^{12} x_{ijk}}{t_j}\right] + C_2\left[\sum\sum_{i=1}^{4}\frac{\sum_{k=9}^{12} x_{ijk}}{t_j}\right] + C_3\left[\sum\sum_{i=1}^{4}\frac{\sum_{k=9}^{12} x_{ijk}}{t_j}\right]$$

*Note: The first summation following each C represents the summation of large, medium, and small surgical groups, respectively.

Objective Function Value: 9.76417

Total Weekly Allocated Hours: 414

Total Capacity Hours: 475

Utilization: 0.871578947

Individual Surgical Group Allocation Summary:

Surgical Group	Target (Hours)	Allocated (Hours)	Difference (Hours)	Absolute Difference (Hours)	Absolute Percentage Difference
A	2.693589744	4	-1.306410256	1.306410256	48.50%
B	2.183333333	2.5	-0.316666667	0.316666667	14.50%
C	4.585897436	5	-0.414102564	0.414102564	9.03%
D	1.533333333	2	-0.466666667	0.466666667	30.43%
E	163.95	94.5	69.45	69.45	42.36%
F	103.3423077	103.5	-0.157692308	0.157692308	0.15%
G	0.526282051	2	-1.473717949	1.473717949	280.02%
H	0.928205128	2	-1.071794872	1.071794872	115.47%
I	12.3775641	13	-0.622435897	0.622435897	5.03%
J	1.731410256	2	-0.268589744	0.268589744	15.51%
K	0.958974359	2	-1.041025641	1.041025641	108.56%
L	1.762179487	2	-0.237820513	0.237820513	13.50%
M	7.950641026	8	-0.049358974	0.049358974	0.62%
N	24.87051282	25	-0.129487179	0.129487179	0.52%
O	3.967307692	4	-0.032692308	0.032692308	0.82%
P	52.16282051	36	16.16282051	16.16282051	30.99%
Q	1.991025641	2	-0.008974359	0.008974359	0.45%
R	6.860897436	18	-11.13910256	11.13910256	162.36%
S	14.61602564	15.5	-0.883974359	0.883974359	6.05%
T	2.896794872	4	-1.103205128	1.103205128	38.08%
U	34.46410256	34.5	-0.035897436	0.035897436	0.10%
V	6.755769231	7	-0.244230769	0.244230769	3.62%
W	23.39358974	23.5	-0.106410256	0.106410256	0.45%
X	1.814102564	2	-0.185897436	0.185897436	10.25%
Total	--	--	--	**106.9089744**	--

Day Preference Weights (C_1, C_2, C_3)

$C_1 = 2$ large (Target Values > 100 Hours)

$C_2 = 5$ medium (10 Hours < Target Values < 99)

$C_3 = 10$ small (Target Values < 10)

Schedule for Large Formulation with Absolute Value in Objective Function with Friday Penalties:

																				Emergency		
	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	21	22	23
Mon	B	I	N	P	P	U	U	U	U	U	V	R	W	W	U	F	W	W	W	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	D	E	I	M	N	O	O	P	P	U	R	U	W	U	F	W	W		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Tues	E	F	F	F	F	F	F	F	F	F	N	R	P	P	U	F	W	W		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	E	E	E	G	I	J	K	M	P	R	P	Q	U	F	T	X		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Wed	C	C	F	F	F	F	F	F	F	F	F	R	N	N	U	F	P	P		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	A	E	E	E	E	F	I	L	M	N	N	R	P	P	U	F	T	V		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Thurs	F	F	F	F	F	F	F	F	F	I	N	R	N	P	U	F	P	V		--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	F	F	F	F	F	F	F	F	H	I	M	R	N	N	U	F	P	P		--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Fri	E	E	E	E	E	E	E	E	E	E	E		E	E			E	E	E	--	--	--
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	E	E	E	E	E	E	E	E	E	E	E		E	E			E	E	E	--	--	--
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Sat																						
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

*Note: This is schedule is identical to the schedule in Appendix D.2.

APPENDIX E: Current Boone Hospital Block Schedule

		1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	21	22	23
Mon	AM	F AM	F AM	W AM	W AM	P AM	AM	AM	I AM	X AM	A AM	E AM	R AM	P AM	AM	U AM	AM	F AM	AM	E AM	E AM	E AM	E AM
	PM	PM	F PM	W PM	PM	P PM	E PM	PM	I PM	X PM	PM	F PM	PM	P PM	PM	U PM	PM	F PM	E PM	PM	E PM	PM	PM
Tues	AM	F AM	F AM	W AM	W AM	P AM	N AM	AM	E AM	K AM	J AM	E AM	AM	P AM	N AM	U AM	AM	F AM	E AM	E AM	AM	AM	E AM
	PM	PM	F PM	W PM	PM	P PM	PM	PM	E PM	F PM	E PM	I PM	PM	P PM	N PM	U PM	PM	F PM	PM	E PM	PM	PM	PM
Wed	AM	V AM	F AM	W AM	U AM	P AM	AM	AM	I AM	AM	O AM	E AM	AM	P AM	AM	U AM	AM	AM	E AM	E AM	E AM	E AM	E AM
	PM	F PM	F PM	W PM	PM	P PM	PM	PM	I PM	PM	O PM	E PM	PM	P PM	PM	U PM	PM	PM	PM	PM	E PM	E PM	PM
Thurs	AM	F AM	F AM	AM	AM	P AM	N AM	AM	E AM	AM	S AM	E AM	R AM	P AM	N AM	U AM	AM	F AM	E AM	E AM	E AM	E AM	E AM
	PM	PM	F PM	PM	PM	P PM	PM	PM	E PM	O PM	PM	E PM	PM	P PM	N PM	U PM	PM	F PM	PM	E PM	E PM	E PM	PM
Fri	AM	F AM	F AM	F AM	AM	P AM	AM	AM	C AM	U AM	F AM	AM	AM	P AM	AM	U AM	AM	AM	E AM	E AM	E AM	E AM	AM
	PM	PM	F PM	F PM	PM	P PM	PM	PM	F PM	U PM	F PM	PM	PM	P PM	PM	PM	PM	PM	PM	E PM	PM	PM	PM
Sat	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

APPENDIX F: Formulation with Original Capacities

	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	21	22	23
Mon	E	E	E	E	E	E	J	K	M	S	E		U	U			U	V	E	E	E	E
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	G	K	M	N	P	N	O	O	R	A	R		P	U			U	V				
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Tues	F	F	F	F	P	N	F	D	J	K	Q		P	N			F	S				
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	B	G	W	J	P	K	W				I											
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Wed	F	F	F	F	P	F	F	I	F	F	F		P	F			K	S	U			
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	C	K	N	N	P	R							P									
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Thurs	B	B	G	J	P								P									
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	B	B	K		P					A			P									
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Fri	B	I	J	K	P	L	T	U	U	U	U		P	U			U	U	X			
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	M	S																				
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Sat																						
	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM	AM
	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM

*Note: The shifts outlined in red are consistent with the current block schedule in Appendix E.

APPENDIX G: Comparison with Current Block Schedule

Surgical Group	Allotted Time (Current Schedule)	Target Time (Calculated)	Allotted Time (Proposed Schedule)	Distribution of Time (Current Schedule, Across Days of the Week)		Distribution of Time (Proposed Schedule, Across Days of the Week)	
				Day	***Hours***	***Day***	***Hours***
A	5	2.69	3	Mon	5	Mon	2
				Tue	-	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	1
				Day	***Hours***	***Day***	***Hours***
B	0	2.18	2.5	Mon	-	Mon	-
				Tue	-	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	2.5
				Fri	-	Fri	-
				Sat	-	Sat	-
				Day	***Hours***	***Day***	***Hours***
C	5	4.59	5	Mon	-	Mon	-
				Tue	-	Tue	5
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	5	Fri	-
				Sat	-	Sat	-
				Day	***Hours***	***Day***	***Hours***
D	0	1.53	2	Mon	-	Mon	-
				Tue	-	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	2
				Sat	-	Sat	-
				Day	***Hours***	***Day***	***Hours***
E	172.5	163.95	139.5	Mon	32.5	Mon	35.5
				Tue	32.5	Tue	24.5
				Wed	37.5	Wed	14
				Thu	47.5	Thu	2.5
				Fri	22.5	Fri	51
				Sat	-	Sat	12
				Day	***Hours***	***Day***	***Hours***
F	105	103.34	103.5	Mon	20	Mon	4.5
				Tue	20	Tue	4.5
				Wed	10	Wed	41
				Thu	20	Thu	45
				Fri	35	Fri	4.5
				Sat	-	Sat	4
				Day	***Hours***	***Day***	***Hours***
G	0	0.53	1	Mon	-	Mon	-
				Tue	-	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	1

H	0	0.93	1	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	-
				Tue	-	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	1
I	17.5	12.38	12.5	***Day***	***Hours***	***Day***	***Hours***
				Mon	7.5	Mon	2
				Tue	2.5	Tue	4.5
				Wed	7.5	Wed	2
				Thu	-	Thu	2
				Fri	-	Fri	2
				Sat	-	Sat	-
J	5	1.73	2	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	2
				Tue	5	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	-
K	5	0.96	1	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	-
				Tue	5	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	1
L	0	1.76	2	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	-
				Tue	-	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	2
				Fri	-	Fri	-
				Sat	-	Sat	-
M	0	7.95	8	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	2
				Tue	-	Tue	-
				Wed	-	Wed	2.5
				Thu	-	Thu	-
				Fri	-	Fri	2
				Sat	-	Sat	1.5
N	25	24.87	25	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	2
				Tue	12.5	Tue	9
				Wed	-	Wed	4
				Thu	12.5	Thu	7
				Fri	-	Fri	-
				Sat	-	Sat	3
O	10	3.97	4	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	2
				Tue	-	Tue	2
				Wed	7.5	Wed	-
				Thu	2.5	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	-

P	75	52.16	50	***Day***	***Hours***	***Day***	***Hours***
				Mon	15	Mon	9
				Tue	15	Tue	9
				Wed	15	Wed	9
				Thu	15	Thu	9
				Fri	15	Fri	9
				Sat	-	Sat	5
Q	0	1.99	2	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	-
				Tue	-	Tue	2
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	-
R	10	6.86	9.5	***Day***	***Hours***	***Day***	***Hours***
				Mon	5	Mon	4.5
				Tue	-	Tue	2
				Wed	-	Wed	2
				Thu	5	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	1
S	5	14.62	15	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	4.5
				Tue	-	Tue	2
				Wed	-	Wed	2
				Thu	5	Thu	4.5
				Fri	-	Fri	2
				Sat	-	Sat	-
T	0	2.90	3	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	-
				Tue	-	Tue	-
				Wed	-	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	2
				Sat	-	Sat	1
U	47.5	34.46	34.5	***Day***	***Hours***	***Day***	***Hours***
				Mon	7.5	Mon	4.5
				Tue	7.5	Tue	4.5
				Wed	12.5	Wed	4.5
				Thu	7.5	Thu	4.5
				Fri	12.5	Fri	4.5
				Sat	-	Sat	12
V	5	6.76	7	***Day***	***Hours***	***Day***	***Hours***
				Mon	-	Mon	4.5
				Tue	-	Tue	-
				Wed	5	Wed	-
				Thu	-	Thu	-
				Fri	-	Fri	-
				Sat	-	Sat	2.5
W	32.5	23.39	24.5	***Day***	***Hours***	***Day***	***Hours***
				Mon	12.5	Mon	6.5
				Tue	12.5	Tue	14
				Wed	7.5	Wed	-
				Thu	-	Thu	2
				Fri	-	Fri	2
				Sat	-	Sat	-

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