The Efficiency of Block Scheduling in Operating Rooms

by

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Abstract

Block scheduling is a common method to arrange surgeries in operating rooms. This paper aims to use historical data from Virga Jesse Hospital in Belgium to examine the benefits of block scheduling. One major reason to group elective surgeries is to reduce set up time associated with gathering the surgical team and necessary equipments. Only the first surgery within a block of surgeries done in sequence encounters set up and variable time while any subsequent surgeries incur only variable time that's equivalent to actual procedural time. Another reason to use block scheduling is to reduce the coefficient of variation of a single block, which decreases in an exponential manner as the number of surgeries in the block increase.

I would like to sincerely thank Professor Pinedo for his guidance and suggestions throughout this project as well as Virga Jesse Hospital for providing all data used in this research. I would also like to acknowledge Professor Simon for providing suggestions for statistical analysis and Sebastian Souyris for his insight and time. They have provided endless support throughout the past year without which my project would not have been possible.

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Issue

Perhaps one of the pressing issues in today's society is the steeply rising health care cost. At the center of public attention, this will be one of the most highly debated issues for the 2008 presidential election. Although health care is a necessity of any society, the majority of citizens in US find it unaffordable. In fact, medical bills is the top reason most people file for personal bankruptcy in the US.[1] According to National Coalition on Health Care, total health expenditures increase 6.9% in 2005, which is two times the rate of inflation. Furthermore, health care cost is expected to reach 2.5 trillion dollars by 2015, nearly 20% of GDP.[2]

Currently, the US healthcare system is a mix of public and private funds supported by taxes, insurance premiums, and private out-out-pocket payments. 59.7% of Americans receive their health insurance coverage through an employer, though more employers are less willing to provide such benefits due to increasing premiums.[3] Recent data from the U.S. Census Bureau shows that 15.8% of Americans had no health insurance at some point during 2006. [4] This mostly includes workers whose employers do not provide health insurance, but earn too much to qualify for governmental health insurance. According to the Institute of Medicine, U.S. is the only industrialized nation that does not provide universal coverage.[5] Whether this is the right solution to America's healthcare system will become a major topic of debate among policy makers for the coming years.

In 2000, the World Health Organization ranked US the first healthcare system in

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1 D. U. Himmelstein, et al, "Illness and injury as contributors to bankruptcy," Health affairs (Project Hope) Suppl Web Exclusives (2005): W5,63-W5-73,.

2 NCHC | Facts About Healthcare - Health Insurance Cost, , 4/23/2008 2008 <http://www.nchc.org/facts/cost.shtml>.

3 2007 Kaiser/HRET Employer Health Benefits Survey - Kaiser Family Foundation, , 5/9/2008 2008 <http://www.kff.org/insurance/ehbs091107nr.cfm>.

4 Carmen DeNavas-Walt, Income, Poverty, and Health Insurance Coverage in the United States: 2006, August 2007 ed. U.S. Census Bureau, 2007).

5 Institute of Medicine, Insuring America's health: principles and recommendations (Washington, DC : National Academies Press, 2004) 205.

responsiveness and expenditures, but 37th in performance and 72nd in overall level of health of citizens.[6] Most experts agree that the current health care system is buried in inefficiency, excessive expenses, and poor management. However, they disagree on the best way to solve this issue. Recently, operation research applied to a healthcare setting has gained increasing interest aiming to increase the efficiency in scheduling staff, operating rooms, nurse, trainees, and radiotherapy.

Hospital administrations usually focus attention on operation room hours because it is one of the most expensive resources of the hospital in terms both equipment and staffing needs. Availabilities of OR have a dramatic impact on other units of the hospital such as bed capacity and medical staff requirements. More importantly, 60%-70% of all hospital admissions involves utilization of OR. Thus, the OR can be considered a core to the hospital operations.

When a patient seeks healthcare service, his or her knowledge of need, treatment options, and efficiency of each option is limited. This leads to an agency relationship between patient and the physician where the patient hires the physician to act on his behalf in determining the needed services and select best treatment available. Fee-for-service business model is where the patient pays in full or out of pocket for each the services rendered. The more service that the physician provide, the more money he receives. However, this also creates an adverse economic incentive for physicians to provide all service regardless of how small the benefit is. Therefore, US have controlled hospital spending by strictly limiting their annual budget. If OR budget is reduced, the OR manager must decide which surgical groups will have shorten their allocated OR time.[7] If the surgeon is paid on a fee for service basis, reduced OR time may significantly affect their income.

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[6] B. Darussalam, et al, "Annex Table 1 Health system attainment and performance in all Member States, ranked by eight measures, estimates for 1997," .

[7] J. T. Blake, F. Dexter, and J. Donald, "Operating Room Managers' Use of Integer Programming for Assigning Block Time to Surgical Groups: A Case Study," Anesthesia & Analgesia 94.1 (2002): 143-8,.

Therefore, the OR manager must juggle between the conflicting interests between the administration, surgeons, and patients to maximize the quality of care and productivity of the hospital. Operation research provides a consistent and objective approach to scheduling procedures thus reducing conflicts among surgeons and between surgeons and OR manager.

Past Research

One way to lower health care costs is to increase the efficiency of the healthcare system. Therefore, operation research can become an important tool by applying optimization models to healthcare settings. Linear programming, which “allocates limited resources among competing activity in the best possible way”, has been particularly useful since hospital beds and equipments are limited within a hospital.[8] The objective is to optimize a set of decision variable with these variables satisfying a set of constraints. Integer programming (IP), where all decision variables must have integer value, has also been found particularly applicable in healthcare operation research. IP is applicable to scheduling problems where decision variables are restricted to integers as they determine assignment of resources to specific activities.

The variability in operations room scheduling creates critical challenges to preplanning surgeries. There are essentially two types of variability: natural variability and artificial variability. Natural variability arises from the variability inherent in healthcare industry such as emergency cases and complications during surgeries. Artificial variability stems from poor scheduling processes, which can be minimized with optimization models. For example, a rearrangement of elective procedures can smooth out needs for hospital beds to avoid shortage or surplus of beds. Although natural variability is uncontrollable, with algorithms optimized to minimize its variation, one can mitigate impacts of natural variability.[9]

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[8] F. S. Hillier and G. J. Lieberman, Introduction to operations research McGraw-Hill, 2005).

[9] F. E. EN and T. ECONOMISCHE, "Exact and Heuristic Methodologies for Scheduling in Hospitals: Problems,

According to Belien, current literature on scheduling can be separated according to the 3 different stages in developing OR schedules. The first stage, case mix planning, is where the OR manager decides how available operating rooms are allocated for different surgeons or different surgical groups.[10] After assigning each surgical group to an operating room, a master surgery schedule can be developed. A master surgery schedule is a cyclic timetable that defines the number and type of ORs available at a facility, the hours that ORs will be open, and surgical groups or surgeons who are to be given priority for the OR time.

Current research focusing on master surgical schedules has mostly applied integer programming. OR time can be assigned based on an open block or closed block method. In open block method, OR time is assigned after specialties arrived and thus patients are always ready for standby. Therefore, different specialties may share use a single OR per day. In the closed block method, blocks of surgery are assigned to specialties and each specialty assigns their patients to their own blocks. [11]

The third stage is planning of elective cases, which are assigned on a daily basis and involves the detail of operation scheduling. In this level, the managers assign specific cases to particular operating rooms, determining order and start and end times of the cases, and availability of specialized equipment.

Several objectives can be considered in building surgery schedules. Most focus on maximizing operating room utilization or minimizing operating room staffing cost. Blake et al suggests an algorithm that minimize the weighted average undersupply of operating room hours thus matching the number of operating room hours as close to target operating room hours as

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Formulations and Algorithms," .

[10] J. Beliën and E. Demeulemeester, "Building cyclic master surgery schedules with leveled resulting bed occupancy," European Journal of Operational Research 176.2 (2007): 1185-204,.

[11] Erwin W. Hans, Tim Nieberg, and Oostrum, Jeroen M. van, "Optimization in surgery planning," MET 15.1 (2007).

possible. His algorithm also aims to create a stable schedule that changes little from week to week.[12] Santibanez proposes a system wide optimization model for block scheduling to balance tradeoffs between OR availability, surgeon book privileges, bed capacity, and waitlists for patients.[13] However, recent research is starting to focus on minimizing the uncertainty, which requires understanding into the interplay between elective and emergency cases and managing the natural variability. Gerchak uses a stochastic dynamic programming model to manage the uncertain demand for emergency cases.[14] Kim examines the flexible allocation scheme that can schedule beds within the intensive care to balance demands of both elective surgery and emergency surgery patients. Using a quota system and his flexible allocation scheme, Kim aims to minimize the number of cancelled elective surgery.[15]

Reasons for Block Scheduling

Although much of the past research has based their models on scheduling operations in blocks, none has examined data to determine whether block scheduling is an efficient method to allocate OR time. There are three main reasons why many ORs has adopted a block scheduling method, in which similar elective surgeries are scheduled to be completed in a series

I. Reduction in coefficient of variation

II. Reduction in set up time

III. Reduction in OR Idle time

The portfolio effect states that variation of returns is reduced when assets are combined relative to the average of variation of individual assets, assuming each asset is independent of the

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[12] Blake, Dexter, and Donald, 143-8

[13] P. Santibanez, M. Begen, and D. Atkins, "Managing surgical waitlists for a British Columbia health authority," Research report (2005).

[14] Y. Gerchak, D. Gupta, and M. Henig, "Reservation Planning for Elective Surgery under Uncertain Demand for Emergency Surgery," Management Science 42.3 (1996): 321-34,.

[15] S. C. Kim, et al, "Flexible bed allocation and performance in the intensive care unit," Journal of Operations Management 18.4 (2000): 427-43,.

other. Applied to a block of surgeries, one should expect that the duration of a block consisting of only one surgery to be much more variable than the duration of a block consisting of six or seven surgeries. By lowering the coefficient of variation for a block of surgeries, one can better predict the duration of one block and ensure that a certain number of surgeries can completed during that block of time.

Each block of surgery has a fixed set up time and a variable component, which can be modeled as

$$\text{Duration of a Block} = \text{Setup Time} + n * \text{Variable Time} + \varepsilon$$

Setup time consists of equipment setup and staffing the OR with surgeons, nurses and anesthesiologists. Variable time mainly involves the time needed to administer the anesthesia and complete the surgical procedure. For the remainder of this paper, n is a variable that represents the number of surgeries performed. Meanwhile, ε, is a residual value whose expected value is 0 and includes any natural variability that may be encountered such as complications during the surgical procedures. All of these variables depend significantly on the type of surgery that is completed. Therefore, by placing a group of surgeries in series, setup time should not be incurred after the first surgery assuming any subsequent surgeries use the same surgical team and equipments. There is also a possibility that variable time is reduced as surgeons experiences a slight learning curve as he completes the same surgeries in a series.

By grouping a set of operations, idle time of the operation room can be minimized. If a surgery took less time than expected, the operating room will remain idle until the next scheduled surgery begins. In scheduling a string of similar operations, it will be the same surgical team who will be completing all surgery in the string. Therefore, the next scheduled patient can begin if the first surgery ended early since all other necessary resources are in place. As mentioned previously, OR is one of the most expensive resources of a hospital. Therefore, by lowering idle time, the hospital can make maximize the availability of OR time.

Data Background

All data used in this paper originates from the Virga Jesse Hospital in Hasselt, Belgium. In 2004 alone, 19,347 surgeries were performed completing more than 20,000 hours of total net operating time. The data focuses on the 13 operating rooms in which 72 surgeons have been assigned operating room time. These surgeons are grouped into 15 different specialties. Each operating room is available from Monday to Friday for 8.5 hours. There are no elective cases scheduled on weekends, meaning most surgeries are scheduled and pre-planned.[16]

Example of Model using Block Scheduling Method[17]

In *Optimization in Surgery Planning*, the closed block is considered, in which each specialty is assigned blocks on a weekly basis. In Erasmus University Medical Center which was studied in the paper, 60% of capacity is divided once a year and 40% every 3 months. Such protocol guarantees that each specialty has a base level of OR availability, while providing flexibility for seasonal fluctuations. Additional fine-tuning occurs in the weekly block schedule when specialties already know ahead the list of surgeries they need to schedule. The surgical block that needs to be assigned is based on 3 rules: 1. cases are planned using historical mean case durations 2. slack is added to deal with emergency and variability of case duration 3. exceeding OR block time is not allowed.

In the paper, Hans et al. describes an approach for dividing the OR capacity to different surgeons. The formulation features a method that allows for varying block sizes. The block sizes

[16] Beliën and Demeulemeester, 1185-204
[17] Hans, Nieberg, and Oostrum, Jeroen M. van,

are adjusted such that the amount of unused OR time is minimized. Because the schedules of staff are not that flexible, reasonable block sizes are provided as inputs into the problem to better accommodate staff schedules.

The model proposed by Hans will be used to generate an efficient OR schedule for Virga Jesse Hospital, which has a list of surgeries that it must schedule. They must assign these surgeries to blocks (i.e. the actual ORs during a day) of various capacities. They want to assign these surgeries to blocks in manner that maximizes total block utilization. This is a two part problem that, first, requires Virga Jesse to determine the capacity of each blocks and then assign surgical cases to each blocks.

The objective is to maximize OR utilization of a block capacity by minimizing the total unused OR time. The problem must determine the capacity of each block and assign each surgery to a block. The constraints include

1. all surgical cases listed must be planned
2. The difference between total available bock capacities must be greater than the total duration of surgical cases.
3. The total capacity of blocks must be less than or equal to total time allocated to the specialties

The input variables used in the optimization model and their explanations are as follows:

- T_{max}= maximum total time allocated to the specialty
- c_l = list of available duration of one block, l= 1,2,3,… L (in minutes)
- k = block index, k=1…K
- S_i = surgical cases to be performed
- s_i = frequency of the number of times surgery S_i occurs

- d_i= duration of surgery S_i, based on historical durations from Virga Jesse

Let y_{kl} to be a binary variable determining the duration of block k from list L. If y_{kl} is 1, it means that the duration of block k is the corresponding duration in list c_l. Let V_{ik} to be the number of times surgery i is assigned block k. For example, if V_{ik} is 2, it means surgery i is assigned two times to block k. Both y_{kl} and V_{ik} are decision variables.

Mathematically, the objective function is

Minimize $\sum_{k=1}^{K}\left(\sum_{l=1}^{L} c_l y_{kl} - \sum_{i=1}^{S} V_{ik} d_i\right)$

$\sum_{l=1}^{L} c_l y_{kl}$ represents the total available block capacity, while $\sum_{i=1}^{S} V_{ik} d_i$ represents the total time used to perform surgeries. Therefore, their differences represent the unused OR time. By minimizing the total unused OR time, one is essentially maximizing OR utilization.

The objective is subject to the following constraints:

1. $\sum_{k=1}^{K} V_{ik} = s_i$ for i= 1, …S
2. $\sum_{l=1}^{L} c_l y_{kl} - \sum_{i=1}^{S} V_{ik} d_i \geq 0$ for k= 1, …K
3. $\sum_{k=1}^{K}\sum_{l=1}^{L} c_l y_{kl} \leq T_{\max}$
4. $\sum_{l=1}^{L} y_{kl} \leq 1$ for k=1,…K
5. V_{ik} integers for i=1,…S; k= 1,…K
6. y_{kl} binary variable for k= 1,…K; l=1,….L

Constraint 1 ensures all surgery will be planned in one of the blocks. Constraint 2 ensures that the surgery must be assigned to an existing block. In other words, if a block is not assigned to any duration in list c_l, no surgeries can be assigned to that block. Constraint 3 requires duration of all blocks added together must be less than the total allocated time for the specialty. Constraint 4 expresses that only one duration is chosen for a block.

The above model was formulated in Microsoft Excel. The input data was randomly selected from surgeries that were assigned to one of Virga Jesse's 13 operating rooms in 1 day. We assume there were 3 blocks since on average 3 surgeons would be assigned to 1 operating room. Furthermore, we assumed that the specialty was allotted a maximum of 25 hours since each surgeon was allowed to work a 8:20 hour shift. Therefore, the assumptions associated with the input variables are:

- T_{max}= 1500 minutes
- c_l = {100, 120, 140…500}
- k = 3
- S_i = {4 Teeth Extraction, Implantation, 3 Teeth Extraction, Chin Osteotomy, Extraction of Lesion}
- s_i = {5, 3, 5, 1, 1}
- d_i= {42.09, 82.25, 39.93, 169.24, 33.37}

From the model, the optimal solution would be to schedule the surgeries as follows:

Block	**Block Duration**	**Surgeries**
1	5 hours	• 3 Three Teeth Extractions • 1 Chin Osteotomy
2	3:20 hours	• 1 Implantation • 2 Three Teeth Extractions • 1 Extraction of Lesion
3	6:20 hours	• 5 Four Teeth Extractions • 2 Implantations

The above solution results in 20 minutes of unused OR time.

The model is unique in that it essentially allows the surgeon to choose how many hours they want to work per week through the list of available capacities c_l. If the surgeon is paid on a fee for service basis, this model provides them with the needed flexibility to decide how much they want to earn. Currently, the model assumes that the same list of available capacity apply to all blocks. Thus, different surgeons are assumed to be available to work for the same amount of time. However, the model can be modified such that each surgeon can chose their preferred capacity sizes.

Another strength of the model is that it completes two task simultaneously for the OR manager. Not only does it determine the duration of a block, it also assigns which surgeries should be placed in a block. The model proves how these two decisions are intricately linked and can be adjusted to maximize OR utilization.

Because decision variables were either binary variables or integer variables, these restrictions caused a long run time to find the optimal solution. If there were a couple more decision variables, this problem would have taken much longer time to solve. Furthermore, the model fails to take into account the variability in surgical duration by only considering the expected duration of a procedure. This model would have been more robust if it requires some slack time. This way, if a surgeon took longer than expected, it will be less likely that the next surgeon will have to wait. One way to ensure there slack time is to change constraint 2 to $\sum_{l=1}^{L} c_l y_{kl} - \sum_{i=1}^{S} V_{ik} d_i \geq slack\,time$. In this case, the OR manager will have to determine the appropriate slack time, which can be a portion of the blocks duration.

Research Problem

Many mathematical models proposed by operation researchers, including the one above, involves scheduling elective surgeries in blocks. However, the impact of block scheduling have not been studied with existing data. Therefore, two key questions which will be examined are:

1. Can block surgery allow for better predictions of a block's duration by reducing natural variability?
2. To what extent can block surgery reduce set up time?

Methodology

Because surgical procedures vary widely, duration highly depends on the type of procedure being performed. Therefore, I have chosen to examine the impact of completing surgeries in a series by focusing on specific procedures. For the most part, a procedure of interest was selected based on its length and the number of times it was performed in 2004. The average time for such a procedure must be short enough such that a surgeon can be expected to complete a series of such procedure in 1 day. Then, given existing data, those surgeries that were performed in a series, were extracted for all 13 operating rooms. Each series is defined as a block, which consists of 2 or more surgeries completed consecutively. A 15-minute leeway was given such that if the previous surgery ended within 15 minutes prior to the next surgery begins, they are still considered to have been completed consecutively. Therefore, we assume that a different procedure cannot be completed within those 15 minutes. This allows us to gather a sufficient sample size, since the starting time of one surgery does not necessarily match the ending time of the previous surgery although they were done in series.

Coefficient of Variation

Coefficient of variation is defined as the ratio of the standard deviation to the mean.

$$\textit{Coefficient of Variation} = \frac{\sigma}{\mu}$$

This ratio measures the dispersion of data points around the mean. For each type of surgery, the coefficient of variation for a block was calculated by finding the square root of sum of variance in duration and dividing it by the sum of average duration each procedure in the string. This can be written as

$$Coefficient\ of\ Variation = \frac{\sqrt{\sum_n \sigma^2}}{\sum_n \mu}$$

where n= number of surgeries within block

Reduction in Set up time

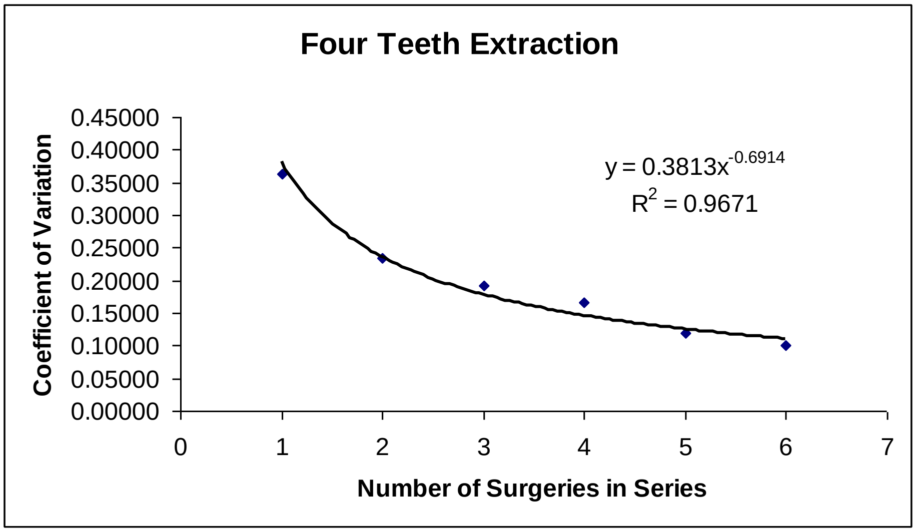
Set up time is usually observed by graphing the relationship order of surgery within the block and its average duration. To test whether the difference in surgical duration was statistically significant, paired t-test, which determines whether the duration means are equal to one another, was used. Because we are comparing the surgical time between different surgeries within the same string, their duration are dependent one another making a paired t test suitable. An alpha of 0.05 is set to determine whether the means are statistically significant. Therefore, the probability of stating that the average durations of the two surgeries in the series are different when, in fact, they are the same is 5%.

Surgery 1: Wisdom Teeth Extraction

In 2004, there were 949 wisdom teeth extractions performed. A majority of the surgeries were done using general anesthesia. The procedure entails the surgeon opening up gum tissue over the tooth, separating the tissue connected to the tooth, and removing the tooth. Since this procedure could be completed within a short amount of time, surgeons could easily complete multiple surgeries within one day. Furthermore, one, two, three, or four teeth could be extracted in 1 operation. By studying the duration depending on how many teeth are extracted, one can gain a better understanding of set up and variable time within a teeth extraction procedure.

Coefficient of Variation

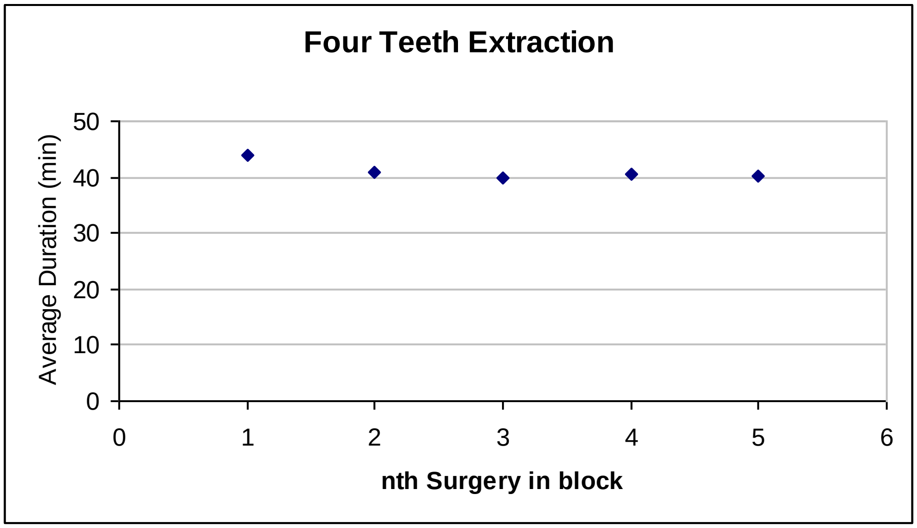
The coefficient of variation was calculated on a four teeth extraction since this was the most frequently performed operation in Virga Jesse. In fact, six consecutive surgeries were completed in a series in four instances. With an average duration of 41.5 minutes per operation, this is a 4:09 hour block for the surgeon. Calculating the coefficient of variation, for blocks of size n where n= 1,2,3…6 yields the following results:



Based on the above graph, as the number of surgeries increase in a block, there is a reduction in the coefficient of variation. This indicates that by increasing the number of surgeries within a block, we can reduce the natural variability of surgical duration for the entire block. The coefficient of variation can be best regressed with an exponential equation, meaning the marginal reduction of coefficient of variation in the first couple of surgeries is higher than the marginal reduction of coefficient of variation in the subsequent surgeries within the series.

Reduction in Set up Time

We further examined the four wisdom teeth extraction looking for a reduction in set up time by scheduling surgeries in a string.



The above graph compares the order of surgery within the block and its average duration. Based on the graph, the first surgery has a longer duration than any subsequent surgery. Furthermore, the average duration of the subsequent surgeries seems to be similar, taking approximately 40 minutes.

In order to prove that the means were statistically significantly different from one another, a paired t test was performed. Detailed results of tests performed for wisdom teeth operations can be found in Appendix A. Comparing the duration for first surgery and second surgery, a t-value of 2.01 was obtained resulting in a p-value of 0.046. Therefore, it is with 95% confidence that the mean duration of first surgery and second surgery in a string are statistically significant from each other. Because the first surgery in a string lasts on average 44.01 minutes and the second surgery in a string lasts 40.83 minutes, it is concluded that the decrease in the surgical time is statistically significant.

Other paired t tests were performed comparing the mean duration of the first and third surgery and first and fourth surgery. If our model is correct, the means between these pairs of surgeries should also be statistically significant since the first surgery incurs set up time, but any subsequent surgeries do not. The paired t test between the first and third surgery resulted in a t value of 2.72 and p value of 0.09. The paired t test between the first and fourth surgery resulted in a t value of 2.36 and a p value of 0.036. Because the results of both tests were statistically significant, it further supports our hypothesis.

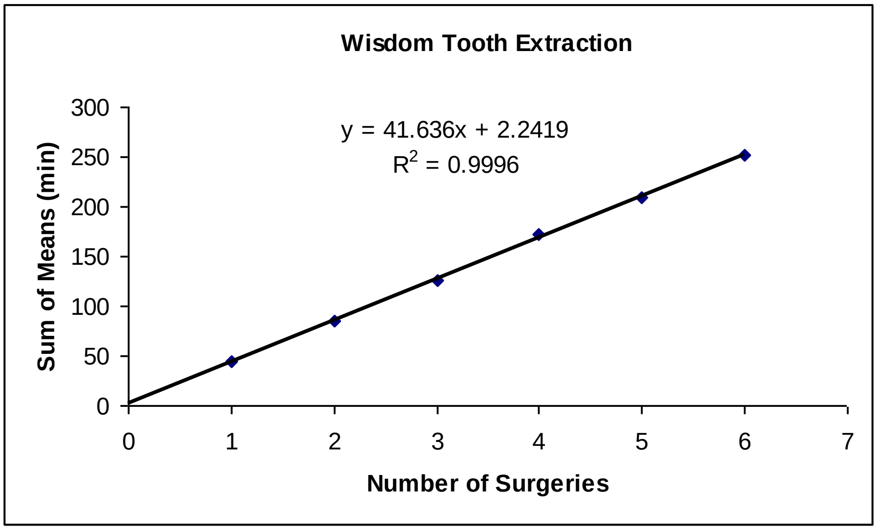
Paired t test were performed for the subsequent surgeries in the string. The findings are as follows:

Paired T Test	**T value**	**P value**
2nd and 3rd surgery	-0.17	0.870
2nd and 4th surgery	-0.57	0.576
3rd and 4th surgery	0.87	0.407

As expected, the difference in their average duration were not statistically significant because any subsequent surgeries after the first one only accounts for the actual operation itself without any set up time.

Sum of Average Duration

If the sum of average duration was graphed against blocks with different number of surgeries, the following is obtained:



The linear regression represents that the marginal increase in duration by adding an extra surgery to the block is constant. The slope indicates each additional surgery would take 41.67 minutes. The R^2 implies the 99.93% variability in data is accounted for by the linear regression.

The high R^2 suggests a linear regression is a good estimate of a block's duration with a series of identical operations. The above regression allows the OR manager to effectively predict given the number of surgery that a surgeon needs to perform.

Analysis of Other Wisdom Teeth Extractions

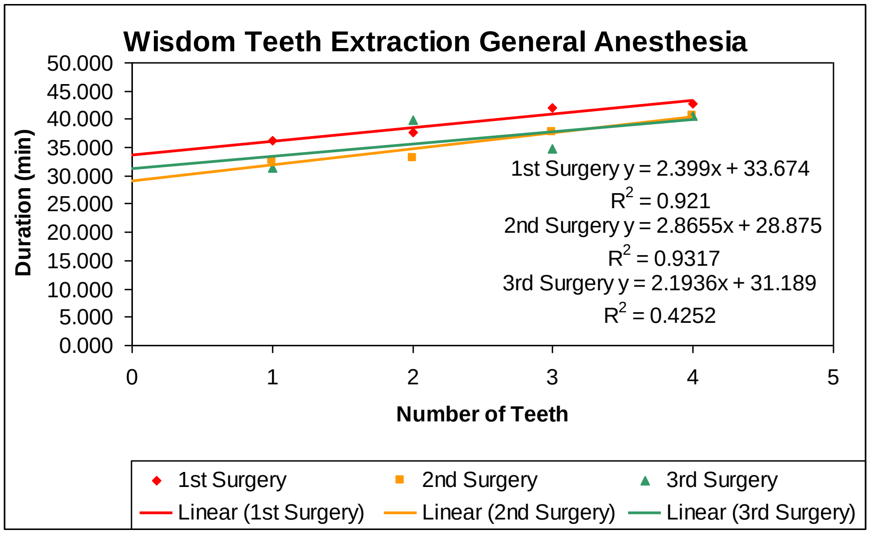
Because one, two, three or four wisdom tooth could be extracted, further analysis were completed to examine what was the additional time of pulling one tooth, as well as the set up time for *each* individual surgery. Thus, our model above

$$\text{Duration of a Block} = \text{Setup Time} + n * \text{Variable Time} + \varepsilon$$

becomes

$$\text{Duration} = \text{Setup Time} + n * (\text{setup time for individual surgery} + \text{number of teeth extracted} * \text{variable time}) + \varepsilon$$

By regressing the duration against the number of tooth that is extracted, we should be able to determine what was the set up time incurred for each wisdom tooth operation and the additional time to extract one tooth. Because the operation's set up time includes the amount of time to administer the anesthesia, all data examined in this section originates from wisdom teeth extractions completed with general anesthesia to eliminate any differences due to how anesthesia was administered.



In the above graph, the intercept can be taken to mean the set up time for each tooth extraction surgery since it is theoretically the duration of an operation in which zero teeth is removed. The slope indicates the additional time of removing one tooth. Overall, the first surgery, as shown by the red line, takes the most time, with a setup time of 34 minutes. The second surgery takes less time for setup, which is approximately 28.9 minutes. The reduction is due to the assembling of the surgical team and the preparation of the OR. However, based on reduction of slope, it takes slightly more time for the surgeon to remove an additional tooth. This might be possibly because the surgeon is getting tired at this point. The third surgery takes 31 minutes in set up time, which is longer than the second surgery, but the marginal time needed to remove an additional tooth seems to be shorter. Before making any conclusions based on the third surgery, one should note the low R^2 for the regression meaning that the regression does not fit the data very well and does not do a good job in explaining the change in variables.

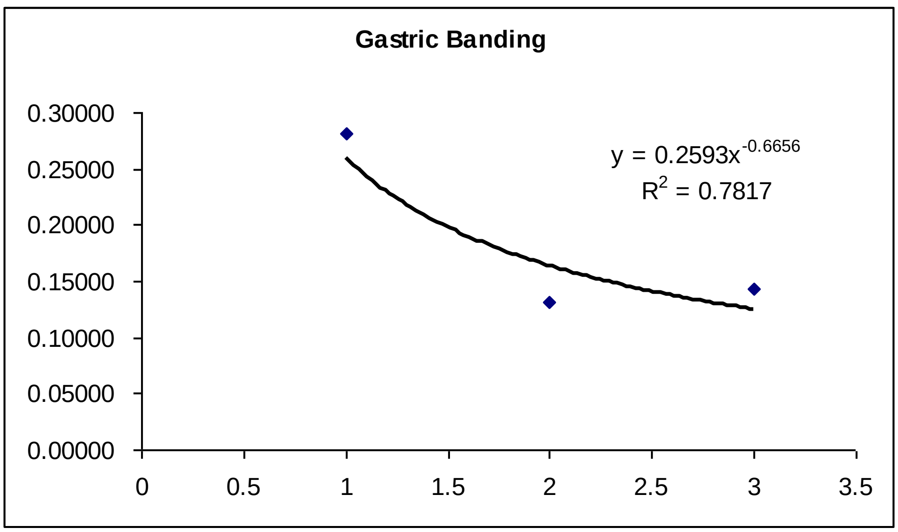
A more general conclusion from the graph above is that setup time is a large portion of the surgery itself. Therefore, much of the surgical time is devoted to preparation of the actual procedure, as least in the case of wisdom tooth extraction. Any efforts in reducing this setup time can drastically reduce surgical time and maximize OR’s utilization.

Surgery 2: Laparoscopic Gastric Banding

Laparoscopic gastric banding is one of the longer surgeries in our sample, taking an average of 1 hour and 42 minutes. This operation involves making a tiny incision and inserting a gastric banding device around the upper part of the stomach. This creates a small pouch in the upper part of the stomach thus limiting food intake. This operation allows obese patient to lose weight continually until they reach their goal.[18]

Coefficient of Variation

Given the longer duration of the procedure, the surgery can be completed in a series in few instances. The coefficients of variation for a block of n surgeries were as follows:



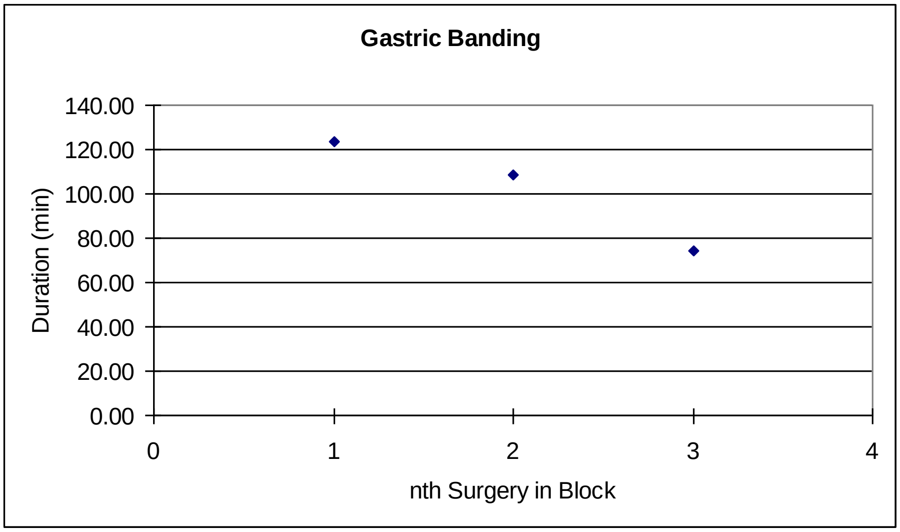
Between a block of a single surgery compared to block of two surgeries, the coefficient of variation decreased by half from 0.28160 to 0.13080. This again supports our hypothesis that the marginal decrease in coefficient of variation is much larger for the first few surgeries. However, for a block of 3 surgeries, the coefficient slightly increased. This might be because there were only 2 instances in which three gastric banding operations were performed in a series. The lack

[18] LAP-BAND: Laparoscopic Obesity Surgery | Procedure, 2005 , 4/17/2008 2008 <http://www.obesitylapbandsurgery.com/tecmain.html>.

of samples could have caused the anomaly.

Reduction in Set up Time

The relationship between the order of the operation within the block and its average duration is graphed as follows:



Based on the graph, there is a decrease in duration between the first and second surgery due to the set up time. However, there is also a decrease between the second and third surgery as well, which was not expected. Again, this might be because only 2 data points were used to calculate the average duration. Furthermore, one of the third surgeries lasted 45 minutes, the shortest of all gastric banding surgeries in the sample. Therefore, this might have been an outlier that influenced the mean duration for the 3^{rd} surgery.

A paired t test was performed to test whether the difference between the first and second surgery were statistically significant and the results are in Appendix B. In 2004, at least two gastric banding surgeries were scheduling one right after another in 43 instances. On average, the first surgery lasted for 123.45 minutes and the second surgery lasted 108.76 minutes. The paired t tests indicate a t value 3.51 and a p value of 0.001 which means the difference is statistically significant. Based on the difference between the duration of the first and second surgery, the setup time is estimated to be 14.69 minutes representing an 11.9% reduction for any subsequent surgeries.

Sum of Average Duration

Because a maximum of only 3 surgeries were completed in a string, the sum of average duration graphed against blocks with different number of surgeries results in only 2 points. Therefore, a graph would not be very informative in predicting the trend.

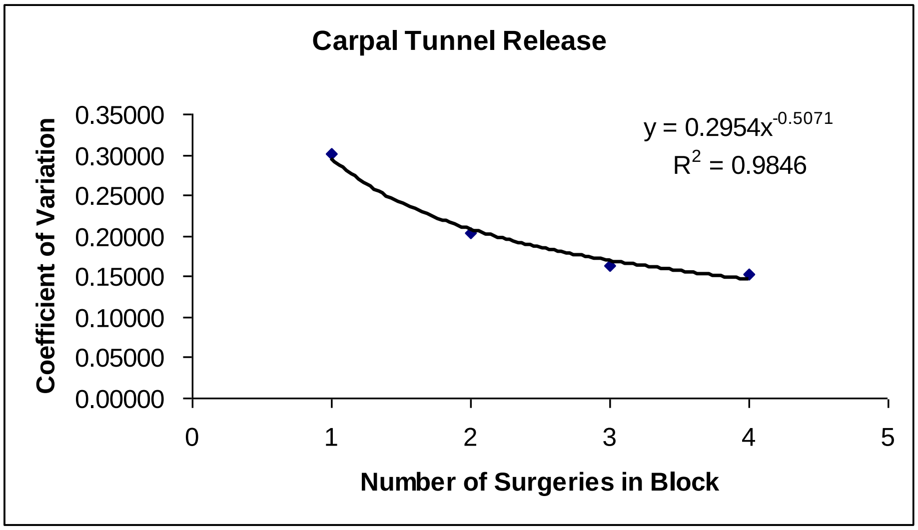
Surgery 3: Carpal Tunnel

Carpal tunnel release is a surgical procedure which treats pain caused by compression of the median nerve in the wrist. The surgery involves cutting the band of tissue surrounding the wrist to reduce the pressure to the median nerve. This procedure was traditionally completed by open release in which a 2” incision is made to access and cut the carpal ligament thus enlarging the carpal tunnel. Alternatively, endoscopic surgery allows for faster recovery and requires the surgeon to make two tiny incisions: one in the wrist and another in the palm. With a camera, the surgeon observes the tissue and cuts the carpal ligament under the skin.[19]

Coefficient of Variation

Averaging 34.4 minutes, the maximum number of carpal tunnel surgeries completed in a series was four. The coefficient of variation for surgery of n blocks were calculated where n ranges from 1 to 4.

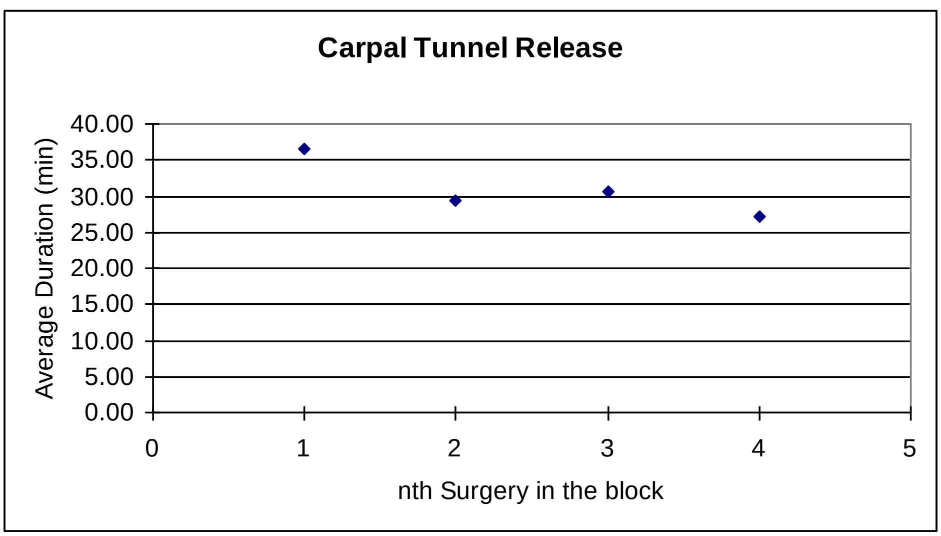
[19] Carpal Tunnel Syndrome Fact Sheet: National Institute of Neurological Disorders and Stroke (NINDS), , 4/23/2008 2008 <http://www.ninds.nih.gov/disorders/carpal_tunnel/detail_carpal_tunnel.htm#115153049>.



Again, the graph above illustrates that the coefficient of variation decreases in an exponential manner. This emphasizes the marginal reduction in variability decreases as the number of surgeries in the block increases.

Reduction in Set up Time

The average duration of a carpal tunnel release and its placement within the block are related as follows.



The first surgery took substantially more time than the rest of the surgeries. For the most part the subsequent surgeries fluctuate around 30 minutes.

In examining for reduction in setup time, paired t tests were performed comparing duration of the first surgery in the series to any subsequent surgeries in the series. Please see Appendix C. When carpal tunnel release was completed in a series, the first surgery takes on average 36.62 minutes while the second surgery takes on average 29.31. A paired t test comparing the two sets of duration results in a t value of 3.4 and a p value of 0.001. Therefore, the reduction of 7.31 minutes is concluded to be statistically significant. In fact, this means a 20% reduction in duration by scheduling a series of carpal tunnel release together. If the OR manager requires carpal tunnel surgeries to be completed in series, this can significantly reduce OR time.

Paired t test were performed comparing the duration of the first surgery and the third and fourth surgery of the sequence. We would expect that the duration would be statistically significant since the first surgery encounters set up time while the third and fourth one does not. The results were as follows:

Paired T Test	**Sample Size**	**T value**	**P value**
1^{st} and 3^{rd} surgery	21	1.34	0.195
1^{st} and 4^{th} surgery	7	0.53	0.617

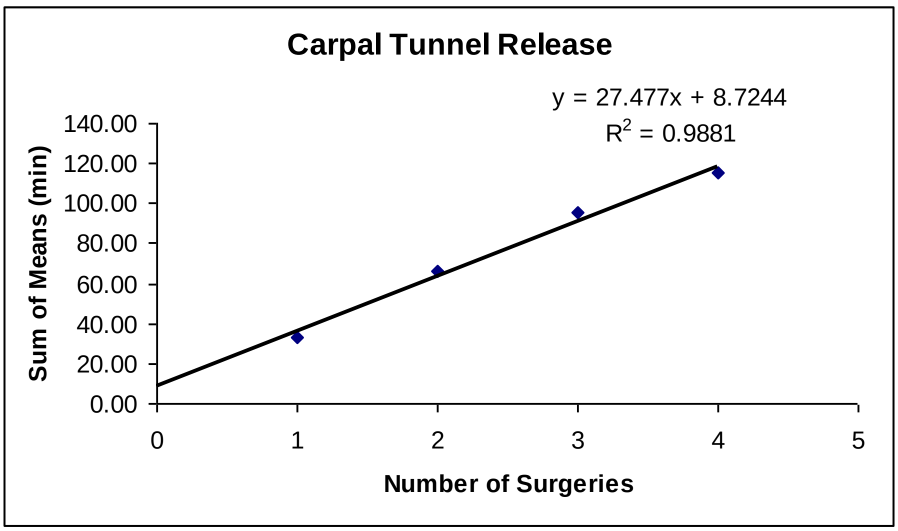
Contrarily to our expectations, the paired t tests indicate that the difference in duration between these pairs could have been due to chance and failed to prove the means were statistically significantly different from one another. However, this does not necessarily invalidate our model. The t test might have failed to show statistically significance perhaps because of the sample size. There were not enough instances in which surgeons completed three or four surgeries in sequence. Alternatively, it could mean that the surgeons were getting tired as they perform more and more surgeries. Therefore, any savings in avoiding set up time is washed out by increased procedure time.

As expected, paired t tests comparing duration of subsequent surgeries indicates their difference were not statistically significant. The results are summarized by the following table:

Paired T Test	**Sample Size**	**T value**	**P value**
2nd and 3rd surgery	21	-0.83	0.417
2nd and 4th surgery	7	0.57	0.587
3rd and 4th surgery	7	0.42	.689

Sum of Average Duration

Based on the given data, a block of n carpal tunnel release can be predicted by the following regression:



The number of surgeries within a block and the block's duration are related in a linear fashion. Therefore, if one additional surgery were added to a block with 4 surgeries, one would predict an additional 27 minute for the block. The high R^2 for this regression implies that 99% of the variability in the data is accounted for in the equation.

Comparing Different Surgeries

Coefficient of Variation

An interesting question to ask is whether the rate at which coefficient of variation is reduced depends on the procedure. The percent decrease in coefficient of variation between block with n surgeries and block of n+1 surgeries was calculated and the following was obtained:

Between Surgeries	**1 - 2**	**2 – 3**	**3 - 4**	**4 - 5**	**5 - 6**
Teeth Extraction	0.357793	0.182717	0.128084	0.287361	0.152736
Carpal Tunnel	0.325556	0.199834	0.060768		

Again, the rate of decrease was not calculated for gastric banding due to lack of data. Based on the table, it seems that the coefficient of variation decreases at similar rates for different procedures.

Reduction in Set Up Time

Based on our equation for the duration of 1 block, the y intercept of a graph comparing number of surgeries in the block and the expected duration of that block is the set up time for the block. Because gastric banding only had a maximum of 3 surgeries in sequence, the difference in duration between the first surgery and the second surgery in the sequence was assumed to be the set up time.

Operation	**1st Surgery Duration (min)**	**Set up Time (min)**	**% Reduction**
Extraction of 4 Wisdom Teeth	44.0127	2.2419	5.09%
Gastric Banding	123.447	14.692	11.90%
Carpal Tunnel	36.6216	8.7244	23.82%

Carpal tunnel enjoys the most reduction in time if grouped together in series by avoiding a 8.7 minute set up time for subsequent surgeries. Meanwhile, wisdom teeth extraction enjoys the least reduction in set up time. Based on these preliminary results, it seems that surgeries with more involved procedures enjoy a greater benefit if placed in series. However, more procedures should be examined before making this conclusion.

Conclusion

This research paper aims to use actual data from Virga Jesse Hospital to justify the benefits of grouping same surgeries in a series. There are three main reasons to group surgeries together 1.

to reduce coefficient of variation which helps better predict duration of 1 block and minimize natural variability of surgery 2. to reduce set up time and 3. to reduce OR idle time. The first two reasons were quantitatively examined, while the third reason could be fulfilled by a model as described above.

As the number of surgeries increase in one block, the coefficient of variation decreases. This implies that one can predict the duration of a block with more surgeries with more accuracy compared to the block with less surgeries. Furthermore, the coefficient of variation decreases in an exponential manner, meaning the marginal reduction in coefficient of variation is greatest for the first few surgeries. All surgeries studied in this paper indicate an exponential decrease in coefficient of variation as the number of surgeries in the block increases.

Grouping surgeries together can also reduce block duration by avoiding set up time. In a single block, set up time is only incurred in the first surgery where a surgical team of surgeons, anesthesiologists, and nurses has to be gathered. However, with a team in place, any remaining surgeries incur the same time. The duration of a block can be modeled as

$$\text{Duration of a Block} = \text{Setup Time} + n * \text{Variable Time} + \varepsilon$$

where n is the number of surgeries in a block. Based on this model, the duration of a block and the number of surgeries are linearly related. In fact, from empirical data, one can predict what is the impact of the block's duration on adding an additional surgery to the block. If this regression was ran on every procedure, an OR manager can efficiency determine the length of the block for a surgeon to complete n number of a particular operation.

Applications

Based on the above analysis, there is certainly a benefit to grouping a series of similar surgeries together. Not only does it lower OR utilization by reducing block time, it also makes block time more predictable. Managing the length and variability are two of OR manager's main concerns. However, the marginal benefits decreases as the number of surgeries in a block increases. Based on the analysis completed, it is advisable for an OR manager to place approximately 2 to 3 surgeries in a series.

By modeling healthcare situations, there will be a systematic way to solve various scheduling problems. These optimal solutions from the models will not only lower the healthcare cost, by minimizing idle time in operation room for example, they will also increase the quality of healthcare by lowering the waiting time for patients. Block method seems to provide an efficient method to reduce expected duration and variability in duration of a block. Therefore, future optimization models can apply this method in arranging OR surgeries to satisfy the needs of surgeons, nurses, anesthesiologists, and patients.

Once implemented, these models can significantly improve efficiency of hospital operations, cutting their fixed costs by lowering idle time in their capital equipments and increasing patient satisfaction by decreasing waiting time. Operation research application to healthcare settings will take us one step closer to control the rising healthcare cost and making healthcare more affordable.

Appendix A: Wisdom Teeth Extraction Paired T Tests

Paired T-Test and CI: First Surgery wi, Second Surgery.D

Paired T for First Surgery within Set.Durati - Second Surgery.Duration(min)

	N	Mean	StDev	SE Mean
First Surgery wi	137	44.0127	16.4329	1.4040
Second Surgery.D	137	40.8331	11.1345	0.9513
Difference	137	3.17964	18.48371	1.57917

95% CI for mean difference: (0.05673, 6.30254)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.01 P-Value = 0.046

Paired T-Test and CI: First Surgery wi, Third Surgery.Du

Paired T for First Surgery within Set.Durati - Third Surgery.Duration(min)

	N	Mean	StDev	SE Mean
First Surgery wi	62	45.9268	16.7104	2.1222
Third Surgery.Du	62	39.7026	13.3027	1.6894
Difference	62	6.22419	18.04318	2.29149

95% CI for mean difference: (1.64208, 10.80630)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.72 P-Value = 0.009

Results for: Worksheet 4

Paired T-Test and CI: Second Surgery.Duration(min), Third Surgery.Duration(min)

Paired T for Second Surgery.Duration(min) - Third Surgery.Duration(min)

	N	Mean	StDev	SE Mean
Second Surgery.D	12	42.2492	11.7068	3.3795
Third Surgery.Du	12	43.3842	19.2461	5.5559
Difference	12	-1.13500	23.50845	6.78631

95% CI for mean difference: (-16.07156, 13.80156)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.17 P-Value = 0.870

Paired T-Test and CI: First Surgery wi, Fourth Surgery.D

Paired T for First Surgery within Set.Durati - Fourth Surgery.Duration(min)

	N	Mean	StDev	SE Mean
First Surgery wi	13	49.1462	15.0205	4.1659
Fourth Surgery.D	13	40.3408	10.4794	2.9065
Difference	13	8.80538	13.45080	3.73058

95% CI for mean difference: (0.67715, 16.93362)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.36 P-Value = 0.036

Paired T-Test and CI: Second Surgery.D, Fourth Surgery.D

Paired T for Second Surgery.Duration(min) - Fourth Surgery.Duration(min)

	N	Mean	StDev	SE Mean
Second Surgery.D	13	38.5846	10.2968	2.8558
Fourth Surgery.D	13	41.1538	10.8078	2.9975
Difference	13	-2.56923	16.11786	4.47029

95% CI for mean difference: (-12.30915, 7.17069)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.57 P-Value = 0.576

Paired T-Test and CI: Third Surgery.Du, Fourth Surgery.D

Paired T for Third Surgery.Duration(min) - Fourth Surgery.Duration(min)_1

	N	Mean	StDev	SE Mean
Third Surgery.Du	10	45.1440	20.5743	6.5062
Fourth Surgery.D	10	40.7430	11.0494	3.4941
Difference	10	4.40100	15.99599	5.05838

95% CI for mean difference: (-7.04184, 15.84384)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.87 P-Value = 0.407

Appendix B: Gastric Banding Paired T Tests

Paired T-Test and CI: First Surgery Wi, Second Surgery.D

Paired T for First Surgery Within Series.Dur - Second Surgery.Duration(min)

	N	Mean	StDev	SE Mean
First Surgery Wi	43	123.447	26.429	4.030
Second Surgery.D	43	108.755	14.967	2.282
Difference	43	14.6921	27.4588	4.1874

95% CI for mean difference: (6.2415, 23.1427)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.51 P-Value = 0.001

Paired T-Test and CI: First Surgery Wi, Third Surgery.Du

Paired T for First Surgery Within Series.Dur - Third Surgery.Duration(min)

	N	Mean	StDev	SE Mean
First Surgery Wi	2	141.490	14.863	10.510
Third Surgery.Du	2	74.285	41.415	29.285
Difference	2	67.2050	26.5519	18.7750

95% CI for mean difference: (-171.3540, 305.7640)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.58 P-Value = 0.173

Paired T-Test and CI: Second Surgery.Duration(min), Third Surgery.Duration(min)

Paired T for Second Surgery.Duration(min) - Third Surgery.Duration(min)

	N	Mean	StDev	SE Mean
Second Surgery.D	2	120.000	19.799	14.000
Third Surgery.Du	2	74.285	41.415	29.285
Difference	2	45.7150	61.2142	43.2850

95% CI for mean difference: (-504.2731, 595.7031)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.06 P-Value = 0.483

Appendix C: Carpal Tunnel Paired T Tests

Paired T-Test and CI: 1st Duration(min), 2nd Duration(min)

```
Paired T for 1st Duration(min) - 2nd Duration(min)

                   N     Mean     StDev  SE Mean
1st Duration(min  44  36.6216   11.4205   1.7217
2nd Duration(min  44  29.3136    7.0018   1.0556
Difference        44  7.30795  14.26755  2.15091


95% CI for mean difference: (2.97022, 11.64569)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.40  P-Value = 0.001
```

Paired T-Test and CI: 1st Surgery.Duration(min), 3rd Surgery.Duration(min)

```
Paired T for 1st Surgery.Duration(min) - 3rd Surgery.Duration(min)

                   N     Mean     StDev  SE Mean
1st Surgery.Dura  21  34.9081    9.6565   2.1072
3rd Surgery.Dura  21  30.8619    9.8919   2.1586
Difference        21  4.04619  13.83835  3.01977


95% CI for mean difference: (-2.25295, 10.34533)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.34  P-Value = 0.195
```

Paired T-Test and CI: 2nd Surgery.Duration(min), 3rd Surgery.Duration(min)

```
Paired T for 2nd Surgery.Duration(min) - 3rd Surgery.Duration(min)

                   N      Mean     StDev  SE Mean
2nd Surgery.Dura  21   28.6667    8.0208   1.7503
3rd Surgery.Dura  21   30.8619    9.8919   2.1586
Difference        21  -2.19524  12.12850  2.64666


95% CI for mean difference: (-7.71606, 3.32559)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.83  P-Value = 0.417
```

Paired T-Test and CI: 1st Surgery.Duration(min), 4th Surgery.Duration(min)

```
Paired T for 1st Surgery.Duration(min) - 4th Surgery.Duration(min)

                  N     Mean     StDev  SE Mean
1st Surgery.Dura  7  29.2857   10.1770   3.8465
4th Surgery.Dura  7  27.1429    4.8795   1.8443
Difference        7  2.14286  10.74598  4.06160


95% CI for mean difference: (-7.79552, 12.08124)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.53  P-Value = 0.617
```

Paired T-Test and CI: 2nd Surgery.Duration(min), 4th Surgery.Duration(min)

```
Paired T for 2nd Surgery.Duration(min) - 4th Surgery.Duration(min)
```

	N	Mean	StDev	SE Mean
2nd Surgery.Dura	7	30.0000	10.8012	4.0825
4th Surgery.Dura	7	27.1429	4.8795	1.8443
Difference	7	2.85714	13.18368	4.98296

95% CI for mean difference: (-9.33573, 15.05002)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.57 P-Value = 0.587

Paired T-Test and CI: 3rd Surgery.Duration(min), 4th Surgery.Duration(min)_1

Paired T for 3rd Surgery.Duration(min) - 4th Surgery.Duration(min)_1

	N	Mean	StDev	SE Mean
3rd Surgery.Dura	7	28.5714	8.0178	3.0305
4th Surgery.Dura	7	27.1429	4.8795	1.8443
Difference	7	1.42857	8.99735	3.40068

95% CI for mean difference: (-6.89259, 9.74974)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.42 P-Value = 0.689

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