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Operating room utilization and turnover behavioral study

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OPERATING ROOM UTILIZATION AND TURNOVER BEHAVIORAL STUDY

by

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DISSERTATION

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DEDICATION

I dedicate my dissertation to my beloved mother, Liping Xu, whose continuous support and words of encouragement, and whose positive life attitude and unbelievable strength inspire me to work to my best abilities.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

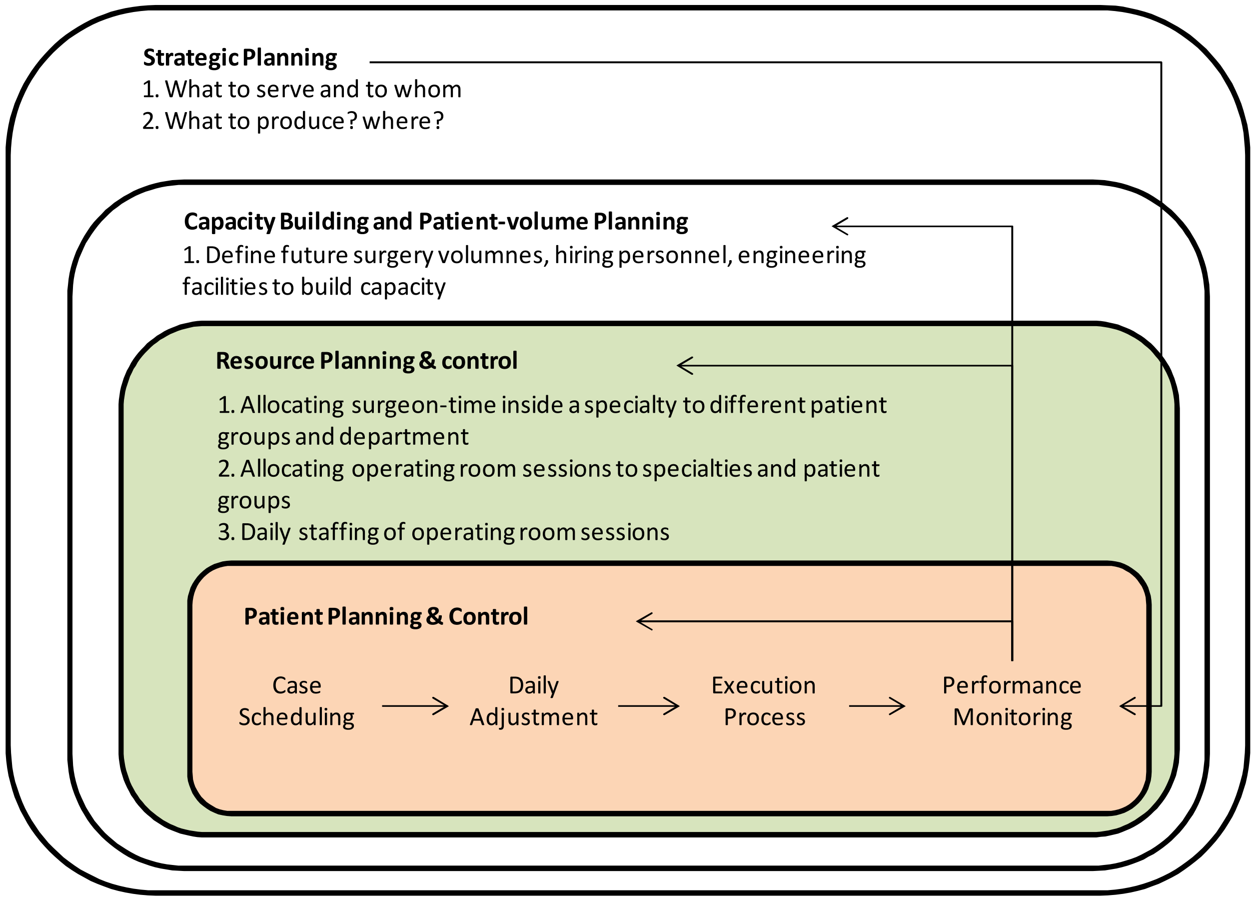
The United States national health expenditures (NHE) consumed a large portion of gross domestic product (GDP). In 2009, the NHE grew to $2.5 trillion and accounted for 17.6% of GDP. This number has been projected to reach 4.6 trillion and 19.8% of GDP in 2020 (CMS 2010). The expensive health care costs impose high pressure on the economy and limit the access, fairness, and quality of care. The striking numbers raise the need to improve the efficiency of health care. For any health care systems, the key area to focus in order to maintain the costs level is operating room (OR). According to some study, the operating rooms represent more than 40% of a hospital's total revenue (HFMA 2005). In addition, Macario et al. (1995) pointed out that 33% of inpatients costs was from OR. Thus, operating room represents both the highest revenue and highest costs care unit.

To keep track of OR's performance, there have been several defined measures, including staffing costs, daily OR start-time tardiness, case cancellation rate, turnover time, utilization and so on (Macario 2006). Many healthcare organizations run under a fixed budget (e.g. VA system and healthcare systems in Europe). For such organizations, utilization of care resources needs to be maximized to maintain good cost efficiency. The majority of OR costs are fixed costs, such as buildings, equipment, and labors (Macario 2010). To optimize the cost efficiency of OR, the OR management needs to focus on increasing the usage of the fixed-cost related resources. For example, when OR is staffed for 8 hrs, OR management would like to schedule cases to fully utilize OR staff without incurring too much sunk costs due to the un-utilized OR time. Or, for another example, when there are 30 ORs available for surgery, OR management wants to use as many rooms to meet the patients' surgery demand instead of having many unused ORs. The OR utilization can potentially be impacted by many different factors, such as OR availability and cases scheduling policies. An identification of the key factors that influence the OR utilization assists the OR management to focus on the most influential factors for utilization improvement, from where OR management and analysts can develop efficient interventions to improve the performances.

1.2 Background

The operating room management, based on the timeline of planning, can be divided into three stages, i.e. strategic, tactical, and operational. Based on the framework set by Vissers et al. framework for planning of healthcare organizations (Vissers et al. 2001), a hierarchy for operating room planning was developed (Peltokorpi et al. 2009). As shown in Figure 1 ((Peltokorpi et al.(2009)), the first level in the hierarchy is for strategic planning. During this phase, the management decides on what type of surgeries to be done and what kind of patients to be treated in house vs. sending to other facilities. The typical decisions include the surgical specialties, surgeon expertise to be included in the facility, etc. For example, the management decides to open a new surgery center for orthopedic patients or set a budget level for each specialty. This type of decision is effective for years, and is not changed on a regular basis. Once the strategic decisions have been made, the planning proceeds to the next level, where the management estimates the demand of surgery from the patients, and determine how the OR capacity meets the demand. The decisions at this level can be the number of ORs to open or the additional block hours to be allocated to surgeons/specialties. Such decisions are made on a yearly basis. At the third level, the available OR capacity is separated to each specialty based on the demand and cost efficiency. The allocation of OR time usually takes place every 2-3 months in U.S. healthcare systems to adjust to the dynamics of demand.

Figure 1: A hierarchy for operating unit production planning and control



The allocated OR time is the interval of OR time with a specified start and end time on a specified day of the week that is assigned by the facility to a service for scheduling cases (Dexter et al. 2001; McIntosh et al. 2006). For example, on Monday, the current allocation of OR time to General in the studied facility is from 8 AM to 4 PM. The allocation of OR time is determined in such as way that the OR cost efficiency is maximized by minimizing the inefficiency of use of OR time. The inefficiency of use of OR time is calculated as the sum of cost of under-utilized OR time (the positive difference between the allocated OR time and OR workload) and cost of over-utilized OR time (the positive difference between OR workload and allocated OR time) (Strum et al. 1999, Dexter et al. 2001; McIntosh et al. 2006). The staff planning for each OR and specialty also lies in this decision level. Finally, cases are scheduled, rearranged or adjusted, and performed (Figure 1). Once the cases are completed, OR management can track the performances, which in turn, feed back to the planning of OR.

All levels of decisions have impacts on the performances of ORs. To investigate the impacts of management decisions on OR, Peltokorpi tested 11 hypothesis that related strategic and operational decisions to the productivity of OR (Peltokorpi 2011). They collected data from 15 hospitals in Finland, German, and USA. It was concluded that the case mix, representing the complexity level of case and proportion of urgent cases, production strategy, which included the size of OR and number of specialties, multi-skilled and flexible nurses and parallel processes were key factors that affected the raw OR utilization. Wachtel and Dexter (Wachtel and Dexter 2008) studied the OR utilization problem from the tactical decision level and pointed out that the expansion of OR capacity should not be based on utilization performance of subspecialties but the contribution margin per OR hour, the potential for growth and need for limited resources. In addition, the complexity of the OR suite and whether the surgery lists overran were the identified strong predictor of OR utilization (Faiz et al. 2008).

Traditionally, the OR utilization was defined as the ratio of how many hours the OR was in use and the allocated OR time, regardless of if the use of OR was outside of allocated OR time. Later, people decided the OR utilization should only consider the usage of OR within the allocated OR time and any over-utilized OR time is not counted towards the numerator. Thus, if the last case ends one hour beyond the allocated OR time, the one-hour over-utilized OR time is not included in the numerator of the utilization calcualtion formula. The problem with the traditional definition is that from cost perspective that 10 hours used in allocated OR time is not the same as 10 hours used outside of allocated OR hours. On observation of this, Strum et al. brought up the concept of under-utilized OR time and over-utilized OR time (Strum et al. 1999). In the cost model developed in the paper, the optimum allocated OR time depends on the relative costs of under- and over-utilized OR time. The optimum OR allocation was the one that ensures the OR workload can be completed within the allocated OR time with a probability that equals the ratio of the unit cost of over-utilized OR time and sum of the unit cost of under- and over-utilized OR time. Based on this pioneer work, Dexter et al. (Dexter et al. 2001) explored the cost savings that can be achieved by re-allocating OR time. They compared the inefficiency of use of OR time of different combinations of number of ORs and allocated OR time. They concluded that their studied facility could have been saved 3% to 43% of the costs by pursuing optimum OR allocation.

Compared to the operational decisions, the strategic and tactical decisions are relatively static. The OR management generally do not change such decisions on a frequent basis. Thus, operational decisions provide the management with more flexibility to achieve a desirable performance level where management can adjust factors such as case schedules or turnover activities in a short time frame. With respect to operational decisions, researchers came up with solutions on how to schedule cases (Dexter et al. 1999; Dexter et al. 2002),how to release allocated OR time (Dexter et al. 2003, Dexter and Macario 2004), and how to make decisions on the day of surgery (Dexter and Traub 2000; Dexter et al. 2004) to maximize OR cost efficiency. In the review paper (McIntosh et al. 2006), several interventions were studied with respect to their impacts on the efficiency of use of OR time, including turnovers and first-case delays. It was concluded that interventions to reduce either of them will only result in small reduction in OR labor costs, but the degree of reduction is highly related with allocated OR time. Dexter and Epstein (Dexter and Epstein 2009) used the same methods to propose a screening mechanism to quantify the potential savings from the reduction of tardiness at the beginning of the workday for ORs with workload greater than 8 hours (i.e. with over-utilized OR Time). By using this methods, the OR team can evaluate the economic impacts of improving on-time performance of first case and determine if focusing on starting workday on-time is the right decision economically or to practice other interventions. According to the restuls, the first-case delays were not a strong indicator to the performance on OR cost efficiency.

Many current research in OR management at operational level focuses on the efficiency of use of OR time and OR utilization. However, the efficiency of use of OR time is not equivalent to OR utilization performance. For example, given the cost ratio of under-utilized OR time to over-utilized OR time is 1 to 2, then for an OR allocated with 8 hours (e.g. 8 AM to 4PM), a day closes at 2PM (i.e. two under-utilized OR hours) is equivalent to a day close at 5PM (i.e. one over-utilized OR hour). The utilization of the first OR would be likely to be smaller than it of the second OR. Because the second OR has over-utilized OR time, it could be that the OR worload within the allocated OR time for the second OR is more than the OR workload in the first OR. From the perspective of utilization, OR manager would prefer the second OR given no compromise in the efficiency of use of OR time and quality of care. For another example, if there is a one-hour tardiness of the first case in the room closing at 2PM, then it does not impact the overall utilization as the delay postpones the OR closing at 3PM but still all cases can be done within the allocated OR time. On the other hand, if the tardiness is observed for the second OR, then it matters as the tardiness may cause some OR workload that could have otherwise been completed within the allocated OR time become over-utilized OR time; thus, decreasing both the utilization and efficiency of use of OR time. It ususally is the goal of the OR management to have effective plans to balance the performance between the OR utilizaiton and the efficiency of use of OR time.

1.3 Research Motivations and Objectives

In current OR management studies, one of the key assumptions is that surgeons have open access to the OR and the allocated OR time can be adjusted on a regular basis to achieve an optimum efficiency of use of OR time. While this assumption is held for many healthcare systems, such flexibility does not always present in healthcare systems, especially those in Europe. Thus, for those OR facilities, given a fixed allocated OR time, to achieve a good OR utilization level while control the over-utilized OR time is important.

Many factors could potentially influence the OR utilization, such as staffing, scheduling, or turnover times; however, all the factors do not exhibit the same level of influences on the utilizations. For more efficient OR operations, the identification of the key factors that influence the OR utilization assists the OR management to focus on the most influential factors for utilization improvement, from where OR management and analysts can develop efficient interventions to improve the performances. Thus, in the first phase of our study, we intended to distinguish the most important factors from the rest.

Once the key factors that impact the OR utilization have been filtered out, approaches that target on the most important factors need to be designed to provide OR management with decision-making tools that the OR manager can use to evaluate the rationality of current OR practice and policies. As a sequence, the second goal of our study was to develop effective interventions that OR managers can use to tackle the problems with the key factors.

Tardiness of case start time is frequently observed in OR, especially towards the end of the workday. The tardiness makes patients unsatisfactory and prevents OR achieving better efficiency of use of OR time by causing over-utilized OR time and cancellations. There are multiple reasons for such tardiness, some of the reasons are more critical to others with respect to performance in over-utilized OR time and cancellations. If the prioritization of these critical reasons can be accomplished, then the OR manager can take proactive approach in advance to prevent them from causing undesirable outcomes. We proposed an approach to facilitate the identification of critical reasons for tardiness of case start.

One of the main differences between healthcare systems and manufacturing systems is that human factor plays critical part in routine activities rather than machines. The complexity of human behaviors and psychological conceptions impact the way care givers provide care to patients (Reason 1995, Institute of Medicin 1999). The success of implementation of tools new policies or new processes is subject to people's response to the new regulations. If there is psychological bias in OR staff's behavior, tools and policies need to be implemented in order to prevent bias from causing suboptimal performance level of OR. As a result, we explored the OR staff's behavior pattern during turnover times to obtain insights into how they perform work given different workload and made recommendations regarding how to correct the bias of OR staff.

In summary the primary objectives of our dissertations are:

- Identify the most influential factors on OR utilization
- Develop approach to assist OR managers making decisions on identified key factors
- Develop methodology to prioritize reasons for tardiness of case start in order to reduce over-utilized OR time and cancellations
- Explore the OR staff's behavior due to their psychological bias, if any.

1.4 Organization of Dissertation

In Chapter 2, we focus on identifying the most important factors that affect the OR utilization. We first review current studies relate to OR utilization, then a few factors are identified as candidates that highly correlate to OR utilization. We used the data collected from a government healthcare organization to demonstrate the methods for filtering out from all the identified factors the most influential ones that impact the OR utilization. Results from different approaches were compared to each other and the best model was identified.

Based on the results from Chapter 2, we propose a new methodology in Chapter 3 for surgical case scheduling where the goal is to meet the OR utilizatin and the over-utilized OR time targets set by OR management. A background and literature review section is given at the beginning of the chapter to provide readers with introduction of this topic and identify the gaps in the literature. In next subsection, we adopt and discuss a new parametric distribution to estimate the percentiles of the distribution of the duration of surgery lists with multiple cases. One-year of surgery lists are used to compare the accuracy between our approach with currently used student t-distribution in identify different percentile values. Based on the reliable percentiles estimates, OR management can make changes to the schedule to control the risks associated with both under- and over-utilized OR time.

Chapter 4 discusses about a simulation approach that the OR management can use to tackle tardiness at the beginning of each case. The tardiness at the beginning of cases increase the amount of both under- and over-utilized OR time. Such tardiness causes wastes in allocated OR capacity. We propose an approach that has the ability to iteratively prioritize the delay risks associated with each delay reason for each case. A case study is presented at the end to illustrate the use of the simulation model as well as its limitations and benefits. Given such information, the OR management has the ability to identify key tardiness for any given schedule and take proactive approach to prevent adverse outcomes from the delays.

In Chapter 5, we tested the hypothesis if OR staff work faster on days with more OR workload is expected than days with fewer OR workload by constructing a structural equation model that consider the interactions and correlations among different schedule variables. This analysis complements current studies in phychological bias of OR staff, proves the commonness of defined bias, which the OR management can accomendate in new policy and decision making.

In the last chapter, we summarizes the contributions and findings of our research. We also suggest scope of future research for OR management.

CHAPTER 2 FACTORS INFLUENCING OR UTILIZATION

2.1 Introduction and Literature Review

In the previous chapter, we described the background of OR management and emphasized the importance of OR utilization. The OR management prefers a high OR utilization as it generally is an indicator that the expensive OR resources are providing patient care. There are two ways to calculate the OR utilization. One is the raw utilization, and the other one is the adjusted utilization. The raw utilization equals the total actual case duration of the OR divided by its allocated OR time. The adjusted utilization equals the sum of total case duration of the OR and turnover times (i.e. OR workload) divided by its allocated OR time (Abouleish et al. 2003, Dexter et al. 2003). The adjusted utilization gives credits to OR staff for housekeeping and room set ups (turnovers). Although turnover times are non-value added, they are necessary preparation for surgeries during which OR staff fulfill their job duties. Thus, the adjusted utilization accounts for all the time that OR staff work in OR. Peltokorpi (Peltokorpi 2011) looked at the utilization problem from a rather high-level angle, such as the complexity level of cases, the size of OR and the number of specialties. These factors usually do not/cannot vary on a regular basis for a given facility. For example, the number of ORs or the number of specialties cannot be changed randomly. It requires a lot of planning in advance, like the extra space for the new OR, the capacity planning of the new specialties and the hiring of new surgeons and staff. Besides, the good performance of OR is not the only goal of strategic planning of OR. It also emphasizes on providing values to the community and to the needs of patients. Some hospitals, especially no-profit hospitals in the U.S. perform surgeries that are of small or even negative contribution margins to cure patients of particular needs (OR Manager 2000, Moody's Investor Services 2000). Thus, given preceding relatively static strategic and tactical decisions, the OR management should optimize the OR utilization by making good operational decisions.

With respect to the OR utilization study, there are several preceeding literature that studied the problem at operational level. There is a significant amount of papers on how to schedule cases to meet performance targets. Arnaout and Kulbashian (Arnaout and Kulbashian 2008) tested the impacts of three heuristic algorithms (LEP, SEP, and LEPST) of sequencing of case on the OR utilization. The inclusion and exclusion of turnover time in scheduling impacts the optimum sequence. Jebali et al. (Jebali et al. 2006) established a optimization model to assign operations to different rooms and sequence cases based on two strategies. The model minimizes costs of patient waiting and overtime. Lamiri et al. (Lamiri et al. 2008) used column generation approach to minimize the costs associated with underutilized and overutilized costs. Ozkarahan (Ozkarahan 2000) used this approach to assign cases to make sure that any specialty that with allocated OR time has privilege to its own block hours, each OR is used to optimum level. By using a hierarchical goal programming to solve the surgical operations scheduling problem in case of multiple operating rooms, multiple surgeon groups, and conflicting goals in an acceptable solution time, Ogulata and Erol (Ogulate and Erol 2003) optimized OR performance in three phases, aiming at balancing patients selection from different categories to increase utilization, balancing distribution of operations among surgeon groups while taking into account of priority and arrival time. There are other research on the OR utilization using simulation and statistical analysis. For example, Tyler et al. (Tyler et al. 2003) examined the mean case duration, the case duration variability, and turnover times on achieving optimum utilization by using simulation. A higher variability of case duration results in a lower utilization. Turnover times do not affect utilization but number of cases can be done. Dexter et al. (Dexter et al. 1999) identified factors influencing variability of day-to-day utilization. Structural equation modeling was using to establish relation among the statistics and related random effects, after which Monte Carlo simulation were applied to analyze the impacts of the elimination of the random terms, combination of terms and allocated OR time. The results from the analysis indicated that selecting the days to perform procedure is important in the reduction of variability. By using simulation, Steins et al. (Steins et al. 2010) evaluated different planning and scheduling techniques to improve the OR utilization in a Sweden hospital. Through the experiments, the OR utilization was improved through re-allocation of OR resources to fit demand, redesign workflow of inpatients and outpatients, and different staff scheduling.

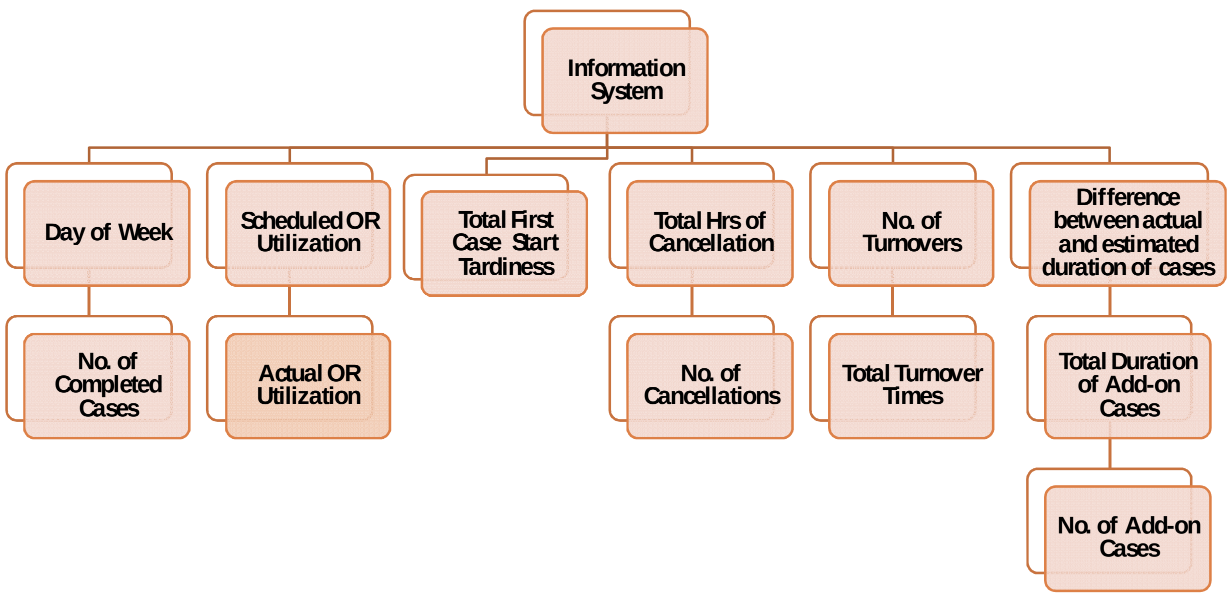
In NHS, OR utilization has been the principle measure of their OR performance (Cranfield and Soljak 1989, The Modernisation Agency 2002, Faiz et al. 2008), as it reflects the surgical volumne successfully admitted and operated on surgery lists of elective cases. For facilities that have an unsatisfactory OR utilization level, the importance of OR utilization usually coincides with the efficiency of use of OR time as the inefficiency is primarily caused by the wasted unused OR capacity rather than over-utilized OR time and the improvement in utilization always results in a better OR cost efficiency for such facilities. The prior studies focused on the impacts of process redesign or specific factors on the utilization and evaluated the effectiveness of interventions. There are multiple operational factors on the day of surgery that potentially can influence the OR utilization. The impact level of each factor is different. Some factors are more important than the other. Thus, the interventions targeting the most important factors are more effective than resolving the problems with less important factors. In this chapter, we ranked the importance of identified operational factors. Based on the conclusions from this chapter, the following chapters study particular aspects that are important to the OR utilization performance.

2.2 Method

2.2.1 Data

Two data sources were used to retrieve the data we needed. One was from the surgical package within the VISTA information system in the John D. Dingell VA Medical Center. The other was the CPRS, which we used to gather the duration of cancelled cases. The data we collected was from May 1, 2009 to September 30, 2009 (exclude weekends, May 25, 2009 for the Memorial Day, July 3, 2009 for the Independence Day, and September 7, 2009 for the Labor day). On August 26, 2009, the OR suites were closed due to water leakage. There were two working days did not have complete schedule information (July 1, 2009 and July 2, 2009), so we also excluded these two days. Thus, in total, we had 103-day data for analysis. We captured the following data fields for each case: surgery date, OR, specialty, the time the patient entered the OR, the time patient left the OR, scheduled case start and end time, cancellation status, and case type (i.e. elective, emergent, add-on, and urgent). From the raw data, we calculated 12 variables for each day as shown in Figure 2:

Figure 2: Data structure of our study



1. Day of week. The block schedule of each day of week was different, and the OR utilizations of different specialties were not necessarily the same (Wachtel and Dexter 2008). Thus, for each day of week, the actual OR utilization was expected to be different.

2. Scheduled OR utilization. It was the baseline utilization. If the scheduled OR utilization was high, then the actual OR utilization was expected to be high as well. The

scheduled OR utilization equals the scheduled OR workload within the allocated OR time divided by the allocated OR time.

3. Total first case start tardiness. If the day started late, then there was un-utilized OR time in the allocated OR time at the beginning of workday, which would reduce the actual OR utilization. This term equals the time difference between the time the patient entered the OR of the first cases of the day and the scheduled case start time. If patient entered the OR before the scheduled case start time, then the term was considered zero (Dexter and Wachtel 2009, Wachtel and Dexter 2009).

4. Total hours of cancellation and number of cancellations: these two factors acted negatively on the schedule by reducing the scheduled OR utilization.

5. Total hours of add-on cases and number of add-on cases: They were the opposite of cancellations. If we added more cases, then the allocated OR time was more likely to be filled up.

6. Differences between actual and estimated duration of cases: If the actual duration of cases was less than the estimated duration, then there was unfilled space in allocated OR time, causing OR utilization to decrease. On the opposite, if the actual duration was greater than the estimated duration, then the close time of OR would be delayed to increase the OR workload within the allocated OR time and the actual OR utilization.

7. Number of turnovers and total turnover times: as we calculated the adjusted utilization in our study, if we had more turnovers or the turnovers take long time, then the adjusted utilization was expected to increase. From this point on, if we did not specify, then we used utilization to simplify adjusted utilization. Whenever the turnover times were greater than 90 minutes, we rounded down the turnover times to 90 minutes. Longer turnovers might due to gaps in schedule (i.e. non-sequential cases) (Dexter et al. 2005).

8. Number of completed cases. The more cases were scheduled, the more the allocated OR time was filled. When we had more cases, the case duration of each case was

less, meaning the complexity of procedures was not high; thus, the prediction of case duration would be more accurate. Consequently, it was more likely to fill up the allocated OR time by scheduling many short cases.

9. Actual OR utilization. This is the dependent variable of our model. It depended on the above 11 independent variables. It equals the actual OR workload within the allocated OR time divided by the allocated OR time.

After the identification of factors that correlate with OR utilization, the most important factors needed to be selected from the set of factors. We applied feature selection approaches to achieve this objective. The following two subsections discuss the methods we used.

2.2.2 Stepwise Regression

Stepwise regression is one of the widely used methods to identify important factors (Montgomery et al. 2001, Myers 1990) relate to the response variable. This method first fits all possible one-variable models (i.e. the regression model with only one factor variable). The factor with the largest t-statistics is selected as the best one-variable predictor of the response. Then, the two-variable models are fitted by keeping the original selected factor and select the second factor that has the largest t-statistics among the rest factors. At this point, the model re-checks the significance of the first factor to see if it remains to be significant. If not, then the first factor is removed, and another factor with the greatest absolute t-statistics in the presence of the second factor will be included in the model. This process continues, and more and more factors enter into the predictor set by adding one at a time. The process stops when there is no more factors yielding significant t-statistics at a given α level (Type I error) (Mendnhall and Sincich 2003, and Weisberg 1985). In their book, Mendenall and Sincich (Mendenall and Sincich 2003) mentioned that the stepwise regression is vulnerary to Type I / Type II errors due to the large amount of t-tests; thus, they proposed another approach to supplement stepwise regression, which was the all-possible-regressions selection procedure that is commonly referred as best subset method.

2.2.3 Best Subset

In this approach, models with all possible combinations of factors are examined. For each number of included factors, the model with highest R-square value is selected. Based on the results, we selected the model with relatively small mean square error (MSE), good adjusted R-square value, and a small Mallow's C_p value close to the number of factors included in the model (Mendnhall and Sincich 2003). Mallow' C_p value measures the ratio of total mean square error for the subset regression model with the variance of the random error for the true model. A small C_p value approximating the number of prediction variables is an indicator of good model performance.

2.2.4 Model Performance Evaluation

There are many criteria to select regression models (Montgomery et al. 2001, Myers 1990), such as R-square and adjusted R-square. For stepwise regression, we used the default Minitab alpha value (0.15) to select the most important factors. C_p value was used to select models of best subset method. To evaluate the model performance, we calculated several prediction error evaluation terms, including prediction sum of squares or PRESS (Miller 1974), mean absolute deviation (MAD), mean absolute percent error (MAPE), and root mean squared errors (RMSE) (Chopra and Meindl 2006). The model whose prediction had the least deviations from the observations was selected as the best one.

2.2.5 Model Validation

We applied the cross-validation method to validate our factor selection from stepwise regression and best subset methods. Data set was split into two groups: training set and testing set. The former set was used to establish the model. We checked if the model generated accurate enough predictions against observations by substituting the testing set data into the model concluded from the training set. We had five-month data. If data was collected sequentially in time, we could select a time point to divide the data (Snee 1977). By using a four-year data set, Cady and Allen (Cady and Allen 1972) developed a corn yield prediction model. They used the first three years to build the model and tested on the last year. Feng et al. (Feng et al. 2005) used best subset combined with cross-validation to set a predictive model of honing surface roughness. By the same story, we divided our data by month. Each month's predicted values from the model derived from the rest four-month data were tested against the observed values. Model validation was conducted on Microsoft Excel 2007 (Microsoft Corporation, Redmond, WA) for preliminary data processing and Minitab 15 (Minitab Inc., State College, PA) for model building.

2.2.6 Simulation

Some of the factors defined were not in full control of OR management, such as cancellations or add-on cases from emergency department. The most controllable decision of OR management was the scheduling of cases. Majority of papers on OR case scheduling assumed a deterministic duration of the OR and solved an optimization problem. In order to have a better understanding on the schedule's impacts on the performance of OR provided there is variability in surgery duration, we built a discrete-event simulation model. In our model, a single OR's performance was analyzed, and it was assumed that the OR repeatedly did one type of procedures. Although in real scenario, the situation is more complex as the procedures are usually different for the cases scheduled in the same OR, it is infeasible to simulate by using real case data as the realization of cases in each OR on each day is different. For example, on May 1, 2009, OR3 had three General cases, 1 Plastic Case and 1 Vascular Case, and on May 11, 2009, it only had 3 General cases. However, the conclusions from such a simplified model could be generalized to other facilities by varying input parameters to generate different scenarios that represent different OR conditions.

The scenarios were generated by varying parameters with respect to: case duration distributions, first case start tardiness distributions and scheduled OR utilization (as shown in the results that the case duration distribution and scheduled OR utilization are the most important factors to influence OR utilization). In total, we had 72 scenarios. We selected an eye cataract surgery for a particular surgeon in the studied facility during 2009 to have enough sample size. Then, we used Arena 13 student version (Rockwell Automation, Wexford, PA) to fit distributions to the case duration data set. We hypothetically generated other three types of case duration by changing the coefficient of variation and mean case duration.

Figure 3: Distributions of Four Types of Case Duration for Simulation

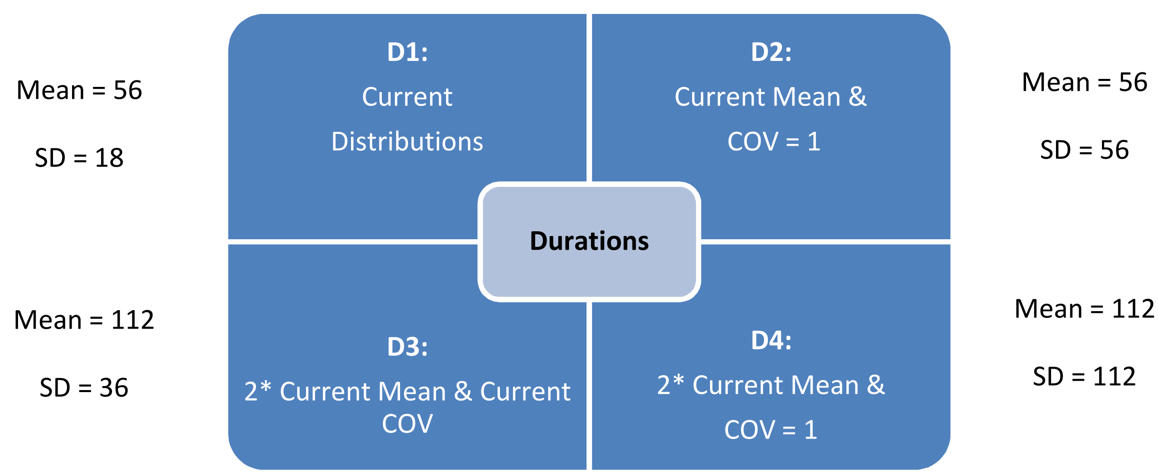
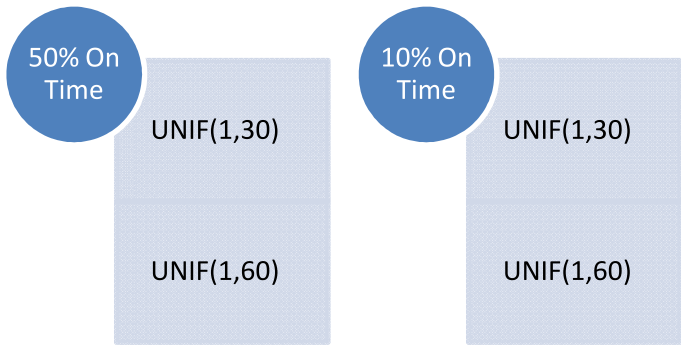


Figure 3 illustrates the four case duration statistics we used in the simulation analysis. The resulted distributions captured a large variety of case durations. In 2009, the facility assigned 1 hr to this type of surgery; thus, the scheduled case duration for case type 1 and case type 2 surgeries was 1 hour. As the mean case duration for case type 3 and case type 4 was twice as many as those for case type 1 and case type 2. We assigned 2 hrs to the scheduled case duration for the latter two types of case duration distribution.

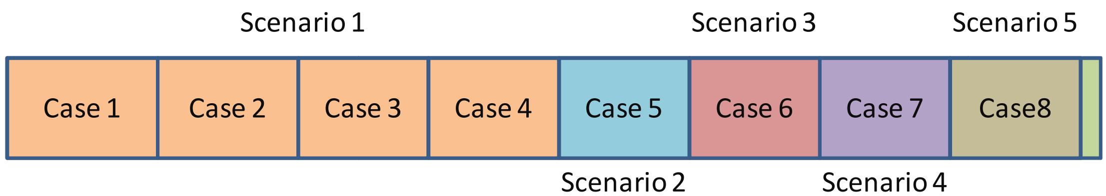
We assumed two different distributions for the first case start tardiness. Either 50% of the first cases started on time or 10% of the first cases started on time. If there was tardiness, then the duration followed a uniform distribution either from 1 to 30 minutes or from 1 to 60 minutes (Figure 4).

Figure 4: First Case Start Tardiness Parameters



We also adjusted the number of cases on the final schedule (including cancellations and add-on cases). A half-scheduled day was the baseline, and then we added case one by one until the OR was approximately 100% scheduled (Figure 5).

Figure 5: Scheduling Strategy for Simulation



The turnover times we used for our analysis was a constant 15 minutes as it was what was used in the studied facility. There was variability in turnover times, but the amount was relatively small compared to that of the case distribution. Based on the data of 2009, 52% of the turnover times for this type of surgery were shorter than this number; thus a 15-minute turnover time was approximately the mean turnover time. In addition, both our statistical analysis (see Results) and some previous research (Tyler et al. 2003, Abouleish et al. 2003) had excluded it as a key factor in determining the OR utilization. For simplicity purpose, we used a constant instead of a distribution to represent the turnover times. Each OR was scheduled to open from 8AM to 4PM. If any portion of the case duration laid beyond 4PM, then the duration was considered as over-utilized OR time. We also assumed that the patients were ready for surgeries 30 minutes ahead of the scheduled case start time. We ran the model for each scenario with 5000 replications. We compared the identified scenarios based on their performances in the OR utilization, the efficiency of use of OR time, and patients' wait time on the day of surgery. The inefficiency of use of OR time was calculated as under-utilized OR time plus 1.75 times the over-utilized OR time (Dexter et al. 2001, Epstein and Dexter, 2002, McIntosh et al. 2006). The patients' wait time equaled the difference between the time the patient entered the OR and the scheduled case start time. When the patient entered the OR earlier than the scheduled case start time, the wait time was considered as zero.

2.3 Results

2.3.1 Statistical Analysis

Table 1 summarizes the model fitting statistics of the two feature selection methods. Type I models were fitted by stepwise regression, and Type II models were from the analysis of best subset. The month before the Greek number was the testing data set. For example, May I refers to the model that was developed by data from June to September (training data) by stepwise regression, and the data of May (testing data) was tested against the observed OR utilization. September II is the model developed by using data from May to August by Best Subset, and the data of September was used to validate the model. The adjusted R-square values do not differ significantly among all the different models. So no model dominates the others. The R-square values are around 0.8, indicating that our models explain a good portion of the variability of the data set, and thus, the model is representative of the system we studied.

Table 1: Stepwise Regression and Best Subset Model Statistics

Model	S	R-Sq	R-Sq(adj)	PRESS	R-Sq (Pred)
May I	0.06490	82.04	80.62	0.42229	76.31
May II	0.06432	82.60	81.00	0.40255	77.42
June I	0.07010	81.31	80.07	0.46902	76.25
June II	0.07014	81.30	80.10	0.46902	76.25
July I	0.06920	79.35	78.00	0.48873	72.59
July II	0.06916	79.30	78.00	0.48873	72.59
August I	0.05690	85.35	84.19	0.28746	82.89
August II	0.05691	85.40	84.20	0.28746	82.89
September I	0.06650	79.76	78.71	0.41205	75.53
September II	0.06623	80.50	78.90	0.41313	75.47

Table 2: Summary of Model Performance

Model	MAD	MAPE	RMSE
May I	5.91% ± 1.10%	7.08 ± 1.23	0.07
May II	6.32% ± 1.14%	7.71 ± 1.28	0.08
June I	4.29% ± 0.69%	6.01 ± 1.01	0.05
June II	4.29% ± 0.69%	6.01 ± 1.05	0.05
July I	4.74% ± 0.77%	5.96 ± 0.92	0.06
July II	4.74% ± 0.77%	5.96 ± 0.92	0.06
August I	8.99% ± 1.37%	14.20 ± 1.96	0.11
August II	8.98% ± 1.37%	14.10 ± 1.96	0.11

September I	6.76% ± 0.95%	9.74 ± 1.34	0.08
September II	7.32% ± 0.86%	10.74 ± 1.28	0.08

Table 2 contains information of the prediction performance of each model. The MAD, MAPE and RMSE do not differ dramatically among the models (Details on the prediction of each model is in Appendix A).

Table 3 summarizes the most significant factors identified by stepwise regression and Table 4 includes those identified by best subset. The most significant factors identified by stepwise regression include the scheduled OR utilization, the difference between actual and estimated duration of cases, total hours of cancellation (except for August), and total hours of add-on cases (except for September). The factors identified by best subset method are the scheduled utilization, the difference between actual and estimated duration of cases, total hours of cancellation (except for August), and total hours of add-on cases (except for September). The total first case start tardiness, however, is not a significant factor for most of Type I and II models. There were some other factors identified to be significant but not at P=0.05 level. These factors include the day of week, number of cancellations, total turnover times and number of completed cases. Apparently, how the schedule looked like at 2PM on the previous day (scheduled OR utilization), the accuracy of case duration prediction, how to manage cancellations and how to add cases on to fill up the schedule are important for OR management to optimize the OR utilization.

Table 3: Top Factors from Stepwise Regression Model Result

Model	Factors	Coefficient	P
May I	Sche Util[1]	0.698	0.000
	Diff (Actual - Estimated) [2]	0.018	0.000
	Cancel Hrs [3]	-0.015	0.000
	Add-on Hrs [4]	0.017	0.001
	First Case Dly [5]	-0.008	0.049
June I	Sche Util	0.836	0.000
	Diff (Actual - Estimated)	0.017	0.000
	Cancel Hrs	-0.016	0.000
	Add-on Hrs	0.020	0.001
	First Case Dly	-0.008	0.047
July I	Sche Util	0.082	0.000
	Diff (Actual - Estimated)	0.018	0.000
	Cancel Hrs	-0.015	0.000
	Add-on Hrs	0.018	0.005
	First Case Dly	-0.009	0.056
Augusut I	Sche Util	0.818	0.000
	Diff (Actual - Estimated)	0.020	0.000
	Cancel Hrs	-0.009	0.101
	Add-on Hrs	0.026	0.000
	First Case Dly	-0.018	0.007
	Cancel Case [6]	-0.009	0.083
September I	Sche Util	0.720	0.000
	Diff (Actual - Estimated)	0.018	0.000
	Cancel Hrs	-0.013	0.000
	Complete Cases [7]	0.006	0.104

[1] Scheduled utilization
[2] Difference between the actual and estimated duration of cases
[3] Total hours of cancellations
[4] Total hours of add-on cases
[5] Total first case start tardiness
[6] Number of cancellations
[7] Number of completed cases

Table 4: Top Factors from Best-subset Model Results

Model	Factors	Coefficient	P
May II	Sche Util	0.775	0.000
	Diff (Actual - Estimated)	0.018	0.000
	Cancel Hrs	-0.016	0.000
	Add-on Hrs	0.024	0.000
	TOT Number [8]	0.009	0.016
	First Case Dly	-0.008	0.076
	WD[9]	-0.012	0.059
June II	Sche Util	0.836	0.000
	Diff (Actual - Estimated)	0.017	0.000
	Cancel Hrs	-0.016	0.000
	Add-on Hrs	0.020	0.003
	First Case Dly	-0.008	0.088
July II	Sche Util	0.818	0.000
	Diff (Actual - Estimated)	0.018	0.000
	Cancel Hrs	-0.015	0.000
	Add-on Hrs	0.018	0.005
	First Case Dly	-0.009	0.056
August II	Sche Util	0.818	0.000
	Diff (Actual - Estimated)	0.020	0.000
	Add-on Hrs	0.026	0.000
	First Case Dly	-0.018	0.007
	Cancel Case	-0.018	0.083
	Cancel Hrs	-0.009	0.101
September II	Sche Util	0.703	0.000
	Diff (Actual - Estimated)	0.019	0.000
	Cancel Hrs	-0.013	0.000
	TOT Time	-0.004	0.118
	Complete Cases	0.006	0.166

[8] Number of turnovers
[9] Day of week

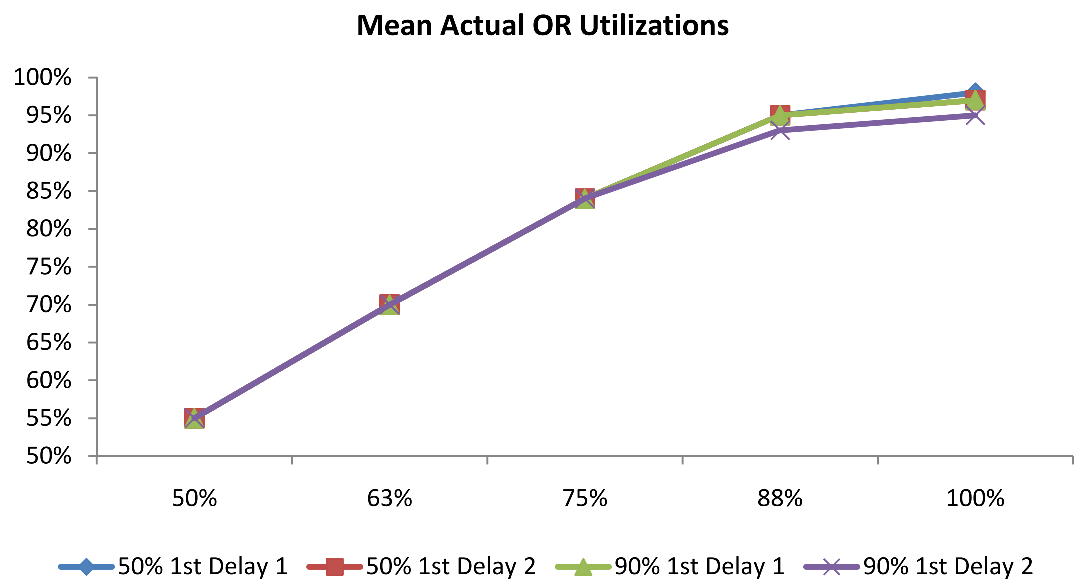
2.3.2 Simulation

When we fitted the case duration distribution using Arena 13 Input Analyzer, it was concluded that the best distribution was a three-parameter lognormal distribution with a mean duration of 56 minutes and a variance of 16.4 minutes. We present the simulation results here as pair-wise comparison. Case type 1 and case type 2 make up a pair, while case type 3 and case type 4 make up another pair. The members in each pair have the same mean case duration but of different case duration variance.

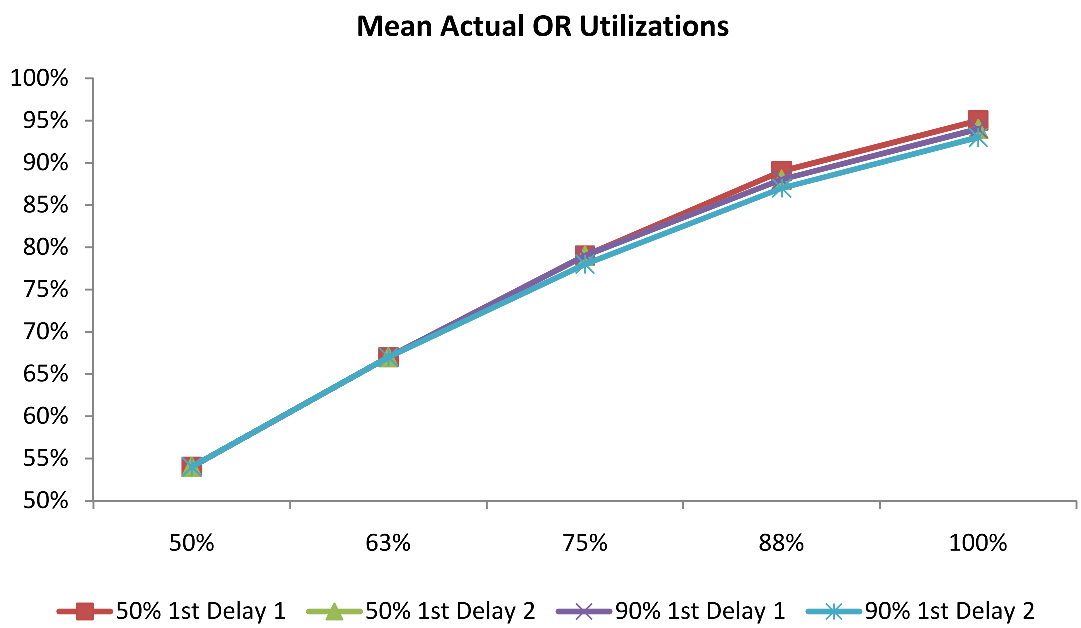
2.3.2.1 OR Utilization

Figure 6 and 7 plot the actual utilization vs. scheduled OR utilization for the pair of case type 1 and case type 2 and the pair of case type 3 and case type 4 based on different first case start tardiness distributions. For both pairs, the utilization increases as more and more cases were scheduled, but the higher the case duration variability, the lower the actual OR utilization on the average given the same scheduled utilization. Also, the increase in actual utilization slows down as more and more cases were scheduled, which is depicted by the flattered slope of the line segments towards the upper right. The first case start tardiness do not affect the actual utilization when there are fewer scheduled cases. This is because that even though there is tardiness at the beginning of the work day, all the cases could be done within the allocated OR time. When the day is fully scheduled, the OR workload that would have been within the allocated OR time if no tardiness happens lays outside of the allocated OR time and is considered over-utilized OR time. Thus, the actual OR utilization of the delayed OR is lower compared to the OR with the same scheduled OR utilization but less first case start tardiness. However, the differences in OR utilization of different first case start tardiness distribution are not significant (0% to 2% given the same scheduled utilization). The statistics on the OR utilization performance of all types of case duration distribution are summarized in Appendix B.

Figure 6: Utilization for Case Duration Type 1 and 2

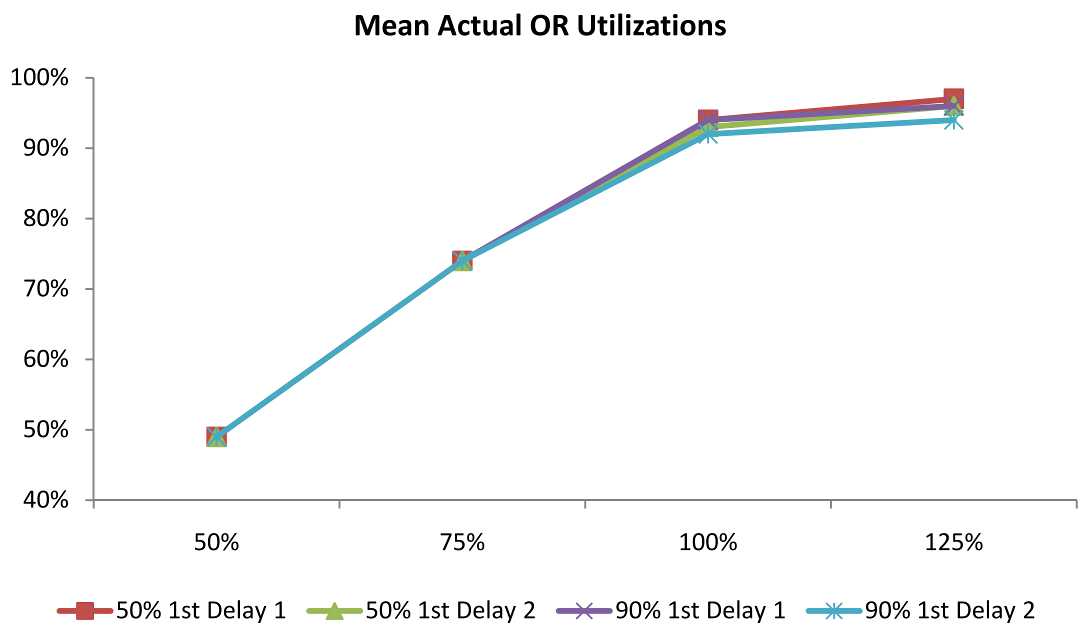


(a) Utilization for case Duration Type 1

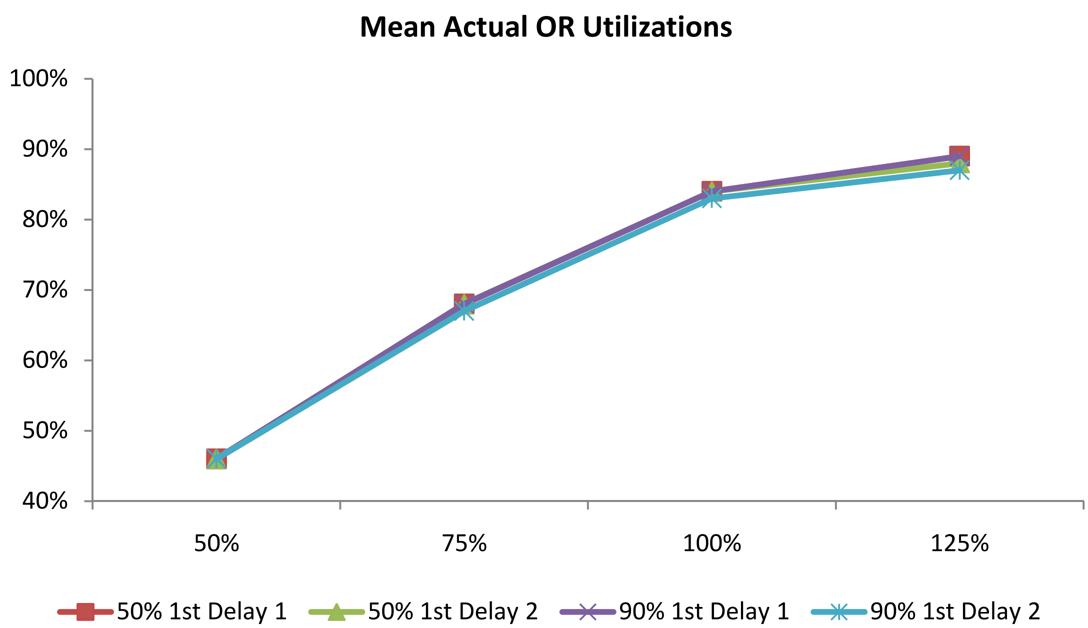


(b) Utilization for Case Duration Type 2

Figure 7: Utilization for Case Duration Type 3 and 4



(a) Utilization for Case Duration Type 3

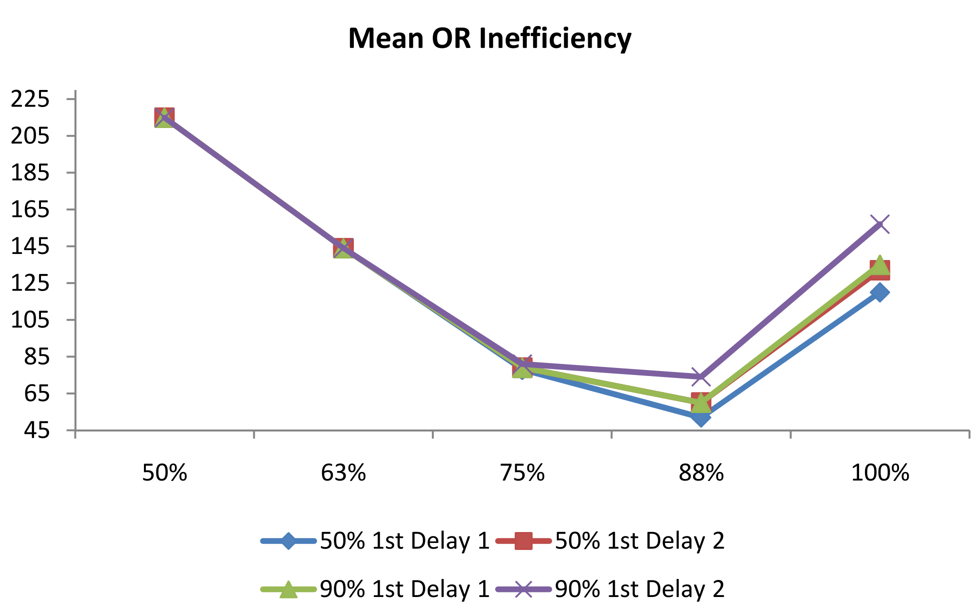


(b) Utilization for Case Duration Type 4

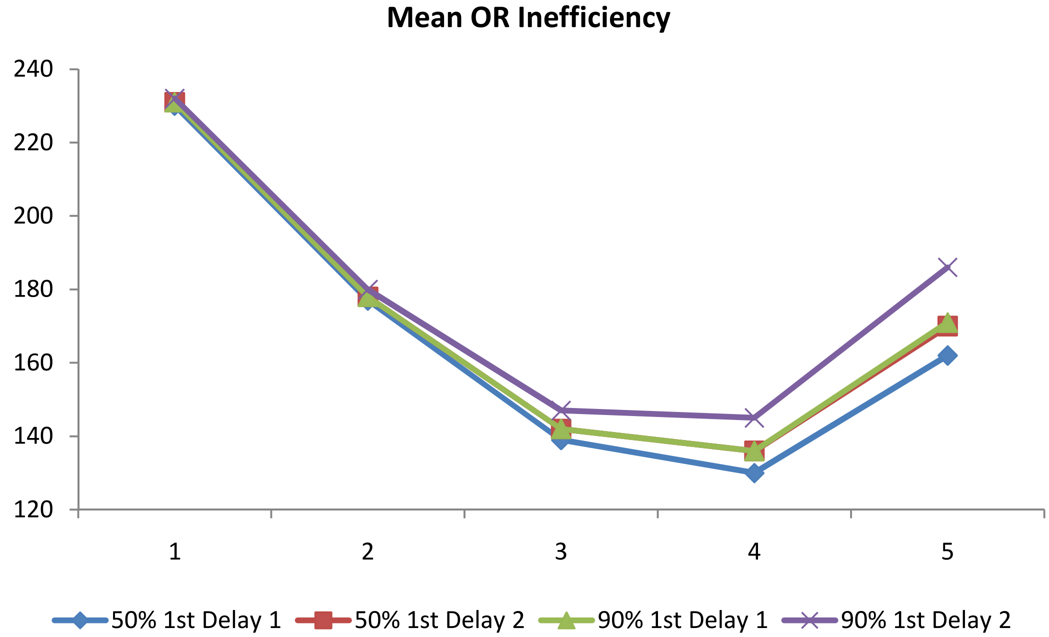
2.3.2.2 Efficiency of Use of OR Time

The X-axis of Figure 8 and Figure 9 are for the scheduled OR utilization. The Y-axis are for the inefficiency of use of OR time (in minutes). The inefficiency decreases as more and more cases are scheduled until beyond the optimum point. The explanation is that when fewer cases are scheduled, the inefficiency of use of OR time is mainly due to the much under-utilized OR time. As more cases are scheduled, less and less under-utilized OR time is expected, so the inefficiency went decreases. However, the byproduct of more scheduled cases is the over-utilized OR time. The over-utilized OR time is more expensive than the under-utilized OR time. After a certain point, the over-utilized OR time becomes dominant, making the inefficiency higher. Similar to the OR utilization, the first case start tardiness does not impact the inefficiency until the day was more fully scheduled. For a 100% scheduled utilization, the differences in OR inefficiency for different first case start tardiness are from 15 to 30 minutes on average. The statistics on the inefficiency of use of OR time are summarized in Appendix C.

Figure 8: Cost Inefficiency for Case Duration Type 1 and 2

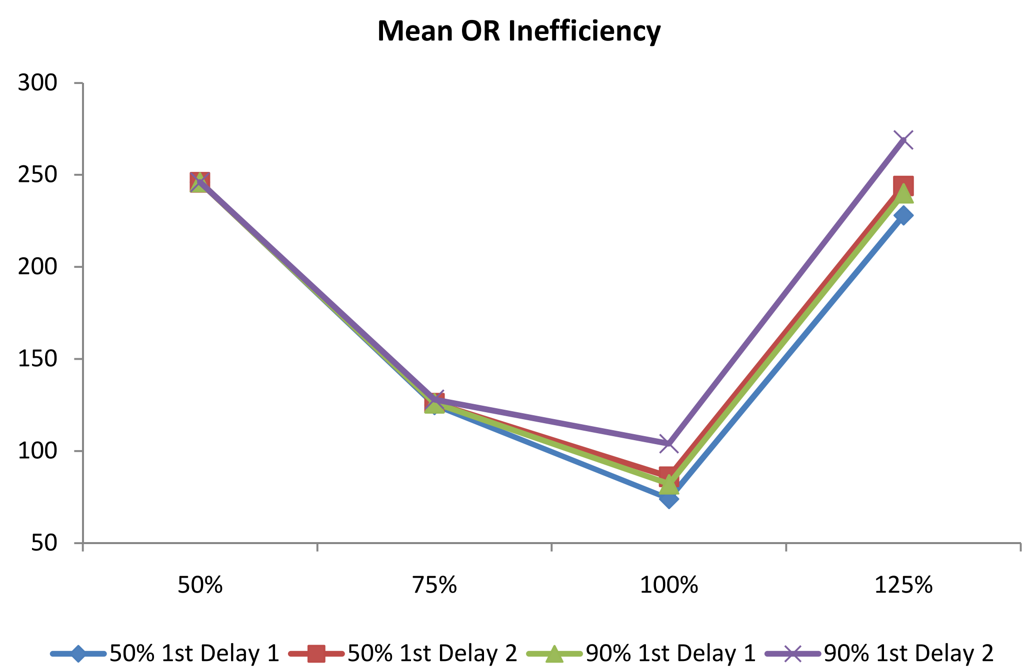


(a) Cost Inefficiency for Case Duration Type 1

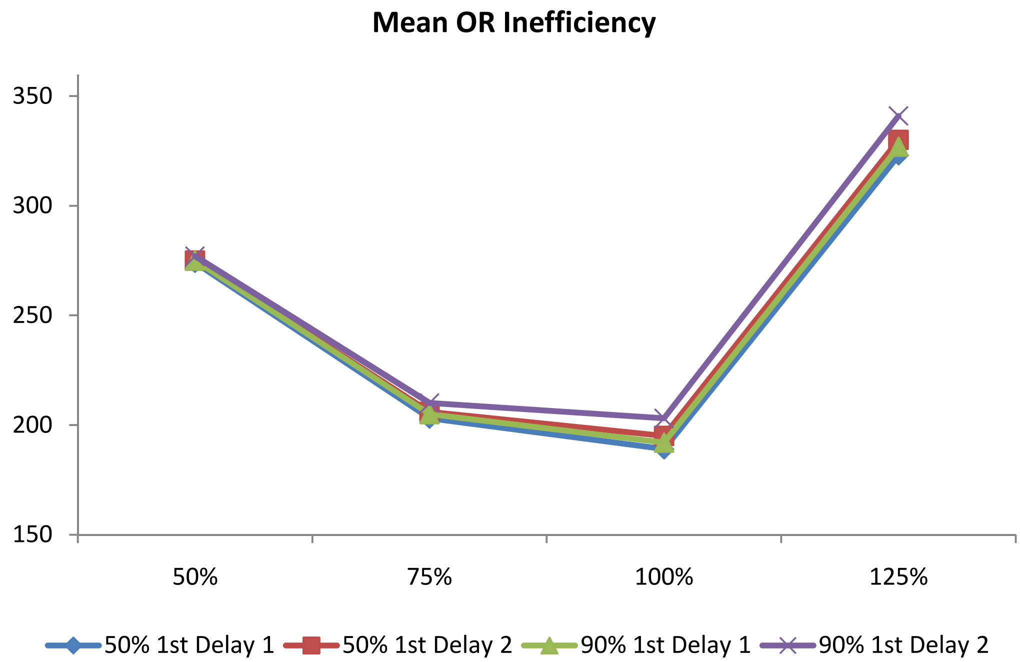


(b) Cost Inefficiency for Case Duration Type 2

Figure 9: Cost Inefficiency for Case Duration Type 3 and 4



(a) Cost Inefficiency for Case Duration Type 3

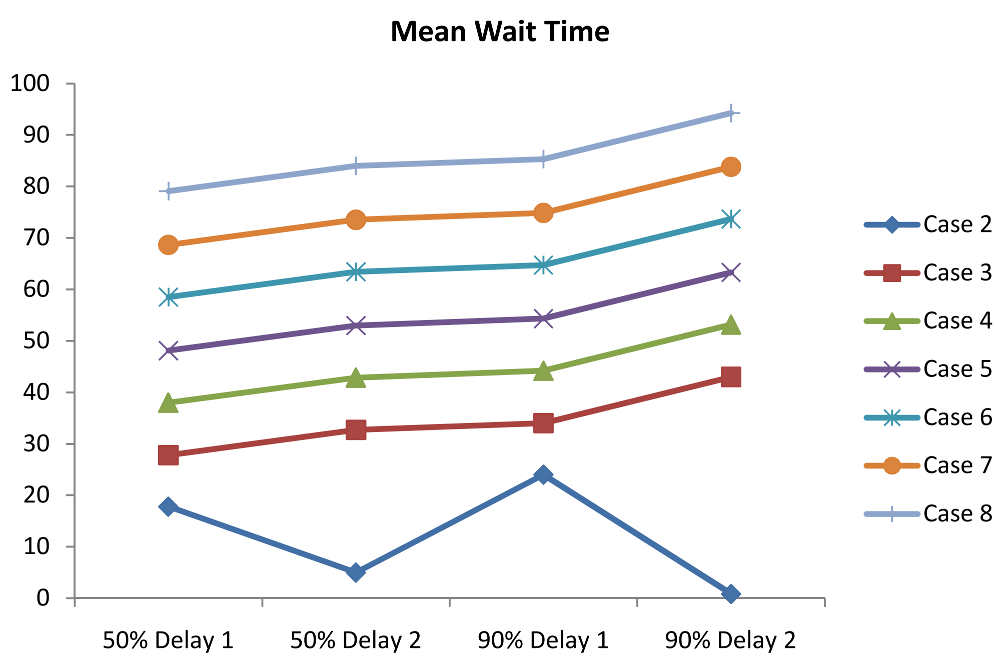


(b) Cost Inefficiency for Case Duration Type 4

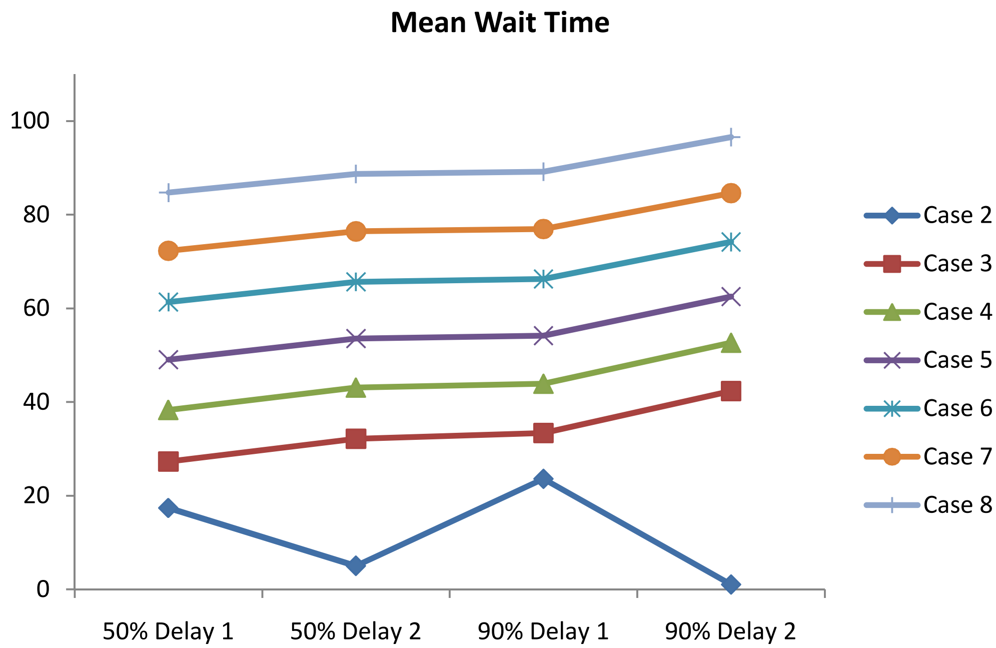
2.3.2.3 Patient Wait Time on the Day of Surgery

The mean wait time increases towards the end of the day, as the variability and uncertainty of total duration of previous cases compounds (Figure 10 and Figure 11). This observation matches the previous study by Wachtel and Dexter (Wachtel and Dexter 2009) that the wait time of case increased with the cumulative duration from previous cases. However, as we simplified our scenarios and did not consider the moving of cases towards the end of the day, the actual wait time for last cases was over-estimated. For the same first case start tardiness probability, the higher the variability of the delay distribution, the more waiting is expected. We also see the behavior of the second case for case type 1 and case type 2 is different from the rest of the cases. The reason lies in the first case start tardiness distribution. For the 2nd first case start tardiness distribution, we assumed that if the first case was delayed, then the duration was uniformly distributed between 1 to 60 minutes. When the first case was delayed for more than 30 minutes, the second patient entered the OR before the 1st case as he/she was ready for the surgery 30 minutes ahead of scheduled case start time, making the wait time less. However, this did not work for the patients with case duration type 3 and case duration type 4. For these two case duration distributions, the scheduled case durations were 2 hours, even if the first patient delayed for one hour, the 2nd patient was not be ready until 30 minutes later, and so the wait time behavior for the patients with case type 3 and case type 4 were consistent. The statistics on patient wait time for each case are summarized in Appendix D.

Figure 10: Pt. Wait Time for Case Duration Type 1 and 2

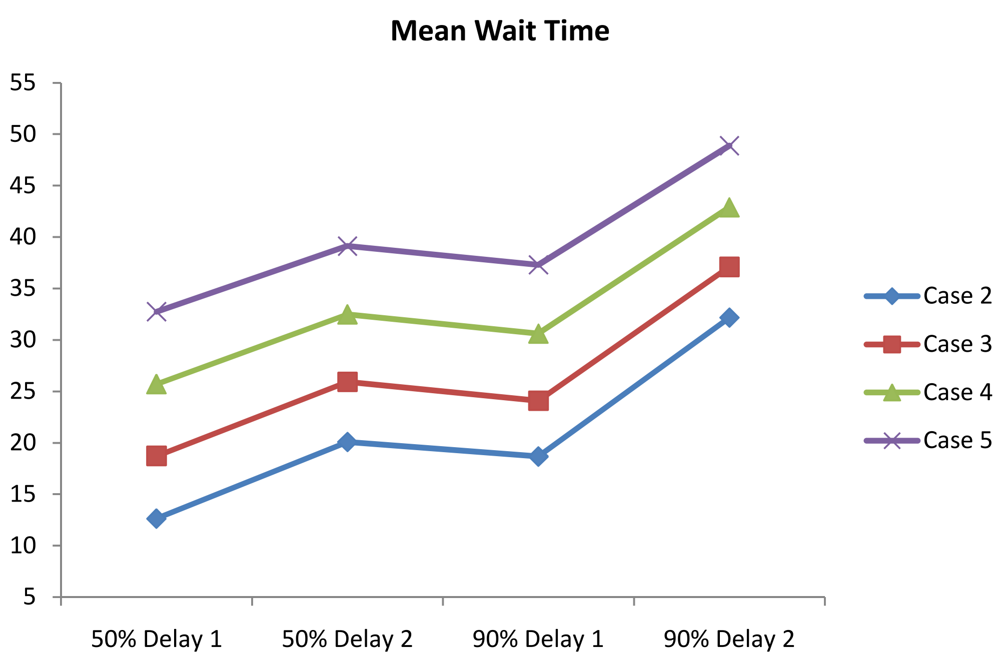


(a) Patient Wait Time for Case Duration Type 1

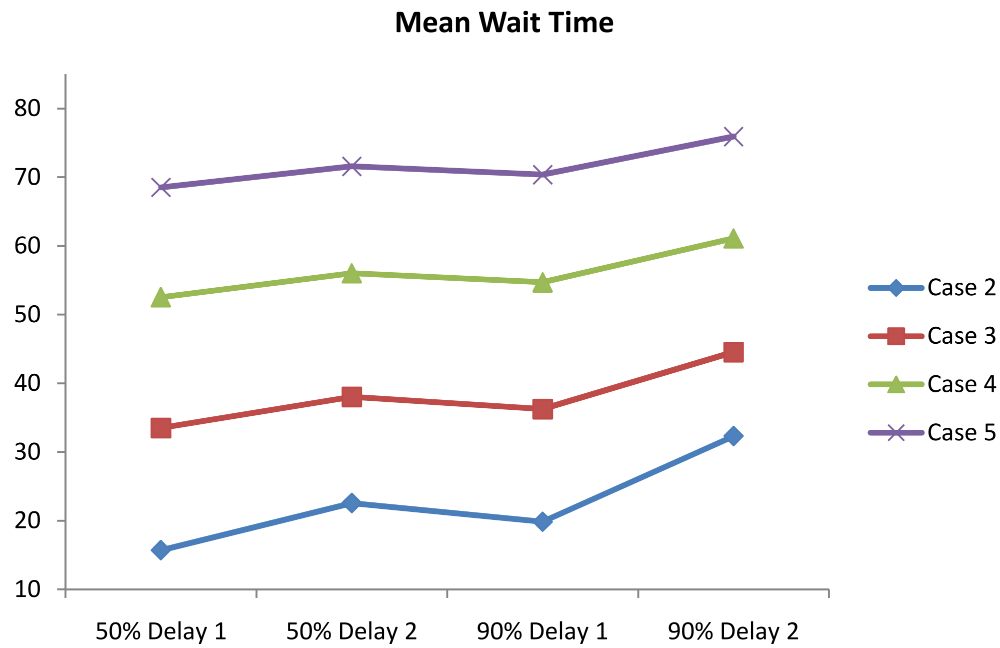


(b) Patient Wait Time for Case Duration Type 2

Figure 11: Pt. Wait Time for Case Duration Type 3 and 4



(a) Patient Wait Time for Case Duration Type 3



(b) Patient Wait Time for Case Duration Type 4

2.4 Discussion

In this study, we identified the most significant factors influencing the OR utilization on the day of surgery. There are a couple of things worthy to be mentioned here. First, the positive sign in the stepwise and best subset models before the scheduled OR utilization is just an indication that a higher scheduled utilization resulted in a higher actual OR utilization. We do not want to over-emphasize that OR suite should schedule as many cases as possible. The OR would face a lot of over-utilized OR time when there are too many cases scheduled, which is not cost efficient. Then, the positive sign before the difference between the actual and estimated duration of cases does not imply that we want to have all surgeries run longer than expected. The tardiness from the under-estimation has the following patients wait in pre-op area and sacrifices customers' satisfaction for a higher utilization. The high ranking of this factor further confirms the previous study in the studied facility that the case duration predictions were not very accurate. In the studied facility, surgeons had a tendency to under-estimate the case durations, resulting in the actual OR utilization usually was higher than the scheduled OR utilization from the performed cases (the mean difference between the scheduled and actual OR utilization was 14% ± 1%). The increase in the OR utilization from the increased under-estimation was because when the previous case overran, the OR did not need to wait for the patient since most of the time the patient was ready for the surgery and waiting for the OR.

In our analysis, the turnover times did not significantly influence the utilization, which matched previous research conclusions (Tyler et al. 2003, Dexter et al. 2003). Although the OR utilization would not be significantly impacted by any shortened turnover times, short turnover times would make OR suites to have less over-utilized OR or need fewer allocated OR time (Dexter et al. 2003), so the efficiency of use of OR time would increase.

The importance of cancellation and add-on case is an indication that strategy is needed to deal with cancellations and add-on cases. If a cancellation is avoidable in advance, the management should identify it early enough, so the utilization can be managed by finding a substitute case to replace the cancellation. If a cancellation is due to unpredictable reasons, it will not adversely impact the utilization as long as OR can find a case to fill the cancelled hours. It is thus important to establish an effective and efficient way to look for cases on the waiting list and manage the cancellation. Dexter et al. (Dexter et al. 1999) studied the scheduling approach of add-on cases. They found out that the off-line best-fit descending algorithm generated the best efficiency of use of OR time. Usually, there is either one or zero add-on case for each OR. When there is an add-on case, the OR manager could use the mean case duration of historical cases to plan the scheduled case duration and assign the case to the OR.

The first case start tardiness did not have significant impact on the OR utilization. When we looked at the first case start tardiness statistics, we figured out that for the studied facility, the first case on-time start performance was not bad during the studied time range (Table 5). On average, during May, 2009 and September, 2009, there were 469 first cases and 63% of them started on time. The mean first case start tardiness was 13 minutes (Max = 62 minutes, Min =0).

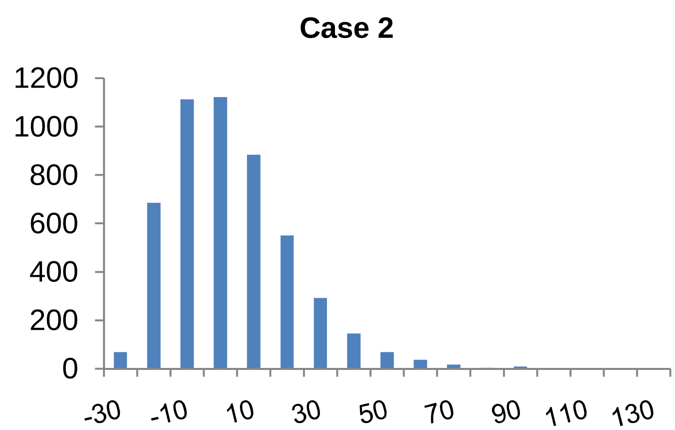
The tardiness thus played no critical role in the utilization numbers. By simulation, we artificially generated two different distributions of first case start tardiness. The results confirmed the conclusions of the statistical analysis. Although there were some differences in OR utilization when the ORs were almost fully scheduled given different first case start tardiness, the differences were small and within 3% (Appendix B).

Table 5: First-case On-time Start Performance

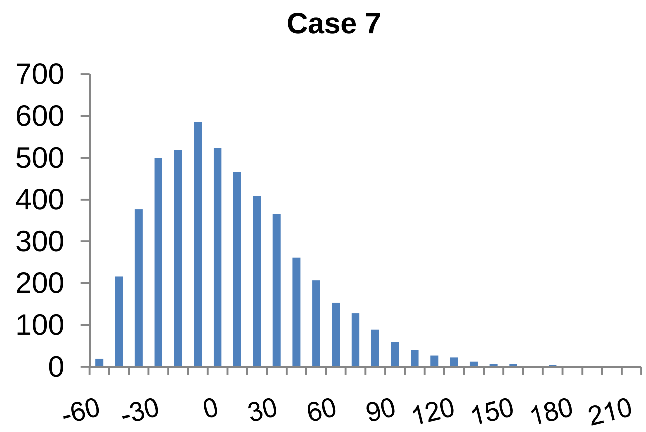
Date Range		**No. of 1st Case**	**% On-time Start of 1st Cases**	**Mean Delay**
5/1/2009	5/31/2009	94	65%	8
6/1/2009	6/30/2009	95	64%	9
7/1/2009	7/31/2009	103	60%	15
8/1/2009	8/31/2009	85	67%	17
9/1/2009	9/30/2009	92	58%	17
Total		469	63%	13

For the simulation model, we assumed that patients were ready 30 minutes ahead of scheduled case start time. We did a gap analysis for between the time the previous patient left OR and the scheduled case start time of next patient. By taking the extreme condition, we considered the 2nd and the last case for case type 1 and case type 4 (i.e. cases with the smallest mean and smallest variability and cases with the largest mean and largest variability). Figure 12 are for the gaps of the cases of case type 1, and the charts in Figure 13 are for cases of case type 4. Towards the end of the day, the uncertainty in patient wait time increased as displayed by the wider range of gaps. While cases are expected to be delayed for longer time towards the end of the day, they are also possible to start much earlier than the scheduled case start time. For example, the maximum wait time for the 4th case of case type 4 could be as much as 470 minutes, whereas it could start 100 minute ahead of the scheduled case start time. On the other hand, the maximum wait time for the 2nd case of the same case type is 330 minutes, and the patient could enter OR 60 minutes ahead of time. As shown, there is also probability of OR staff being idle because the patient was not ready. As a result, another way to increase the utilization by reducing the un-utilized OR time due to not-ready patients is to have patients ready early for their procedures. However, we do not want to have patients wait for 3 or 4 hours also hurt the quality of service and we may face constraints in pre-op beds. As for when to have patients ready, a balance needs to be found between patients' wait and room unoccupied (Dexter and Traub 2000).

Figure 12: Gaps Analysis for Case Duration Type 1

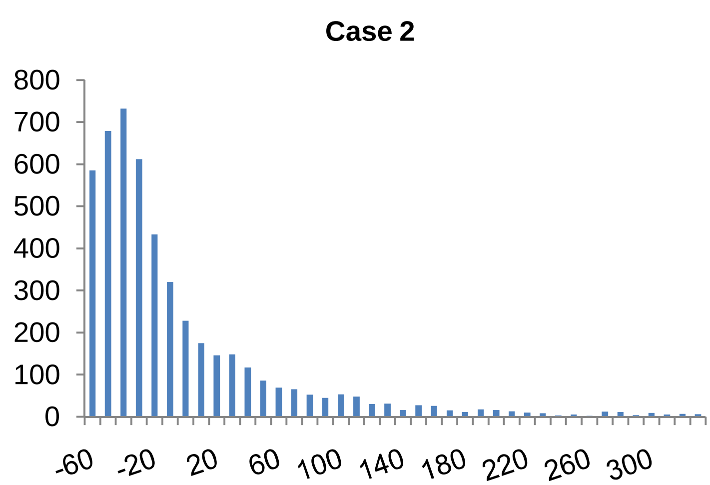


(a) Gaps for the 2nd Case of Case Duration Type 1

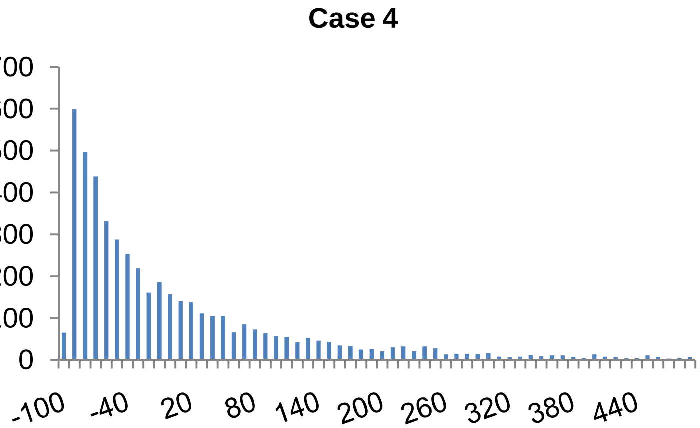


(b) Gap for the 7th Case of Case Duration Type 1

Figure 13: Gaps Analysis for Case Duration Type 4



(a) Gap for the 2nd Case of Case Duration Type 4



(b) Gap for the 4th Case of Case Duration Type 4

To quantify the impact of when the patient is ready for the surgery on the OR utilization, we did additional simulation runs by adjusting the scheduled duration to the closest 15-minute interval to the mean case duration plus the mean turnover times, and having patients ready 60 minutes before the scheduled case start time. The mean wait time for the last case of case type 1 was reduced by almost 80 minutes, and the reduction in mean wait time for the last case of case type 4 was 25 minutes. The utilization has an approximate 1% ± 0.1% increase from the adjustment on the average and the improvement on efficiency is 4.1 ± 1.2 minutes.

Our analysis identified the accuracy of case duration prediction as the second most important factor to determine the OR utilization. An unique characteristics of OR theater is that the case duration in OR suite has high variability. People might see that a case scheduled to run 3 hours takes much less or more time than the scheduled case duration. Inaccuracy in case duration prediction distorts the operation of OR suites. Under-estimation of case duration causes long wait time of the following patients and may cause cancellations of cases scheduled at the end of day (Pandit and Carey 2006). Surgeons may tend to underestimate the surgery duration in order for their cases to be fitted into the allocated OR time (Abouleish and Prough 2002; Dexter and Macario 2004). Over-estimation leaves OR staff idle, reducing OR utilization and the efficiency of use of OR time. Thus, it is important to monitor the inaccuracy in case duration prediction. Dexter et al.(Dexter et al. 2005) developed a method to assist the measure of bias in scheduled case durations. In their paper, the number of minutes of under-estimated case duration per eight hours of OR time was calculated for four-week time intervals. The lower 95% lower confidence bound for the average bias in scheduled case duration could be calcuated by using Student's t-distribution to identify the bias.

The most important factor for OR utilization was the scheduled OR utilization. Simulation results show that when the total estimated duration of cases on the schedule was close to the full capacity, the OR utilization and efficiency of use of OR time reached their optimum values. OR schedulers can refer to the mean duration of historical cases to schedule OR cases. The results from simulation demonstrated and confirmed the influence of case duration variability and case duration prediction on OR utilization, the efficiency of use of OR time, and patient's wait time on the day of surgery. But the problem with OR case duration lies in its high variability. For example, case type 1 and case type 2 were of the same mean case duration; however, the performances differed between these two types of cases. Unlike manufacturing processes, where the process variability is negligible compared to the mean, the OR duration variability is very high. Thus, an effective way to manage the OR utilization and the efficiency of use of OR time is to control the variability of duration of surgery lists besides the mean total scheduled duration of cases. The control of the variability of the duration of surgery lists can be done through surgery lists management that allows the OR scheduler to select cases such that even with their variability, performance of OR can still meet the set targets. We will talk about the surgery lists management in the next chapter.

2.5. Conclusion

In this chapter, we applied stepwise regression and best subset to identify the most influential factors that impact the OR utilization. Simulation models were built to validate the results and provided us with more insights into OR utilization management. Based on the results, to increase OR utilization, the OR management should focus on the scheduling of cases, including the scheduling of add-on cases and management of cancellations. The prediction of the duration of surgery lists is also important in the determination of the utilization as both under- or over-predicted case duration make the actual OR utilization deviate from it scheduled value. For individual case duration prediction, the OR management can refer to the mean case duration of historical cases to assign scheduled case duration as previous indicated this approach provides a simple but useful estimate (Dexter et al.1999, Alvarez et al. 2010).

To manage the OR utilization, it is more important to control the uncertainties brought into the system by the variability of case durations. As illustrated by the simulation study, given the same mean case duration, a higher variability of case duration brings into the system more uncertainty in the patients' wait time and reduced the optimum utilization and the efficiency of use of OR time. After a certain point, an increase in the OR utilization results in a decrease in the OR cost efficiency; thus 100% utilization should not be the goal of management but how to balance between the under- and over-utilized OR time, which requires an approach that would provide the OR managers with accurate estimates of the probability of under- and over utilization, which is the topic of our next chapter.

CHAPTER 3 PROBABILITIES OF UNDER- AND OVER-RUN OF SURGERY LISTS CONSISTING OF MULTIPLE CASES

3.1 Introduction and Literature Review

Operating room (OR) is one of the most expensive units for any hospitals (Macario et al. 1995, Denton et al. 2007). In order to control the costs, it is important for the OR management to ensure that the allocated OR time is utilized as much as possible with little over-utilized OR time, i.e. maximizing the efficiency of use of OR time (Strum et al. 1997, Dexter et al. 2001, Dexter and Traub 2002, McIntosh et al. 2006). When the duration of surgery lists is longer than the allocated OR time, over-utilized OR time is observed. On the other hand, when the duration is shorter than the allocated OR time, under-utilized OR time is seen and some OR capacity is wasted. In previous chapter, we concluded that the scheduling and the accuracy of case duration prediction are the most important factors that affect OR utilization. And the simulation results suggested that scheduling case use the mean case duration of historical cases and having scheduled OR utilization approximately equal the allocated OR time would generate the optimum OR utilization and efficiency of use of OR time. The simulation also show the importance of control the case duration variability as the higher the variability, the lower the OR utilization and efficiency. Thus, it is important for the OR management to have a reliable tool to evaluate and manage the variability of case duration. When surgeons are allowed to schedule elective cases on any workdays they choose, the maximum efficiency of use of OR time can be achieved by predicting the future OR workload (Dexter et al. 1999) and determining the optimum OR allocation (Dexter et al. 2001, McIntosh et al. 2006). If the costs of over-utilized OR time is 1.75 times the costs of under-utilized OR time, then 2/3 of the ORs' should be closed within the allocated OR time (McIntosh et al. 2006). In most U.S. OR suites, the decisions on OR allocation can be made every 2-3 months. For these system, the case duration prediction accuracy is less a problem as the decisions on OR allocation take into consideration of the case duration prediction inaccuracy as they use the actual workload for calculation (Dexter et al. 2001, McIntosh et al. 2006). With more than two historical cases of the same combination of surgeon and procedure(s), the reduction in over-utilized OR time is negligible from a more accurate prediction in case duration model instead of the mean case duration of historical cases. People work late because of the workload rather than underestimation in case durations (Dexter et al. 2004).

However, the OR allocation optimization approach does not apply any more to European OR theaters. In these facilities, the demand for surgery is so high that patients have to enter waiting list and might need to wait months before their surgeries are scheduled. In addition, the allocated OR time is static. The ORs in Europe do not usually change the OR allocation (Pandit and Tavare 2011). The way to maximize the efficiency of use of OR time is to avoid both under- and over-utilized OR time through scheduling versus OR allocation decisions. A method to accurately estimate the duration of surgery lists is needed for this type of system.

Much research has been done in predicting the case duration of single cases (Zhou and Dexter 1998, Strum et al. 2000, Strum et al. 2003, Ejkemans et al. 2010, Li et al. 2010). However, even with very complicated models, the improvements in case duration accuracy were not enough to significantly reduce the tardiness of case starts (Zhou et al. 1999, Wachtel and Dexter 2009) or were better than simpler methods (Strum et al. 2000, Macario and Dexter 1999). More accurate models only improved the prediction on the central tendency (Zhou and Dexter 1999). As there is high variability associated with case duration (Macario 2009), such improvements only would have limited impacts in practice. Especially when there are multiple cases along with turnover times, the cumulative effects of the high variability make it even more difficult to predict the duration of surgery lists accurately.

The expected duration of surgery lists can be derived using the mean case duration of historical cases. However, the high variability of case durations makes the expected close time of OR not a reliable estimate. It is not uncommon to see the surgery lists under- or over-run by more than an hour. To have a good efficiency of use of OR time, it is more practical for OR managers to estimate how reliable that the surgery lists can be done within a pre-defined range with some tolerances in both under-utilized and over-utilized OR time. For example, the allocated OR time is 8 hrs, and the OR manager wants to know what the probability is that the scheduled surgery list can be finished between 7 hrs and 8.5 hrs. If the probability is high, such as 85%, then the list can be finalized as it will not generate huge amount of under- or over-utilized OR time. Otherwise, the OR manager can rearrange the cases on the surgery list until an acceptable probability is obtained. This problem has been barely studied in OR setting. Dexter et al. (Dexter et al. 1999) built an optimization model and concluded that using mean case duration of historical cases to schedule the surgery lists actually generates the optimum efficiency of use of OR time. But their problem is different from ours as it assumed that surgeons had open access to OR and the allocated OR time had been optimized to maximize the efficiency of use of OR time which is not applicable to European systems. Alvarez et al. (Alvarez et al. 2010) explored if the second tertile cut-off point was better than sum of mean case duration in predicting over-utilization. They reached the same conclusion as Dexter et al. (Dexter et al. 1999). However, they only studied the cardiovascular surgeries, and the results could not be generalized to other specialties. In 2011, Pandit and Tavare (Pandit and Tavare 2011) proposed a scheduling algorithm with the concept of planning surgery lists based on the probability that the duration of surgery lists would not exceed the defined limits for under- and over-utilization. In their work, the duration of surgery lists was assumed to followed t-distributions with a mean equaling the sum of mean case durations of each case on the surgery list plus the turnover times and a standard deviation equaling the pooled standard deviation from cases scheduled. They proved that this approach was much better than the ad-hoc scheduling approach in their facility. Although their approach generated promising results, the assumption that the duration of surgery lists followed t-distributions is not a good representation of the duration of surgery lists as indicated by previous research that individual surgery case duration followed log-normal distributions (Strum et al. 2000, Strum et al. 2003). The sum of log-normally distributed case durations does not follow a Gaussian distribution. The probabilities calculated from t-distribution would deviate significantly from the true values.

In this study, we proposed a new way to approximate the real distribution of the duration of surgery lists. First, we tested the hypothesis that the individual case duration was log-normally distributed. Then, the new distribution was introduced to approximate the true distribution of duration of surgery lists. We checked the accuracy of the proposed method by testing the distribution percentiles generated from the proposed distribution against real data from one-year surgery lists with multiple cases (Zhou and Dexter 1998, Dexter et al. 2001, Dexter and Ledolter 2005). If the percentiles were accurate, then the proposed distribution should be close to the real distribution. We compared the results from the proposed distribution with the results generated by t-distribution (Pandit and Tavare 2011). After this, we identified the optimum number of previous cases for the combinations of surgeon and procedure(s) to derive reliable parameters of case duration distribution to facilitate the implementation of the proposed method in practice.

3.2 Methods

Data was collected for all surgeries performed from January 1, 2005 to December 31, 2011 in John D. Dingell VA Medical Center located in Detroit, MI. Among the surgeons who worked in 2011, some surgeons had worked for the studied facility since 2005. Thus, in order to include complete information, we extracted data from back to 2005. Data from January 1, 2005 to December 31, 2010 was used to estimate the parameters of case duration distribution. Data from January 1, 2011 to December 31, 2011 was the testing data set to evaluate the performance of the proposed method.

The analysis was done in two phases. As our proposed method was based upon the fact that individual case duration in a surgery list followed a log-normal distribution, thus in the first phase, we checked the validity of this log-normal assumption of individual case duration. Then, we introduced a new distribution to approximate the duration of surgery lists for the OR managers to evaluate the rationality of the scheduled surgery list and make decisions.

3.2.1 Log-normality Tests of Individual Case Duration Distributions

From January 1, 2005 to December 31, 2010, there were 15646 cases, 0.8% (121 of 15646) of which had incomplete information on case duration. We excluded these cases from analysis. There were 2994 different combinations of surgeon and procedure(s). Studies had shown that type of anesthesia was also an important factor impacting the case duration (Strum et al. 2000); however, when surgeons scheduled cases, they did not consult anesthesiologists and not always know the type of anesthesia to be used, making this information incomplete and unreliable. Thus, we did not consider the type of anesthesia in our studies. There were 127 combinations of surgeon and procedure(s) (7496 cases) with moderate to large sample sizes ($n \geq 20$). We used case durations of these combinations to test whether case durations were log-normally distributed. We calculated the natural logarithms of case durations for each combination. Then, Shapiro-Wilk tests were conducted for the log-transferred data sets. If the P-value for the test was greater than 0.05, then we failed to reject that the case durations of the combination of surgeon and procedure(s) followed a log-normal distribution. The analysis was done using R 2.15.0.

3.2.2 Distribution of Duration of Surgery Lists with Multiple Cases

In 2011, there were 1463 surgery lists. A list consisted of cases taking places in the same OR on the same day. When a case was moved to another OR or was cancelled, the captured data was not able to identify. Thus, we only relied on the actual surgery lists that recorded the actual location and times of finished cases versus the lists on the original schedules. This did not affect the analysis as the method to estimate probability does not change with number of cases on the surgery lists or location of cases. Each surgery list included one up to seven cases, i.e. one to 13 cases and turnovers. As the methods to calculate percentiles of single case duration distribution had been examined (Zhou and Dexter 1998,Dexter and Ledolter 2005) and the focus of our study was on the duration of surgery lists of multiple cases, we excluded 37% (547 of 1463) of the surgery lists containing only one case. Among the remaining lists, 44% (401 of 916) consisted of at least one case with no or only one historical case. It made the estimation of case duration variance infeasible. We excluded these lists as well, leaving 515 lists for analysis.

The sum of log-normal variables has been studied in electronic engineering field to analyze the performance of wireless communication systems (Fenton 1960, Schwartz and Yeh 1982, Wu et al. 2005). The research assumed that the sum of lognormal variables followed a new lognormal distribution. However, this assumption has been proved to be false (Beauliu and xie 2004, Nie and Chen 2007). In order to overcome this shortcoming, Nie and Chen (Nie and Chen 2007) proposed a new model where they used Type IV Pearson distribution to model the sum of log-normal variables. In the model, the distribution of sum of log-normal variables was approximated by matching the mean, variance, skewness and kurtosis of a Type IV Pearson distribution with those of the sum of the log-normal variables. The model was quite accurate in a wide probability range. The following paragraphs describe in details how the approximation works.

Assume there are N independent log-normally distributed variables $X_1, X_2, X_3, \ldots, X_N$. The density function of each variable can be written as:

$$f_{X_i}(x) = \frac{1}{\sqrt{2\pi}\beta\sigma_i x} exp\left[-\frac{(10log_{10}x-\mu_i)}{2\sigma_i^2}\right]$$

Where μ_i and σ_i are the parameters of log-normal distributions in dB.

We introduce another constant $\beta = (ln10)/10$. Then, the sum of the N independent variables equals:

$M_N = \sum_{i=1}^{N} E[X_i] = \sum_{i=1}^{N} a_i\sqrt{b_i}$ Where $a_i = \exp(\beta\mu_i)$ and $b_i = \exp(\beta^2\sigma_i^2)$

The variance of the sum is given by:

$$V_N = \sum_{i=1}^{N} E[(X_i - E[X_i])^2] = \sum_{i=1}^{N} a_i^2 b_i (b_i - 1)\,;$$

The third order central moment of the sum is given by:

$$S_N = \sum_{i=1}^{N} E[(X_i - E[X_i])^3] = \sum_{i=1}^{N} a_i^3 b_i^{3/2} (b_i - 1)^2 (b_i + 2);$$

And the forth order central moment of the sum can be written as:

$$T_N = \sum_{i=1}^{N} E[(X_i - E[X_i])^4]$$

$$= \sum_{i=1}^{N} a_i^4 b_i^2 (b_i - 1)^2 \left(b_i^4 + 2b_i^3 + 3b_i^2 - 3\right) + \; 6 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} a_i^2 b_i (b_i - 1) a_j^2 b_j (b_j - 1)\,.$$

Based on the moments calculated per the above equation, the skewness and kurtosis of the sum are derived as follows:

$$Sk_N = \frac{S_N}{V_N^{3/2}},$$

$$Ku_N = \frac{T_N}{V_N^2}.$$

Many distributions were exploited to evaluate their accuracy in approximating the sum of log-normal variables (Kwan and Leung 2006). They found that Type IV Pearson distribution had the ability to provide accurate approximation in wide probability range. The probability density function of Type IV Pearson distribution approximation to the sum of log-normal variables is:

$$f_{XP}(x) = \; \nu \left[1 + (\tfrac{x-\mu_4}{\mu_3})^2\right]^{-\mu_1} \times \exp\left[-\mu_2 \arctan\left(\tfrac{z-\mu_4}{\mu_3}\right)\right],$$ where

$$\mu_1 = (\gamma + 2)/2,$$

$$\mu_2 = \frac{-\gamma(\gamma-2)Sk_N}{\sqrt{16(\gamma-1) - Sk_N^2(\gamma-2)^2}},$$

$$\mu_3 = \sqrt{V_p[\gamma - 1 - Sk_N^2(\gamma-2)^2/16]},$$

$$\mu_4 = M_N - (\gamma-2)Sk_N\sqrt{V_N}/4,$$

$$\gamma = \frac{6(K\mu_N - Sk_N^2 - 1)}{2K\mu_N - 3Sk_N^2 - 6}.$$

Given the parameters of each log-normal variable, the corresponding parameters of Type IV Pearson distribution can be obtained by using the above formulas. The percentile values for each sum; thus, can be derived by using the inverse function of the cumulative probability.

We adopted this method and evaluated its accuracy in defining the distribution of duration of surgery lists. For each surgery list, we calculated the actual workload (i.e. the total actual case duration of the surgery list plus the total turnover times). Whenever a turnover time was longer than 90 minutes, we rounded the turnover time down to 90 minutes. We used 90 minutes as the maximum because 90 minutes was the 90th percentile of the turnover time in 2010 (McIntosh et al. 2006). Longer turnover times might be due to gaps in the OR schedule (e.g. non-sequential cases) (Dexter et al. 2005). We did not consider using turnover times before 2010 because the further the data was away from the studied date range, the higher the risk that the distribution of turnover times had shifted (Dexter 1996, Zhou and Dexter 1998). We compared the actual workload to the percentiles calculated from the Type IV Pearson distribution for the duration of surgery list. If the actual workload was smaller than a percentile value, then the counter for that percentile increased by one. This process was repeated for each percentile value from 10th up to 90th percentile (Zhou and Dexter 1998, Dexter and Ledolter 2005). At the end, we were able to obtain the proportion of surgery lists whose actual workload fell below each percentile.

If the proposed method was accurate, then the difference between the proportion of surgery lists whose actual workload fell below each percentile and the percentile value should be little. The results generated by this approach were compared with the ones derived by using t-distributions (Pandit and Tavare 2011). In the research of Nie and Chen (Nie and Chen 2007), the range of variability of the input variables was close to each other to test if Type IV Pearson distribution represented the sum of log-normal variables. This did not hold any more for surgery case durations. The standard deviation of the logarithms for case durations in dB for the combination of surgeon and procedure(s) varied from 0.05 to 5.90. To test if Type IV Pearson distribution remained valid, we derived the empirical percentiles for the duration of each surgery list by doing 100,000 replications of Monte Carlo simulations, assuming that each case duration and turnover time in the surgery list followed a log-normal distribution. The large number of replications for simulation ensured that the confidence interval for the empirical percentiles to be so small that it literally converged to a point. The mean absolute differences between the empirical percentiles and the ones calculated from Type IV Pearson distributions along with the standard errors were used for validation. R 2.15.0 was used to derive the input parameters from the surgery lists, calculate percentiles of Type IV Pearson distribution for each list, and perform Monte Carlo simulations. The standard errors for the proportion of surgery lists whose actual workload fell below each percentile were calculated by Clopper-Pearson methods.

To calculate of percentiles of duration of surgery lists, people want to include only the recent data as surgeon case durations of procedures may change (Dexter 2005, Strum et al. 2000). The more the previous cases are included, the higher the probability that the surgeons become faster/slower in doing the procedures. To identify a reasonable decision point for the OR manager to determine how many previous cases to be included to calculate the probabilities, we repeated the calculation of percentiles of Type IV Pearson distribution by selecting different numbers of previous cases used for the estimation of parameters of the duration distribution, ranging from two to 20. For combinations of surgeon and procedure(s) whose numbers of previous cases were smaller than the selected sample size, all the historical data was used for parameter estimation. After this was done, we investigated the problems in current scheduling practice of the studied facility. We identified percentiles of the scheduled duration of the surgery lists with respect to the Type IV Pearson distribution from the scheduled procedures in the surgery lists.

3.3 Results

Among the 127 combinations of surgeon-procedure(s) with moderate to large sample sizes to test whether case durations of combinations of surgeon and procedure(s) followed log-normal distributions, the P-values of Shapiro-Wilk tests on the natural logarithms of case durations of 88 combinations (69%) were greater than 0.05. The majority of the case durations were log-normally distributed, matching the findings of previous research (Strum et al. 2000, Strum et al. 2003). As a result, it is reasonable for us to proceed to the next step to define the distribution of surgery lists with multiple cases assuming log-normal distributions.

The proportions of surgery lists whose actual workload fell below the distribution percentiles defined by Type IV Pearson distribution and by t-distribution were close to each other towards the center of distributions from 40th to 70th percentiles (Table 7). Between 20th and 80th percentiles, the proportions were close to corresponding percentiles of Type IV Pearson distribution when we used 10 or more previous cases with the same combination of surgeon and procedure(s) for parameter estimation. T-distribution was not robust for as a wide range. It was only good for between 40th and 70th percentiles. It performed significantly poor at identifying tail probabilities at both ends. The absolute differences in proportions were 20% ± 2% (mean ± SE) and 19% ± 2% for 10th and 90th percentiles calculated by t-distribution, while the differences were 5% ± 2% at these two percentiles for Type IV Pearson distribution. Overall, the absolute differences in proportions were 3% ± 1% for Type IV Pearson distribution and 11% ± 2% for t-distribution. Table 7 gives the proportions of surgery lists below the defined percentiles from both Type IV Pearson distribution and t-distribution based on different number of previous cases used for distribution percentiles estimation. The accuracy of the empirical percentiles generated by Monte Carlo simulation matched those calculated by Type IV Pearson distribution (Table 8), The absolute difference between the percentile values from simulations and Type IV Pearson distribution for each percentile varied from 0.20 ± 0.01 minutes to 0.43 ± 0.03 minutes (Table 9), validating that Type IV Pearson distribution provided a very accurate approximation to sum of log-normal variables regardless of the ranges in mean and variances (A sample of the percentile values from Monte Carlo simulation, Type IV Pearson distribution and t-distribution with 10 historical cases are documented in Appendix H).

As indicated by the Figure 14, the scheduled duration of surgery lists were very inaccurate in 2011. Based on the calculation of the percentile values of the scheduled duration of surgery lists with respect to associated Type IV Pearson distributions, we saw significant under- and over-estimations (from less than 10% to more than 90%). The mean difference between the scheduled durations of surgery lists based on surgeons' estimates and the actual duration of surgery lists was 5.9 ± 4.5 minutes with an absolute mean difference of 75 ± 3 minutes, whereas the mean difference was 1.0 ± 3.4 minutes with an absolute mean difference of 54 ± 2 minutes if the surgery lists were scheduled per the sum of mean case duration of historical cases with the same combination of surgeon and procedure(s) (Figure 15).

Table 6: Percentages of Lists below Calculated Percentiles for Proposed Method and T-distribution

No. of Previous Cases Used to Estimate Bound	% of Lists Below the Calculated Percentiles																	
	Type IV Pearson Distribution									t- Distribution								
	10%	20%	30%	40%	50%	60%	70%	80%	90%	10%	20%	30%	40%	50%	60%	70%	80%	90%
2	18%	26%	31%	40%	46%	51%	59%	66%	73%	29%	35%	41%	44%	47%	49%	55%	58%	62%
3	14%	24%	30%	37%	45%	51%	61%	67%	76%	28%	34%	40%	43%	47%	50%	55%	60%	63%
4	14%	23%	31%	38%	46%	55%	62%	70%	80%	30%	34%	40%	44%	48%	52%	58%	62%	66%
5	13%	23%	30%	39%	45%	53%	63%	71%	80%	30%	35%	40%	44%	49%	52%	57%	61%	67%
6	13%	25%	31%	39%	46%	53%	63%	72%	81%	30%	35%	39%	45%	49%	52%	55%	62%	68%
7	14%	25%	31%	39%	46%	54%	63%	72%	82%	30%	35%	41%	45%	49%	53%	57%	62%	69%
8	14%	23%	31%	38%	47%	55%	64%	72%	82%	29%	36%	40%	45%	49%	54%	58%	63%	68%
9	15%	24%	31%	39%	48%	56%	66%	74%	84%	29%	36%	40%	45%	52%	56%	60%	65%	71%
10	15%	24%	32%	40%	48%	58%	67%	74%	85%	30%	38%	42%	46%	52%	56%	61%	65%	71%
12	15%	24%	32%	41%	47%	56%	66%	74%	85%	30%	38%	42%	46%	50%	55%	60%	65%	70%
14	14%	22%	29%	40%	46%	54%	64%	73%	84%	29%	37%	42%	45%	50%	54%	58%	64%	69%
16	15%	22%	30%	40%	47%	54%	65%	74%	85%	28%	37%	41%	46%	50%	54%	58%	63%	70%
18	14%	22%	30%	40%	48%	55%	64%	74%	85%	28%	37%	42%	47%	50%	54%	58%	63%	70%
20	14%	22%	30%	41%	48%	56%	65%	74%	85%	28%	38%	43%	47%	51%	55%	59%	64%	70%
All	14%	23%	32%	42%	50%	56%	66%	74%	87%	28%	38%	45%	48%	53%	57%	60%	66%	74%

Table 7: Percentages of Lists below Calculated Percentiles for Proposed Method and Monte Carlo Simulation

No. of Previous Cases Used to Estimate Bound	% of Lists Below the Calculated Percentiles																	
	Type IV Pearson Distribution									Empirical Data from Monte Carlo Simulation								
	10%	20%	30%	40%	50%	60%	70%	80%	90%	10%	20%	30%	40%	50%	60%	70%	80%	90%
2	18%	26%	31%	40%	46%	51%	59%	66%	73%	18%	26%	31%	40%	46%	52%	59%	66%	73%
3	14%	24%	30%	37%	45%	51%	61%	67%	76%	14%	24%	29%	37%	45%	51%	61%	67%	76%
4	14%	23%	31%	38%	46%	55%	62%	70%	80%	14%	23%	31%	38%	46%	55%	62%	70%	80%
5	13%	23%	30%	39%	45%	53%	63%	71%	80%	12%	23%	30%	39%	45%	53%	63%	71%	80%
6	13%	25%	31%	39%	46%	53%	63%	72%	81%	13%	24%	31%	39%	46%	53%	63%	72%	81%
7	14%	25%	31%	39%	46%	54%	63%	72%	82%	14%	25%	31%	39%	46%	54%	63%	72%	82%
8	14%	23%	31%	38%	47%	55%	64%	72%	82%	14%	23%	31%	38%	47%	55%	64%	72%	82%
9	15%	24%	31%	39%	48%	56%	66%	74%	84%	15%	23%	31%	39%	48%	56%	66%	74%	84%
10	15%	24%	32%	40%	48%	58%	67%	74%	85%	15%	24%	31%	40%	48%	58%	67%	74%	84%
12	15%	24%	32%	41%	47%	56%	66%	74%	85%	15%	24%	32%	40%	47%	56%	66%	74%	84%
14	14%	22%	29%	40%	46%	54%	64%	73%	84%	14%	22%	29%	40%	46%	55%	64%	74%	84%
16	15%	22%	30%	40%	47%	54%	65%	74%	85%	15%	22%	30%	40%	47%	54%	65%	74%	85%
18	14%	22%	30%	40%	48%	55%	64%	74%	85%	14%	22%	30%	40%	48%	55%	65%	74%	85%
20	14%	22%	30%	41%	48%	56%	65%	74%	85%	14%	22%	30%	41%	48%	56%	65%	74%	86%
All	14%	23%	32%	42%	50%	56%	66%	74%	87%	14%	23%	32%	42%	50%	56%	66%	74%	87%

Table 8: Absolute Differences between Percentiles Identified by Pearson Distribution and Monte Carlo Simulation

No. of Previous Cases Used to Estimate Bound	Absolute Differences Between the Percentiles of Type IV Pearson Distribution and Monte Carlo Simulation								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
2	0.30 ± 0.03	0.28 ± 0.02	0.26 ± 0.02	0.24 ± 0.02	0.23 ± 0.02	0.26 ± 0.03	0.30 ± 0.02	0.32 ± 0.02	0.43 ± 0.03
3	0.30 ± 0.01	0.32 ± 0.02	0.28 ± 0.02	0.22 ± 0.01	0.20 ± 0.01	0.22 ± 0.01	0.27 ± 0.01	0.34 ± 0.02	0.38 ± 0.02
4	0.33 ± 0.02	0.31 ± 0.01	0.26 ± 0.01	0.22 ± 0.01	0.21 ± 0.01	0.23 ± 0.01	0.27 ± 0.01	0.32 ± 0.01	0.41 ± 0.02
5	0.33 ± 0.02	0.33 ± 0.02	0.27 ± 0.01	0.23 ± 0.01	0.20 ± 0.01	0.22 ± 0.01	0.28 ± 0.01	0.34 ± 0.02	0.39 ± 0.02
6	0.35 ± 0.02	0.38 ± 0.02	0.23 ± 0.02	0.24 ± 0.02	0.22 ± 0.02	0.25 ± 0.02	0.29 ± 0.02	0.33 ± 0.02	0.38 ± 0.02
7	0.36 ± 0.02	0.34 ± 0.02	0.28 ± 0.01	0.23 ± 0.01	0.22 ± 0.01	0.26 ± 0.01	0.30 ± 0.01	0.35 ± 0.02	0.39 ± 0.02
8	0.35 ± 0.02	0.33 ± 0.02	0.26 ± 0.02	0.21 ± 0.01	0.22 ± 0.01	0.26 ± 0.01	0.31 ± 0.01	0.37 ± 0.02	0.42 ± 0.02
9	0.35 ± 0.01	0.34 ± 0.01	0.27 ± 0.01	0.22 ± 0.01	0.21 ± 0.01	0.26 ± 0.01	0.31 ± 0.01	0.36 ± 0.01	0.43 ± 0.02
10	0.34 ± 0.01	0.32 ± 0.01	0.26 ± 0.01	0.22 ± 0.01	0.22 ± 0.01	0.26 ± 0.01	0.31 ± 0.01	0.35 ± 0.02	0.39 ± 0.02
12	0.35 ± 0.01	0.32 ± 0.01	0.26 ± 0.01	0.21 ± 0.01	0.21 ± 0.01	0.26 ± 0.01	0.33 ± 0.01	0.37 ± 0.01	0.38 ± 0.02
14	0.37 ± 0.01	0.36 ± 0.02	0.29 ± 0.01	0.23 ± 0.01	0.23 ± 0.01	0.27 ± 0.01	0.33 ± 0.01	0.38 ± 0.02	0.40 ± 0.02
16	0.38 ± 0.02	0.37 ± 0.01	0.29 ± 0.01	0.22 ± 0.01	0.22 ± 0.01	0.26 ± 0.01	0.32 ± 0.01	0.36 ± 0.02	0.41 ± 0.02
18	0.36 ± 0.02	0.35 ± 0.01	0.28 ± 0.01	0.22 ± 0.01	0.23 ± 0.01	0.27 ± 0.01	0.32 ± 0.01	0.37 ± 0.01	0.41 ± 0.02
20	0.34 ± 0.02	0.33 ± 0.01	0.26 ± 0.01	0.21 ± 0.01	0.22 ± 0.01	0.28 ± 0.01	0.33 ± 0.01	0.37 ± 0.01	0.37 ± 0.02
All	0.40 ± 0.02	0.39 ± 0.02	0.31 ± 0.01	0.23 ± 0.01	0.22 ± 0.01	0.30 ± 0.01	0.37 ± 0.02	0.42 ± 0.02	0.41 ± 0.02

Figure 14: Histogram of Percentiles of Scheduled Duration of Surgery Lists of Type IV Pearson Distribution

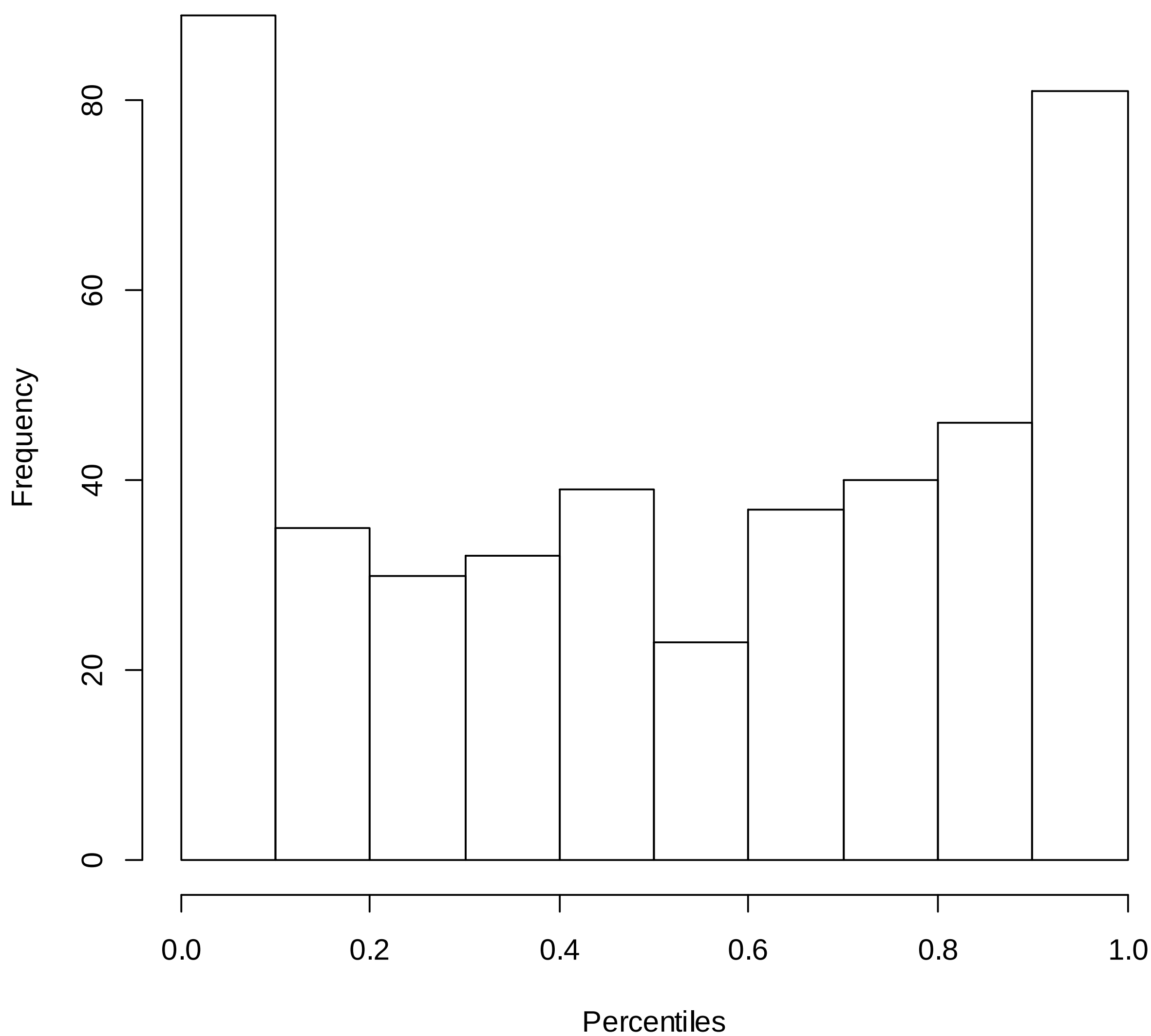
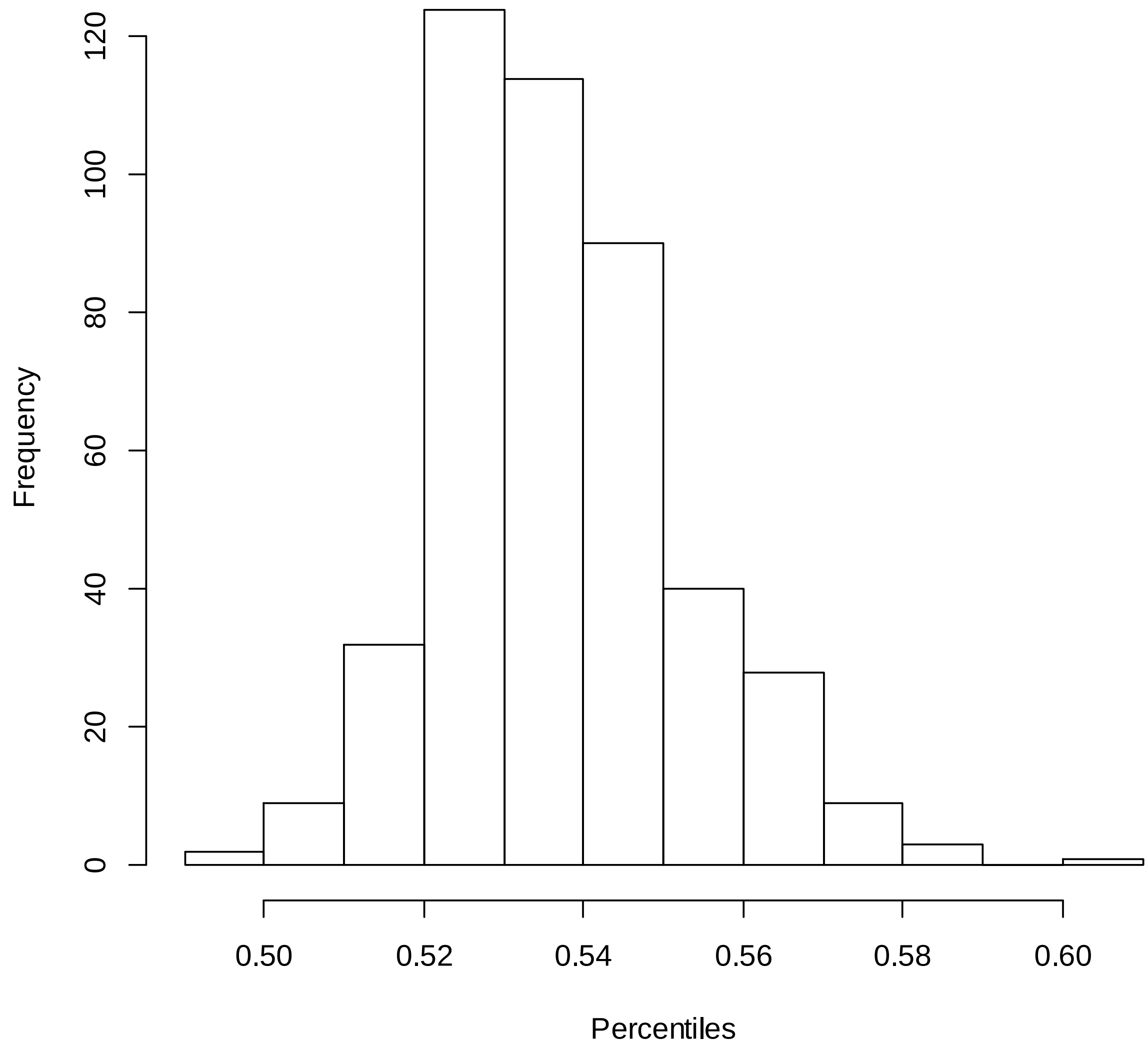


Figure 15: Histogram of Percentiles of Sum of Mean Case Duration of Historical Cases of Type IV Pearson Distribution



3.4 Discussion

Surgery case durations exhibit with high variability (Macario 2009). When multiple cases make up a surgery list where the variability cumulates, the prediction of close time of ORs is more difficult. In order to ensure a good utilization of OR hours and low over-utilized OR time, the planning of surgery lists needs to consider risks at both low and high ends of the distribution of the duration of surgery lists with multiple cases. The accurate identification of the distribution of duration of surgery lists assists the OR schedulers and managers in planning the surgery lists by examining if the current surgery lists have low probability falling outside of the pre-defined limits for under- and over-utilized OR time. The proposed method of using Type IV Pearson distribution to approximate the distribution of total duration of surgery lists is significantly better than assuming a t-distribution of the duration in current studies (van Houdenhoven et al. 2007, Pandit and Tavare 2011), especially towards the tails of the distribution, which are of primary concern for management.

The same case scheduling algorithm proposed by Pandit and Tavare still applies (Pandit and Tavare 2011). However, instead of calculating the probabilities of surgery lists exceeding the defined lower and upper limits by using one-sided t-distributions, probabilities calculated from Type VI Pearson distributions should be used to get more accurate estimates. From Table 7 we also saw that with more than 10 previous cases of same combination of surgeon and procedure(s), the improvements in the identification of percentiles were flattened. Thus, OR management can limit data collection to most recent 10 previous case durations to calculate the probabilities for under- and over-runs. This number matched previous work as well (Zhou and Dexter 1998).

In the studied facility, the scheduled case durations were purely based on surgeons' estimates. Although surgeons' estimates were strong predictor for case durations (Ejkemans et al. 2010, Dexter and Ledolter 2005), the estimates were subject to consistent biases (Dexter et al. 2005). From the results, we saw that significant under- and over-estimations were associated with surgeons' estimates. It was demonstrated that mean case duration of historical cases provided better estimates as they scattered more close to the center of the distribution and less subject to the bias of surgeons' estimates. The absolute difference between the scheduled duration of surgery lists and the actual duration could have been reduced by 20 minutes if sum of mean case duration of historical cases were used compared to using surgeons' estimates alone; however, there was still an absolute difference of approximately one hour.

There were two major limitations in the proposed method. First, we assumed that each case duration and turnover time in the surgery lists follows a log-normal distribution. Although majority of the case durations for combinations of surgeon and procedure(s) were proved to be log-normally distributed, approximately 30% of the cases in the surgery lists were not, which caused mismatches of percentile values at tails of distributions. Then, to use the approach, we had to have at least two previous cases with the same combination of surgeon and procedure(s) to estimate parameters for Type IV Pearson distribution. As have been pointed out, there are many cases with no for very little historical case duration information (Zhou and Dexter 1998, Dexter and Macario 2000, Dexter et al. 2002). These infrequent cases are what cause huge uncertainty in OR decision making. Dexter et al. studied such problem (Macario and Dexter 1999, Dexter and Ledolter 2005) and show that it is appropriate to use the mean case durations of the same procedure(s) by other surgeons to schedule cases (Macario and Dexter 1999). Bayesian model was employed to calculate the prediction bounds for individual case duration (Dexter and Ledolter 2005).[Error! Bookmark not defined.] However, for surgery lists with multiple cases, there are no such models to overcome this challenge. Our proposed method could not apply to surgery lists with cases of less than two historical cases since the estimation of parameters of Type IV Pearson distribution would be infeasible.

3.5 Conclusion

In this study, we brought up and validated a new method to approximate the distribution of the duration of surgery lists. It provides OR management with important information on what they would expect from the planned surgery lists. For a facility whose operations goals does not only include the efficiency of use of OR time but also utilization like the studied facility, after higher and lower limits on scheduled list time have been set, OR managers can rearrange the surgery lists as needed to ensure that the probabilities of the duration of the surgery lists to fall beyond the limits to be low. Despite of some limitations, our approach performs much better than the current proposed methods that assume t-distributions (Pandit and Tavare 2011), especially at tails of distributions, which are of major concerns for OR management. We did not consider tardiness at the beginning of workday. The tardiness of first cases can be easily incorporated in analysis by considering it as an increase in turnover times (McIntosh et al. 2006). Due to incomplete information of the raw data set, we did not include the type of anesthesia, which has been defined as one of the major sources of case duration variability (Strum et al. 2000). For analysts who have access to detailed information on anesthesia and patient's conditions, they can further divide the data into finer segments. Although this would potentially generate more accurate probabilities, it requires larger sample sizes which would limit its application (Zhou and Dexter 1998, Dexter and Macario 2000, Dexter et al. 2002).

CHAPTER 4 PROACTIVE MANAGEMENT OF OPERATING ROOM RESOURCES THROUGH OPERATIONAL SIMULATION

4.1 Introduction and Literature Review

Operating rooms (OR) are one of the most critical units in hospitals. Their importance lies in the fact that surgical procedures not only generate a significant portion of the revenues but also incur significant costs. Recent statistics indicate that ORs account for more than 40% of the hospitals' revenue (HFMA 2005). Macario et al. (1999) estimate that 33% of the hospital inpatient care cost is due to the surgical services. Along with the increase in healthcare expenses and aging population, this percentage has been on the rise over the past decade. Therefore, effective management of the operating room efficiency and costs is critical to lowering the cost of healthcare systems.

The efficient utilization of OR resources depends on multiple factors such as long-term planning (e.g. block time allocations), medium-term planning (e.g., surgery scheduling), uncontrollable operational uncertainty (e.g. surgery durations), and controllable operational uncertainty (e.g., delays in pre- and peri-operative as well as turnover processes). There are many other factors such as case cancellations before/ on the day of surgery, case mix and volume uncertainty, etc. In this study, we consider a single surgical day and the operational factors effecting the utilization of OR resources. The primary cost factors of OR are direct OR staff resources (surgical technician, anesthesiologist, surgeon, circulating nurse, etc.), equipment and facilities, and consumable inventory (implants, sutures, gauzes, etc.). Inefficient utilization of the OR staff, equipment and facility resources leads to lower productivity (i.e., surgery throughput), increased over-utilized OR time and case cancellations, reduced quality of care and lower staff morale. These metrics are not independent. For instance, given the same number of completed surgical cases, an inefficient OR management would lead to more over-utilized OR time and hence lower staff morale. Similarly, under same amount of over-utilized OR time, inefficiencies would lead to increased case cancellations and reduced throughput. Lastly, the over-utilized OR time and case cancellations are correlated since some of the case cancellations are attributable to the excessive tardiness buildup causing later cases to be cancelled. In this study, we consider two metrics, over-utilized OR time and case cancellations. The objective is to minimize the over-utilized OR time in order to maximize the efficiency of use of OR time and reduce the case cancellations (Dexter et al. 2004). For over-utilized OR time, we consider both the expected over-utilized OR time duration and the frequency of over-utilized OR time.

There are a multitude of operational delay reasons effecting the efficient utilization of OR resources. For example, if the surgeon is not available, the patient cannot be brought into the OR and the room will be idle until the surgeon arrives. Similarly, if the patient arrives late, then the surgery cannot start until the pre-op processes are complete and patient is ready. Since the majority of OR processes are executed in series, the lost time in the OR hours propagate throughout the day and cause the tardiness of start for the subsequent cases.[10] This tardiness propagation is analogous to those in the manufacturing environments such as in the assembly line systems. An analogous assembly line system for a multi-OR system is where there are parallel machines (representing each OR) which receive inflow of units from a single machine (pre-op) and send to a single machine (post-op). The flow units in this system are the surgical cases which are routed to different ORs (machines) according to the given schedule. The processing time of each surgical case in each OR is uncertain and includes all the surgery process durations as well as tardiness. The queuing discipline is priority-based where the priorities are determined according to the scheduled order of surgical cases.

In manufacturing settings, the throughput and machine utilizations are commonly increased by identifying and eliminating bottlenecks through preventive (opportunistic) maintenance. Preventive maintenance, different from the corrective maintenance, is carried out

[10] There are some OR processes that are sometimes performed in parallel, such as anesthesia induction and setup.

at the opportunity windows where the production is unaffected by the preventive maintenance action (Iravani and Duenyas, 2002; Zequeira et al., 2008; Chang et al., 2007a; Kenne et al., 2007). Given scarce maintenance resources, the prioritization of the maintenance tasks is essential (Dekker and Smeitink 1994; Dekker 1995; Khanlari et al. 2008). A popular strategy is the bottleneck-based maintenance prioritization (e.g., Langer et al., 2010; Li et al., 2009; Chang et al., 2007b). This strategy prioritizes maintenance tasks in accordance with the historical bottlenecks ordering using the most recent data. While, this approach is suitable for most manufacturing systems with stable dynamics (e.g., product mix), it is not applicable in systems where the interaction between the machines varies with the production mix. In such cases, the historical data on bottleneck machines is not reliable and requires forward looking bottleneck prediction (anticipatory) through simulation. The simulation approach is frequently used in the manufacturing settings, with the goal of determining the ideal design of the manufacturing system considering the average performance across multiple scenarios (e.g., product mix and sequence). The use of simulation for operational performance prediction, identification of dynamic bottlenecks and maintenance prioritization is not considered.

The prior work using simulation approaches in ORs focused on evaluating different OR policies, staffing and case scheduling algorithms on patient flow, making OR suite usage and capacity decisions. Sobolev and Kuramoto (2005) used simulation approach to evaluate the length of surgical patients' waiting list for various intervention policies in order to improve patient flow. They considered intervening 14 peri-operative activities ranging from outpatient clinic appointment, anesthesiology consultation to post-op care activities. Cipriano et al. (2007) developed a simulation model to predict the wait time of patients for total joint replacement surgery and made recommendations for supply and surgical allocation to meet the target demand levels as well as to manage wait time performance. Vasilakis et al. (2007) compared patients from pooled list versus surgeon linked patients and used simulation to evaluate the impact on the time between the appointment and the day of surgery. Denton and Nelson (2006) used Monte-Carlo simulation approach to evaluate the impact of different surgical suite staffing scenarios on multiple competing criteria (i.e. patient wait time and over-utilized OR time of OR suite). Murat and Nepal (2010) used simulation to study the effect of case sequence on the overtime performance. They considered different surgery start time policies and resource coupling levels. Dexter et al. (1999) used simulation and scheduling algorithms to explore the relation between the patients' wait time and the utilization of OR block time. Ballard and Kuhl (2006) employed the simulation methodology to determine the maximum capacity of OR suite by continuously adding patients into the system. They compared resource usage such as OR staff and room utilization as well as patient's satisfaction. In summary, the prior simulation-based research in ORs is focused on long-term decision making rather than what can be done in the short-term, i.e., days before the surgery or on the day of the surgery.

In this study, we develop a simulation based approach, called proactive operational management of OR resources (POM-ORS), for OR managers to anticipate, prioritize and eliminate operational delays to optimize OR performance. This approach is similar to the debottlenecking in manufacturing systems. The main difference is the use of simulation for *operational* performance prediction and prioritization of delays for elimination. The POM-ORS predicts the impact of tardiness in over-utilized OR time and case cancellations, and then prioritizes the tardiness for debottlenecking. This approach helps OR managers' in anticipating and preventing tardiness and improving over-utilized OR time and case cancellations. The remainder of the chapter is organized as follows. In subsection 2, we present the simulation model scope and describe the proposed POM-ORS approach in details. subsection 3 presents the results of a case study application and discusses the limitations and extensions of POM-ORS. Subsection 4 provides conclusions and future research directions.

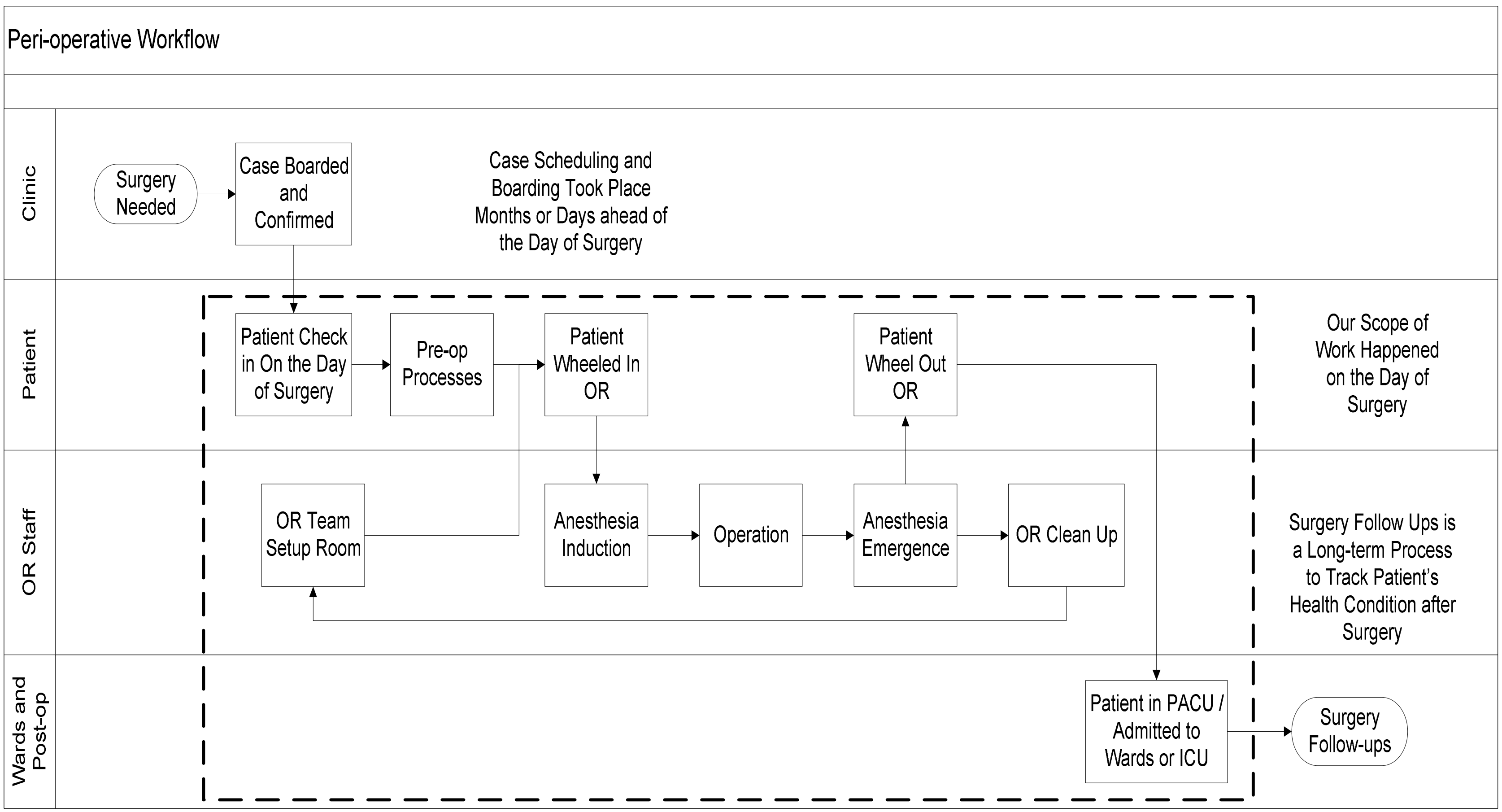
4.2 Method

4.2.1 OR Simulation Model Scope

The surgical cases are first generated in clinics where surgeons, upon examining the patients and medical records, decide the need for surgery. Following the patients' agreement, the surgical case requests are put into the surgery information system. Next, the patients undergo several tests before the day of surgery to ensure that the patients' health status are suitable for the surgery. On the day of surgery, patients are admitted to the pre-op area. Pre-op nurses measure the vitals and carry out final lab tests to ensure the surgeries can be performed on patients without medical concerns. Concurrently, the OR nurses and surgical technicians set up and prepare the ORs for the surgery. Once all the preparations are completed, the patients are wheeled into the ORs. Next, the anesthesia is induced by anesthesia team and surgery is performed by the surgical team. Following the anesthesia resuscitation, the patients are wheeled out to the PACU / ICU for recovery and then either admitted to regular in-patient wards/ICU or discharged to home.

The scope of the simulation model includes all the processes extending from patients' arrival at the pre-op area to wheeling out to the PACU/SICU, i.e. the processes included in the frame in Figure 16. The purpose of our simulation model is to support operational decision-making. Therefore, we limit the simulation to a single day of surgery and assume that the schedule is determined a prior. We do not consider the downstream steps such as bed management, ICU performance or long-term patient health condition tracking. We measure the performance based on over-utilized OR time and case cancellation rate.

Figure 16: Peri-operative Workflow



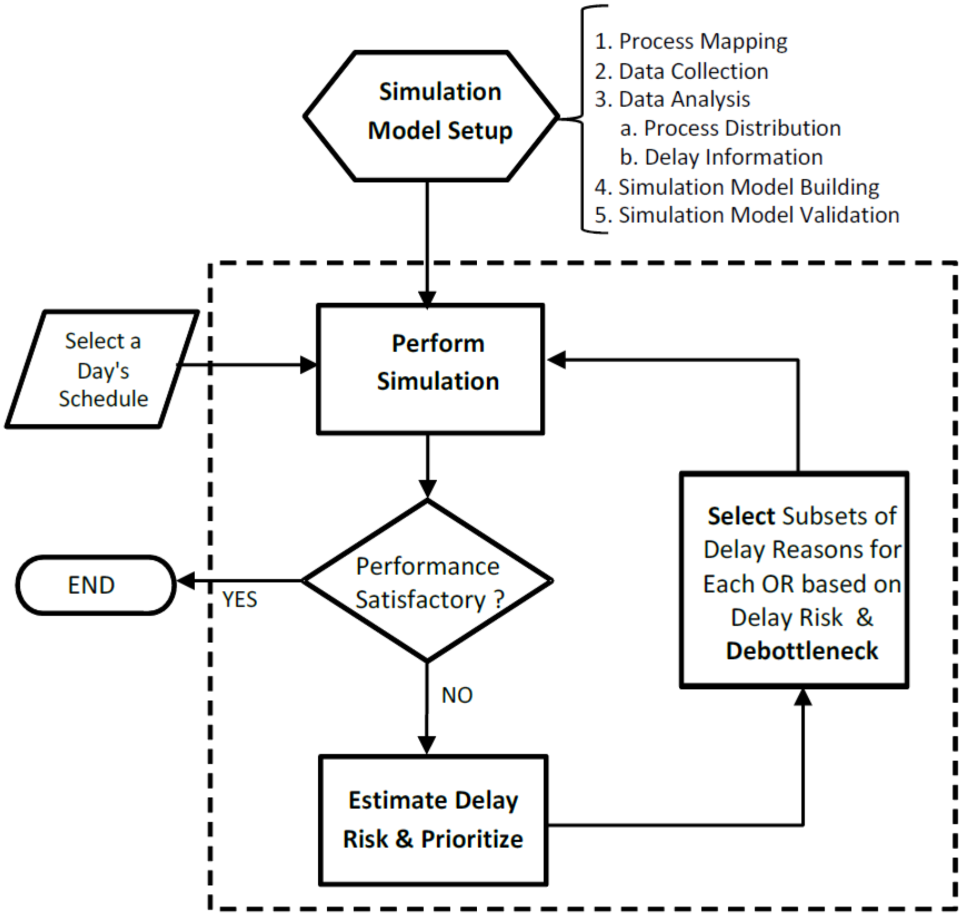
4.2.2 Description of Simulation Model

We used a single day OR schedule as the input to the simulation model, including scheduled start and end time of each case, OR assignment of cases, PACU type, scheduled procedure defined by principle CPT code. The model read the information for each case before running. For each case, the whole process flow started from the arrival of patients. The sequential processes were executed according to the durations generated from their fitted distributions following the steps in Figure 16. The distributions of the arrival pattern of patients to the pre-op area (how early the patient arrives in the pre-op area before the scheduled case start time), the actual case duration, the cleanup and setup time, the length of stay in PACU, and the transfer times such as the time to bring a patient from pre-op are to OR or from OR to PACU were analyzed using historical data. As mentioned in the previous section, tardiness is observed in each process on the day of surgery. If the scheduled duration of the case is 2 hours, but due to some complexity during the operation, the case actually takes 4 hours to complete. As the tackling of tardiness in surgery processes involves medical knowledge, and a reduction of such tardiness might result in undesirable outcomes such as patient safety issues, it is not our intention to create medical issues. The tardiness we focused on was only related to non-operative processes (i.e. pre-op processes and turnover times). To model the tardiness, we built a sub-model for pre-op and turnover time processes where tardiness was assigned according to the probability of occurrence and realized duration distributions from historical data. In a simulation run, when a patient entered into the OR after the scheduled case start time, the tardiness was calculated and attributed to the associated delay reasons. After each simulation run, the statistics were output for analysis.

4.2.3 Proactive Management of Operating Room Resources (POM-ORS)

The POM-ORS is a concept similar to the debottlenecking in manufacturing systems where bottleneck machines are improved through preventive maintenance actions. We adopted this concept to the management of OR with some differences. The process flow map of the POM-ORS framework is presented in Figure 17. This approach begins with simulation model building, where a representation of the workflow on the day of surgery is constructed through process mapping and converted into modules. Data collection is conducted and corresponding distributions are fitted. Then, a single day's schedule is input into the model and baseline performance is established by running the model. If the baseline performance meets the target, then there is no need for the OR management to focus on particular tardiness; otherwise, based on the delay risks which we are going to describe in next subsection, the OR management eliminates the most important tardiness and reruns the model. The new performance data is then collected for the new model without the most important tardiness, and the results are compared with targets again to see if the performance is satisfactory. The process repeats until an acceptable performance level is achieved by continuously removing the most important tardiness from the process. The first difference between this approach and previous simulation studies is the operational nature of the simulation model where a given day's surgical schedule is simulated. Second, we consider the tardiness as the source of bottlenecks and identify which delay reasons are more important than the rest through delay risk prioritization. Thirdly, we use a novel debottlenecking approach that considers multiple delay reasons at a time. In the next two subsections, we describe the delay risk estimation and prioritization, and debottlenecking procedures in detail.

Figure 17: POM-ORS Process Flow Chart



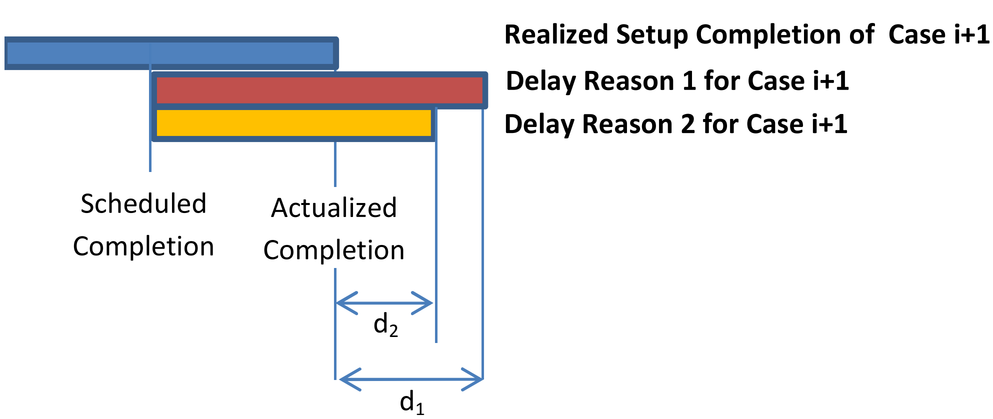
4.2.4 Delay Risk Estimation and Prioritization

We define a case tardiness as the difference between the time the patient entered the OR and the scheduled case start time. For instance, given a scheduled case start time at 10 AM and the patient enters the OR at 10:20 AM, then there will be a 20-minute tardiness. When a patient is wheeled into the room on or before the scheduled case start time, then there is no tardiness. These delay reasons vary in terms of their probability of occurrence as well as their effective duration. We define the delay risk as follows,

$$Delay\ Risk = Effective\ Tardiness\ \times Probability\ of\ Occurence.$$

Some of these delay reasons occur simultaneously. For instance, when the patient's consent form is missing and the anesthesia setup does not start on time, then they overlap. As a result, the effective impact of the delay duration of each delay reason could be different than the realized delay duration. Furthermore, some tardiness can have no effect on the realized schedule as a result of propagated delays of the previous cases. At the end of each simulation replication, we consider the occurrence of each delay reason separately and account for only those portions of the tardiness that is affecting start of the next case. This is illustrated below in Figure 18, where the previous case (i) is delayed and the turnover is completed for case (i+1) later than the scheduled end time. The two delay reasons for case (i+1) are realized as shown. We consider the effective tardiness of delays 1 and 2 as the portions d_1 and d_2 of their respective realized durations. Note that these are truncated durations of the realized tardiness. The effective tardiness of the previous case overrun is then the difference between scheduled and actualized completion times. If the effective tardiness for a delay reason is positive, then we record it as an occurrence for calculating probabilities.

Figure 18: Illustration of Effective Tardiness



The delay probability of occurrence and distributions for each delay reason were available from the historical data (e.g., input in the simulation model). However, the simulation results for the tardiness and probability of occurrence were different than the input distributions. This is because of the difference between realized and effective tardiness. Furthermore, the majority of the effective tardiness for later cases were "previous case overruns" which was attributable to the propagation of tardiness. Lastly, since there was no historical distribution for the previous case overruns, they were estimated directly from the results of the simulation run. A sample of the delay risk calculation based on effective tardiness and occurrence frequency is illustrated in Table 10. This sample case is delayed for 35 reasons plus the "previous case overrun" reason. We note that the majority of the tardiness occurrences (about 73%) are due to previous case overrun.

4.2.5 Debottlenecking Delay Reasons

Once the delay risks are estimated, we first select the bottlenecks (i.e. delay reasons with highest delay risks) and then debottlenecked them using proactive management strategies (Figure 17). The first simulation run of a given day's schedule evaluates the baseline scenario where none of the delay reasons has been debottlenecked. The number of tardiness to be managed can be determined by available resources for proactive management as well as whether the tardiness are controllable or not, e.g. ensuring surgeons are present whenever the rooms are ready or setups start without tardiness following cleanup. Other tardiness such as previous case overruns or patient being late are not controllable thus are not considered for debottlenecking.

Table 9: Example of Delay Outputs

No	Delay Description	Delay Statistics: Probability of Occurrence	Effective Duration	Delay Risk	No	Delay Description	Delay Statistics: Probability of Occurrence	Effective Duration	Delay Risk
1	SURGEON LATE	5.9%	19	1.1	19	VENDOR DELAY	0.4%	30	0.1
2	ANESTHESIA SET UP	5.5%	20	1.1	20	EQUIPMENT FAILURE	0.2%	60	0.1
3	INCORRECT OR NO CONSENT	4.7%	21	1.0	21	HOUSEKEEPING	0.5%	25	0.1
4	PRE-OP LAB WORK	2.2%	34	0.7	22	XRAY DELAY	0.3%	42	0.1
5	PT LATE	1.7%	37	0.6	23	ALTERATION/ADDITION TO CASE	0.3%	31	0.1
6	ROOM/EQUIPMENT SET UP	2.5%	20	0.5	24	EQUIPMENT FROM OTHER HOSP/R	0.3%	24	0.1
7	OR STAFF NOT AVAILABLE	1.1%	33	0.4	25	NO INPT BED AVAILABLE	0.3%	24	0.1
8	OTHER DEPARTMENT DELAY	1.9%	17	0.3	26	PT IN BATHROOM	0.5%	12	0.1
9	EQUIPMENT NOT AVAILABLE	1.0%	28	0.3	27	BOARDED INCORRECTLY	0.2%	26	0.1
10	ANESTHESIA PRE-EVAL/RECHECK	1.6%	17	0.3	28	REGIONAL BLOCK PLACEMENT	0.3%	16	0.0
11	PT REQUEST TO SEE SURGN PRE-OI	0.9%	21	0.2	29	ADMINISTRATIVE DELAY	0.3%	19	0.0
12	STERILIZATION OF INSTRUMENTS	0.4%	50	0.2	30	TRAVEL	0.2%	20	0.0
13	MEDICAL WORK-UP/CLEARANCE	0.5%	33	0.2	31	SURGEON MARKING PATIENT	0.4%	9	0.0
14	LINE PLACEMENT	0.5%	29	0.1	32	SCHEDULING ERROR	0.1%	47	0.0
15	SURGEON UNAVAILABLE	0.7%	20	0.1	33	PT VALUABLES SECURED	0.1%	45	0.0
16	ADD-ON CASE	0.5%	29	0.1	34	PATIENT WANT TO TALKT TO FA	0.1%	13	0.0
17	PT ATE/DRANK	0.3%	40	0.1	35	LISTED AS STAFF PERSON	0.1%	10	0.0
18	MDA/DOA/CRNA NOT AVAILABLE	0.8%	15	0.1		**Total**	**36.95%**		

Given that there are numerous delay reasons for each surgical case, the number of ways that bottleneck tardiness can be selected is innumerable for practical applications. For instance, let's consider that there are 10 cases on the day's schedule, each with 10 delay reasons. Further, let's assume that there are enough resources to debottleneck 30 out of 100 tardiness. Hence, there are about $\binom{100}{30} = 3\text{x}10^{25}$ different subsets of 30 tardiness that can be selected. Clearly, evaluation of performance by simulating all these possibilities is impractical. In the proposed POM-ORS, we use the risk prioritization results to select the tardiness in an iterative fashion. Note that iterative approach is necessary since the estimated delay risks are based on baseline scenario and risk prioritization changes with the elimination of tardiness. Considering the above example and assuming that we select the top delay reason to eliminate in each iteration. The total number of simulations necessary is only 30 for a single OR, which is practical for operational intervention. Once the top delay risk is identified, we remove it from the simulation model and a new round of simulation is performed. This process of eliminating top delay reason is continuously repeated until a desired performance has been achieved.

4.3 Case Study Application

In this case study, we applied the POM-ORS approach using an actual day's schedule and data obtained from the Detroit VAMC (Table 11). In this schedule, there were three specialties, namely, General, Ophthalmology, and Orthopedics. The distributions of surgery durations were obtained using the historical data and based on two significant factors (CPT and surgeon) from January, 2008 to January, 2011. This is in accordance with the earlier research that CPT and surgeon are the two most important factors that impact the surgery duration (Strum et al. 2000). The cases were PRP I/HERN INIT REDUC>5YR (CPT 49505) for general surgeon A, Cataract (CPT 66984) for ophthalmology surgeon B, and Total Knee (CPT 27447) for orthopedic surgeon. The general surgery cases followed a Weibull (50.8, 1.76) distribution. The cataract surgery cases followed an Erlang (16.7, 2) distribution. The orthopedic surgery cases followed a Normal (126, 27.3) distribution. The order of the scheduled end time of the last case in each OR was first OR 1, next OR3, and last OR2. The three different procedure types exhibited different levels of case duration variability. Cases in OR2 had the largest case duration variability; thus, we expected the actual OR close time of this OR to have large differences in each simulation run, whereas the case duration in OR3 has the least case duration variability. Its close time would be more predictable than that of OR2. The three ORs represented different scheduling policies. For OR1, the scheduled end time of the last case was much ahead of the OR close time. For OR2, the last case was scheduled to be end 15 minutes beyond the OR close time. As for OR3, the expected close time was almost the same as the OR close time. By comparing the results of POM-ORS in ORs with different scheduling policies, we expected to obtain insights into the effectiveness of POM-ORS in different OR conditions.

The operating hours of the surgical suite in the studied facility were from 8 AM to 4 PM. The cases were scheduled in a way such that the OR closing times were not past 4 PM except on special cases depending on the patient's condition or other considerations. The scheduled duration of each case was based on the sum of mean case duration of historical cases and the mean turnover time for each specialty except for the last cases where there was only cleanup (Dexter et al. 1999, Alvarez et al. 2010).

Table 10: OR Case Schedule

OR No	Scheduled Start Time	Scheduled Completion Time	Specialty	CPT Code
1	8:00	10:30	GENERAL	49505
1	10:30	13:00	GENERAL	49505
1	13:00	14:45	GENERAL	49505
2	8:00	9:15	OPHTHALMOLOGY	66984
2	9:15	10:30	OPHTHALMOLOGY	66984
2	10:30	11:45	OPHTHALMOLOGY	66984
2	11:45	13:00	OPHTHALMOLOGY	66984
2	13:00	14:15	OPHTHALMOLOGY	66984
2	14:15	15:30	OPHTHALMOLOGY	66984
2	15:30	16:15	OPHTHALMOLOGY	66984
3	8:00	10:45	ORTHOPEDICS	27447
3	10:45	13:30	ORTHOPEDICS	27447
3	13:30	15:30	ORTHOPEDICS	27447

For each case, there were 35 delay reasons in addition to the previous case overrun (Table 10). In POM-ORS analysis, we only considered the tardiness that had at least 1% of probability of occurrence (i.e. top 10 tardiness highlighted in Table 10). These tardiness accounted for 73% of the total probability of tardiness occurrence and also were the top ten in terms of delay risk. This selection was not restrictive and the POM-ORS could be applied with any number of delay reasons. For each model, we ran 1000 replications. Arena 13 student version (Rockwell Automation, Wexford, PA) was used for model building.

4.3.1 POM-ORS Results

We evaluated the effects of POM-ORS on the mean over-utilized OR time, percentage of days with over-utilized OR time, and percentage of days with cancellations. For cancellations, we used the policy of cancelling the upcoming cases if the OR closing time was predicted to past the OR closing time by more than 2 hours.

We first implemented the POM-ORS approach shown in Figure 17 by iteratively eliminating the top delay reasons for each room. We compared the performances vis-à-vis the baseline scenario where no tardiness were eliminated. The results are presented in Table 12a using the historical case durations (e.g. upper part of the Table 12 denoted by Current). The percentage of days with over-utilized OR time (OT) and the mean over-utilized OR time were decreased on the average by 25% and 14%, respectively. These improvements show that the OR managers can improve the over-utilized OR time performance by proactively managing the anticipated tardiness. We noted that the least improvement in percentage of days with over-utilized OR time is in OR2, which was scheduled to complete latest. This is because OR2 had significant over-utilized OR time (mean over-utilized OR time = 58.4 minutes in baseline model). As a matter of fact, this room was scheduled to overrun by 15 minutes of the OR closing time. The debottlenecking of tardiness was not sufficient to reduce the probability (see baseline in Table 12b). By the same analogy, the greatest improvement was observed in OR1. In comparison, the mean over-utilized OR time was mostly improved for OR3 since it had less surgery duration variability than OR2. Furthermore, the percentage of days with cancellations had decreased by 38% on the average. Based on these results, we concluded that the improvement effects of POM-ORS's on over-utilized OR time and cancellation depend on the scheduling policies as well as the surgery duration variability. In particular, when there is significant over-utilized OR time (e.g. due to poor scheduling), then the impact of POM-ORS in reducing the over-utilized OR time and cancellation is less discernible (The results of simulations are documented in Appendix E and Appendix G).

We also investigated the effects of surgery duration variability on the POM-ORS improvements. In Table 12a, we reduced the case duration variance of all surgeries by half (e.g. lower part of the table denoted by 50% Variance) and reran the model. The results show that reducing surgery duration variance improves performance in both over-utilized OR time and the case cancellation. We note that after the reduction of case duration variance there are no cancellations in OR3 in baseline performance. At the same time, the cancellation in OR2 was reduced by 80%. The percentages of days with over-utilized OR time were further improved for both OR2 and OR3. Hence, these results indicate that the benefits of implementing POM-ORS methodology increase with reduced process variability.

In summary, the POM-ORS is most beneficial when the case schedules are developed based on accurate case duration estimates (e.g., reduced variance) and without significant over-utilized OR time.

Table 11: (a) Effects of POOM-ORS on Over-utilized OR time and Case Cancellation; (b) Effect of Debottlenecking Multiple Delay Reasons at a Time on Percentage of Days with Over-utilized OR time

	OR	**OT%**	**Mean OT**	**Cancel %**
Current	1	34%	9%	N/A
	2	10%	14%	35%
	3	30%	20%	40%
	OR	**OT%**	**Mean OT**	**Cancel %**
50% Variance	1	N/A	N/A	N/A
	2	16%	28%	80%
	3	67%	32%	N/A

(a)

Occurrence of Over-utilized OR Time

	3 Tardiness at a Time			1 Tardiness at a Time		
	OR 1	**OR 2**	**OR 3**	**OR 1**	**OR 2**	**OR 3**
Baseline	12.8%	92.6%	44.4%	12.8%	92.6%	44.4%
Top 3	12.2%	92.6%	42.5%	12.1%	92.6%	42.5%
Top 6	11.5%	92.4%	41.1%	11.5%	92.4%	40.6%
Top 9	11.2%	92.3%	39.4%	11.1%	92.2%	39.3%
Top 12	10.4%	92.0%	37.3%	10.4%	92.0%	37.3%
Top 15	9.9%	91.6%	36.6%	9.9%	91.6%	35.8%
Top 18	9.5%	91.5%	35.3%	9.4%	91.5%	34.8%
Top 21	9.2%	91.0%	34.8%	9.1%	90.8%	34.7%
Top 24	8.9%	90.0%	33.9%	8.7%	90.0%	33.9%
Top 27	8.7%	87.6%	33.3%	8.7%	87.5%	33.3%
Ideal	8.4%	82.9%	31.0%	8.4%	82.9%	31.0%

(b)

The results in Table 12a were based on debottlenecking all the delay reasons through POM-ORS. In Table 12b, we present the progression of the percentage of days with over-utilized OR time as we iteratively eliminated delay reasons one at a time for each OR. The POM-ORS improvement increased nonlinearly with the number of eliminated tardiness. The top delay risks for later cases are previous case overrun that mask the other delay risks. Thus, in the first few simulation runs, the top delay risks are associated with delays of early cases. However, the tardiness from the early cases do not impact the OR close time as tardiness of later case because of the high case duration variability. As the tardiness of early cases are removed, the probability of previous case overrun decreases, causing the delay risks for later cases to increase and to be prioritized. This is one of the weakness of our approach and we discuss it in the following section. The POM-ORS is a myopic approach where we debottleneck one tardiness at a time. This is important for restricting the number of simulation runs for practical applications. Some large surgical facilities perform close to 100 cases a day and, with 20-30 delay reasons for each case, the total number of simulations could be daunting. One remedy is to debottleneck multiple tardiness at a time. Table 12b results compared the strategies of debottlenecking one versus three tardiness at a time. The difference between the two strategies in the percentage of days with over-utilized OR time is within 1 percent for the same number of eliminated delay reasons, meaning aggregate tardiness debottlenecking can be used as part of POM-ORS.

We caution that the level of aggregation should be kept as minimal as possible since the risk prioritization of tardiness changes with the debottlenecking. For instance, whereas the anesthesia delay of the last case in OR3 was ranked 9^{th} in the baseline risk prioritization, the sequential debottleneck process identified it as the 5^{th} delay to be debottlenecked (Appendix F). This is because the tardiness preceding the anesthesia delay were masking the effect of anesthesia delay through the previous case overruns. Once these tardiness were eliminated, the risk priority of the anesthesia delay increased. Similar re-orderings of delays were observed in all rooms.

4.3.2 Discussion

Results from the case study clearly show that the POM-ORS approach improves the percentage of days with over-utilized OR time and its mean duration, and reduces case cancellations. The extent of improvements depends on the case schedule as well as the case duration variability. Reducing case duration variance increases the effectiveness of POM-ORS as the effects of delay reasons are no longer dampened as much by the previous case overruns. This is similar to the role of inventory in manufacturing settings where the problems associated with manufacturing processes (e.g., machine breakdowns, quality defects) are masked by the high levels of safety inventory. The highest impact of lean practices is obtained after removing the excess inventory and revealing the underlying process problems. In our analysis, case duration distributions are based on CPT code and surgeon factors. Some other research indicates that anesthesia type, OR team composition, and patients' characters also influence the duration (Cassera et al. 2009, Stepaniak et al. 2009, Stepaniak 2010). By more accurate statistical estimation of the surgery duration distributions, the variability can be further reduced to improve the benefits of POM-ORS approach.

The sequential debottleneck results indicate that there is no significant difference between eliminating one versus three tardiness at a time. This suggests that POM-ORS can be efficiently implemented by aggregating tardiness. However, since the risk priority of tardiness change with sequential elimination, caution must be exercised. We surmise that, as the differences between delay risks increase, the need for sequential decreases and aggregation becomes more acceptable. This is because the tardiness with dominating risks are less likely to shift in their importance order. In general, one might expect the Pareto principle (the law of the vital few) to hold where majority of the POM-ORS benefits could be attained by debottlenecking few tardiness. However, we observed that the benefits of debottlenecking increases with the tardiness eliminated. This is explained by noting that the initial delay risk estimates are not accurate for later case delays as the previous case overruns mask the true effect of these later tardiness. In summary, the sequentially debottlenecking also provides the benefit of accurately estimating the delay risks for later cases' tardiness.

The delay reasons are prioritized based on tardiness of case start time, but the effects of debottlenecking is evaluated in over-utilized OR time and case cancellation rate. Clearly, a 5-minute delay does not necessarily result in 5-minute addition to the over-utilized OR time, and, similarly, a 5-minute of surgeon being late for the 1st case may not have the same effect in over-utilized OR time as a 5-minute of surgeon being late of the last case. Hence, the tardiness prioritization for debottlenecking should ideally be based on performance measures. However, this requires extensive simulation effort due to the need for a separate simulation run for each possible tardiness subset to be eliminated. In the proposed POM-ORS approach, there is need for only a single simulation run. Further, the practice of proactive management requires OR managers to tackle the most important tardiness first and then extend their efforts to the subsequent tardiness.

As we explored the POM-ORS under different scheduling policies (under-scheduled, over-scheduled and matching scheduled) with different case duration variability (low and high). The effectiveness of POM-ORS should be widely applicable to other facilities, regardless of their allocated OR time or complexity of surgeries (i.e. case duration distributions) or surgery specialty characteristics. In the case study, we assumed an 8 hour OR allocation. In other big facilities, ORs might be allocated with 10 or 12 hours. For those facilities, the number of scheduled cases in each OR is greater than the scenario studied here with more delay reasons to be tackled. POM-ORS is more beneficial for big ORs as no matter how many delay reasons present in the system, the number of simulation runs depends only on the number of delay reasons to be eliminated. If the OR manager wants to eliminate top 10 delay reasons in each room, then whether there are 5 ORs or 30 ORs, only ten simulation runs need to be executed. Thus, the complexity of this approach does not increase exponentially with the OR workload as many other optimization/statistical approaches, which makes this approach very useful from practice perspective. In our case study, we simplified the OR operation by assume each OR performed a single type of cases. Wachtel and Dexter (Wachtel and Dexter 2009) explored factors that impact the case start time. They found out that the mean tardiness of case starts does not depend on the mix of case duration nor the type of cases performed in the OR suite, but the total time elapse as the uncertainty in the total duration of series of cases is greater. The conclusions of our studies; thus, are not subject to change as the type of facility changes.

A significant portion of the case is delayed due to previous case overrun, even though some research has indicated that using mean to schedule cases is reasonable (Dexter et al. 1999, Alvarez et al. 2010). The overruns are due to the natural variability of surgery processes. This problem cannot be solved by obtaining more cases for duration estimation (Zhou et al.

1999, Wachtel and Dexter 2009). There are many papers studied the estimation of single case duration. None of it has the ability to prevent the tardiness of case start. A more detailed segmentation of case duration data by using more factors can provide a more detail-oriented mean case duration for case scheduling; however, the case duration variability remains high. And when more factors are included, the sample size for mean case duration calculation decreased, making a lot of cases has no or very few historical duration for scheduling (Dexter and Macario 2000, Dexter et al. 2002). Thus, in order for the OR to optimize the performance, it is more important to allocate the OR time which takes into account of the case duration prediction inaccuracy to achieve an optimum efficiency of use of OR time and coordinate the scheduling of cases to control the total variability of the surgery lists rather than a more accurate estimation of case duration, because the estimation is not accurate. Given an optimum allocated OR time, the POM-OR improves the efficiency of use of OR time further not through re-allocation of OR time, but reducing the cost of over-utilized OR time. Thus, our study complement the current OR allocation study.

There are several adaptations of the POM-ORS. We implemented POM-ORS by selecting the top delay reasons one at a time for each OR. However, this independent selection assumes that there is no interaction among ORs. The degree of interaction between ORs in Detroit VAMC is negligible. In larger OR theaters, surgeons may simultaneously perform multiple surgeries in different ORs or anesthesiologists support multiple cases at any given time. Then, the tardiness in one OR could have impact on the other ORs and vice versa. In such cases, the shared resources across ORs need to be considered as a single resource and the tardiness for those resources need to be evaluated jointly. While we have not explicitly accounted for the costs, the debottlenecking of tardiness requires resources in the form of staff time, expedited orders, and so on. The POM-ORS methodology can be adapted to include the cost considerations by selecting the delays based on their priority as well as the availability and cost of resources.

Here, in our analysis, we assumed that the elimination of tardiness will not impact the quality of care and all the top delay reasons can be completely resolved from the system. However, this assumption is partially correct in reality. For example, a case is delayed because of the patient condition needs further medical evaluation. We do not emphasize the importance of eliminating this tardiness over patient safety by forcing the patient to be in the OR without a thorough evaluation as it would result in severe outcomes. Thus, some of the delay reasons might not be able to completely disappear from the system. In implementation, the team can accommodate the incompleteness of elimination of a specific delay reasons by adjusting the level of delay resolution through modifying the delay probability of occurrence and realized durations.

4.4 Conclusion

We developed a proactive management approach for OR resources based on operational simulation. This approach can be used by OR managers take proactive actions to improve the operational performance (e.g., reduce the over-utilized OR time and case cancellations). The proposed approach quantifies risks associated with operational delays and prioritizes them for elimination subject to available resources. The a simulation model needs to be run iteratively so that the dynamics in the delay risks are captured in such a way the most important delay reasons are output on top of all the delay reasons. In such a way, the OR managers are provided with a number of delay reasons for each OR by eliminating which to generate the most significant performance benefit. The approach is applicable to any OR facility type as long as the historical data on case delay information is available to as input into the model. The execution time of the model depends linearly on the number of delay reasons to be eliminated for each OR per the choice of OR management and not depend on the size of the OR, which makes it really beneficial to large ORs where large number of delays cause the difficulty for delay reason selection at the first place. Through a case study, we demonstrated the benefits of the proposed approach on reducing over-utilized OR time and case cancellations. The benefits increase with effective scheduling practices, reduced surgery duration variance, and accurate prediction of surgery durations.

There are several avenues for further investigation. First research opportunity is the investigation of the interplay between scheduling policies and effectiveness of the proposed approach. Second research direction is to develop a methodology for selecting multiple delay reasons and debottlenecking them collectively so as to improve the efficiency of the proposed approach while maintaining its accuracy.

CHAPTER 5 BEHAVIORAL STUDY OF MEAN TURNOVER TIMES AND FIRST CASE START TARDINESS

5.1 Introduction and Literature Review

Operating room (OR) scheduling systems list allocated OR time by service. The cases are scheduled into the allocated time. When cases end later than the allocated hours, there is over-utilized OR time. Contemporary OR information systems also include electronic displays ("whiteboards") showing information about surgical case progress to facilitate OR managers' decision making on the day of surgery (e.g., to reduce over-utilized OR time). However, decisions involving multiple ORs that are made using these passive displays are significantly *worse* than random chance (Dexter et al. 2007a). Instead, displays with *recommendations* enhance decision-making, and education increases trust in recommendations (Wachtel and Dexter 2010).

Previous work has identified two psychological biases as contributing to the lack of benefit of information alone (Dexter et al. 2007, Stepaniak et al. 2009). First, at the OR control desk, decisions for add-on case scheduling, moving cases between ORs, etc., differ depending on whether the decision-maker is psychologically risk averse or not risk averse (Stepaniak et al. 2009). Second, many OR staff make decisions based on increasing clinical work per unit time during the hours they are assigned (Dexter et al. 2007a). This heuristic (rule-of-thumb) is logical for decisions involving single ORs, because the heuristic serves to reduce the expected hours of over-utilized OR time. However, when applied to decisions involving multiple ORs, the decisions are highly sub-optimal (Dexter et al. 2007a, Dexter et al. 2007b). For example, if there is one empty post-anesthesia care unit bed for two ORs, the bed often would go to the first exiting OR with 1 hr under-utilized OR time rather than to the second OR exiting 10 min later but with > 1 hr over-utilized OR time. For another example, if an anesthesiologist has two ORs each with experienced certified registered nurse anesthetists ready to start, the anesthesiologist often would first do the quick adult induction in one OR with under-utilized OR time and then do the longer pediatric induction with caudal block in the OR with over-utilized OR time (Dexter et al. 2007a). As expected based on being due to a bias, behavior is unaffected by education and by changes to cases' classifications of medical urgency (Dexter et al. 2007a, Ledolter et al. 2010). The bias may be sustained by physician perception of team activity as being favorable (Shapiro et al. 2010, Masursky et al. 2011).

A limitation of the preceding studies (Dexter et al. 2007a, Dexter et al. 2007b) is that information alone (e.g., by electronic white board) was worse than random chance for decisions in simulated scenarios (Dexter et al. 2007a) involving changes in over-utilized OR time (Dexter et al. 2009, Wachtel and Dexter 2009). Most such decisions are made during regularly scheduled hours. However, the explanations for the behavior (i.e., the second bias) were studied in non-operating room settings and on nights and weekends. These periods were studied to isolate the behavior of clinicians throughout the surgical suite (i.e., the second bias) from bias of the perioperative manager at the OR control desk with (or without) risk aversion (i.e., from the first bias) (Dexter et al. 2007b, Stepaniak et al. 2009). Additional research is warranted, because a recent study reported that the work pace of service workers from patient transport services and cardiothoracic surgery were influenced by workload (Kc and Terwiesch 2009). By testing if the work pace of OR staff was impacted by OR workload, we aim to increase understanding of OR staff behavior.

In the current paper, we study a facility with 8 hr allocated time in each OR, staff (e.g. anesthesiologists, CRNA, nurses, OR techs) scheduled for 8 hr, and hardly any over-utilized OR time (see below in Results) (Wachtel and Dexter 2010). At such a facility, decisions at the control desk would be the same, regardless of whether the decision-maker is risk averse or non-risk averse. Regardless of how cases are moved between ORs and/or how staff are assigned, there would be hardly any chance of over-utilized OR time and the staff working late (Stepaniak et al. 2009). Consequently, the (second) bias of increasing clinical work per unit time during the hours to which each staff is assigned would be illustrated by OR staff overall maintaining a constant patient flow, regardless of the day's estimated (total) duration of elective cases (i.e. scheduled OR workload). Such behavior can be tested by estimating the correlations between 1) the scheduled OR workload and the mean turnover times and 2) between the scheduled OR workload and mean first case start tardiness. We hypothesized that the overall ensemble behavior of OR staff were decisions that would maintain clinical work per unit time, resulting in no managerially important correlations (e.g., on less busy days, if the mean turnover times were longer, then they would be so only by tiny amounts).

5.2 Methods

The quality improvement project was performed for the John D. Dingell VA Medical Center located in Detroit, Michigan.

We used one-year data from January 1, 2010 to December 31, 2010. One year was studied (weekends and holidays excluded) so that the same allocated OR time could be used throughout the period (e.g., no trend) (Epstein and Dexter 2002). The use of the longest period possible gave us the advantage of maximal statistical power, as it provided the maximum possible sample size. This was important as our objective was to detect what we hypothesized to be small effects of OR workload on mean turnover times and mean first case start tardiness.

The analysis was done in two phases. In the first phase, we checked that the allocated OR time during the date range was optimum. It was pre-requisite for the behavioral study, since decisions on the day of surgery to move cases or to change start times were sensitive to the allocations of OR time. To proceed, the facility's use of five ORs for 8 hr should be less efficient than running fewer ORs for 8 hr (i.e., staff could reliably know that their workday would end in 8 hr regardless of their decisions). After this phase was completed, we studied the behavior of the OR staff. Although the data were from a hospital, many of the surgical patients were outpatients. The OR conditions we studied in this paper are common for outpatient surgery centers. However, as explained in the Introduction, the usefulness of testing our hypotheses is principally for hospitals with many ORs having more than 8 hr of cases (e.g., large general teaching hospitals).

5.2.1 Allocated OR Time

During the one-year period, there were 46 Mondays, 52 Tuesdays and Wednesdays, and 50 Thursdays and Fridays (holidays excluded). Five ORs were open on each workday for 8 hr, except for Wednesday with one-hour late start for education. The facility functioned as one giant service. On each day of week, surgeons from different specialties shared the allocated OR time, and cases were scheduled using Worst Fit Descending algorithm as if they were from a single service. Nurses, anesthesia providers, etc., cared for patients of all specialties. Although each specialty had its designated OR, each often did cases in other ORs.

This analysis was performed as described in previous studies (Dexter et al. 2001, McIntosh et al. 2006). For each day, the OR workload (including turnover times) was grouped by surgeon. Each surgeon's workload was assigned to an OR using the Worst Fit Descending scheduling algorithm (Galambos and Woeginger 1995, Dexter et al. 1999). What this means is that the surgeon's list of cases was scheduled into the OR providing the earliest possible start time (Galambos and Woeginger 1995, McIntosh et al. 2006, Dexter and Traub 2002). Worst Fit matched the observed behavior of filling all the first case starts (Galambos and Woeginger 1995). With one (typically) or two (occasionally) surgeons per OR per day and typically zero add-on cases, Worst Fit Descending minimized the expected inefficiency of use of OR time (Dexter et al. 1999).

Whenever a turnover time was longer than 90 minutes, we rounded the turnover time down to 90 minutes. We used 90 minutes as the maximum in part because it was the 90th percentile of the turnover times for the data set (Dexter et al. 2001). Longer turnover times might be due to gaps in the OR schedule (e.g. cases not scheduled sequentially) (Dexter et al. 2005).

We deliberately included three days with unusually low workload in the calculations of allocated OR time. Two workdays (July 27, 2010 and December 28, 2010) had no turnover times, as there was only one case performed in each OR. One workday (December 6, 2010) had just one turnover time, and it was longer than 90 minutes. Inclusion of these days (deliberately) biased results toward more over-utilized OR time.

We explored the options of running four ORs, five ORs and six ORs, each with the combination of 8 hr and 10 hr allocation for each day of week. For each combination of numbers of ORs and hours, we compared the inefficiency of use of OR time to the baseline inefficiency from the actual allocated OR time (Strum et al. 1997). The inefficiency of use of OR time was calculated as the daily sum of the under-utilized OR time plus 1.75 times the over-utilized OR time (Epstein and Dexter 2002, Dexter et al. 2001, McIntosh et al. 2006).

The mean potential improvement in the inefficiency of use of OR time and its standard errors were calculated by performing 1000 replications of cross-validation. For each replication, ¼ of the days in the data set were used as testing set and the other ¾ as the training set. The analysis was conducted using Matlab R2010a (The MathWorks Inc., Natick, MA).

5.2.2 Behavior of the OR Staff

The three slow days (i.e. July 27, 2010, December 28, 2010, and December 6, 2010) were excluded from this study since no valid turnover times were available. August 16, 2010 was also excluded because the only turnover was between an elective case and an urgent case. After excluding these four days, there were 246-days total for study.

The turnovers between elective and urgent cases were not excluded in the preceding first part of our analysis (i.e. the optimum allocated OR time). The reason for including the turnovers was because the turnover times were part of OR workload. Excluding them would make the OR workload lower than what actually was observed, resulting in the optimum allocated OR time being smaller than needed. In contrast, for this second part of the analysis (i.e., mean turnover time calculation), the inclusion of such turnover times would have introduced outliers, causing the mean value to be inaccurate. We excluded these days to reduce the impact of potential outliers on our results.

For each case, the data we used were operating room, surgery date, time that patient entered the OR, time that patient left the OR, scheduled start time of the case, scheduled end time of the case, and elective (scheduled) or add-on (urgent). There were 4.4% add-on (urgent) cases (129 of 2906). We did not include the 3.7% of turnover times that included an urgent case (47 of 1259) in the behavioral study as such cases were unexpected to the OR staff.

For each workday, there was one independent variable: allocated OR time. There were also six correlated dependent variables: estimated duration of elective cases, actual duration of elective cases, estimated duration of add-on cases, actual duration of add-on cases, mean first case start tardiness, and mean turnover times. The first four were totals for all such cases during the workday. The latter two were means for all such cases during the day. The percentiles for the variables are summarized in Table 13.

The tardiness of each first case of the day start was calculated as the difference between the scheduled start time of the case and the time that the patient entered the OR (Wachtel and Dexter 2009a, Wachtel and Dexter 2009b). If the time the patient entered the OR was before the scheduled start time of the case (2.2% of first cases), the tardiness was considered to be zero (Wachtel and Dexter 2009a, Wachtel and Dexter 2009b).

The raw data had some missing information. For 1.0% of the cases (30 of 2906), there was no scheduled duration. We did not want to ignore these cases as they occurred on 10% of the workdays (25 of 246). We imputed the missing information from schedules before conducting the behavioral analysis (Wachtel and Dexter 2010).

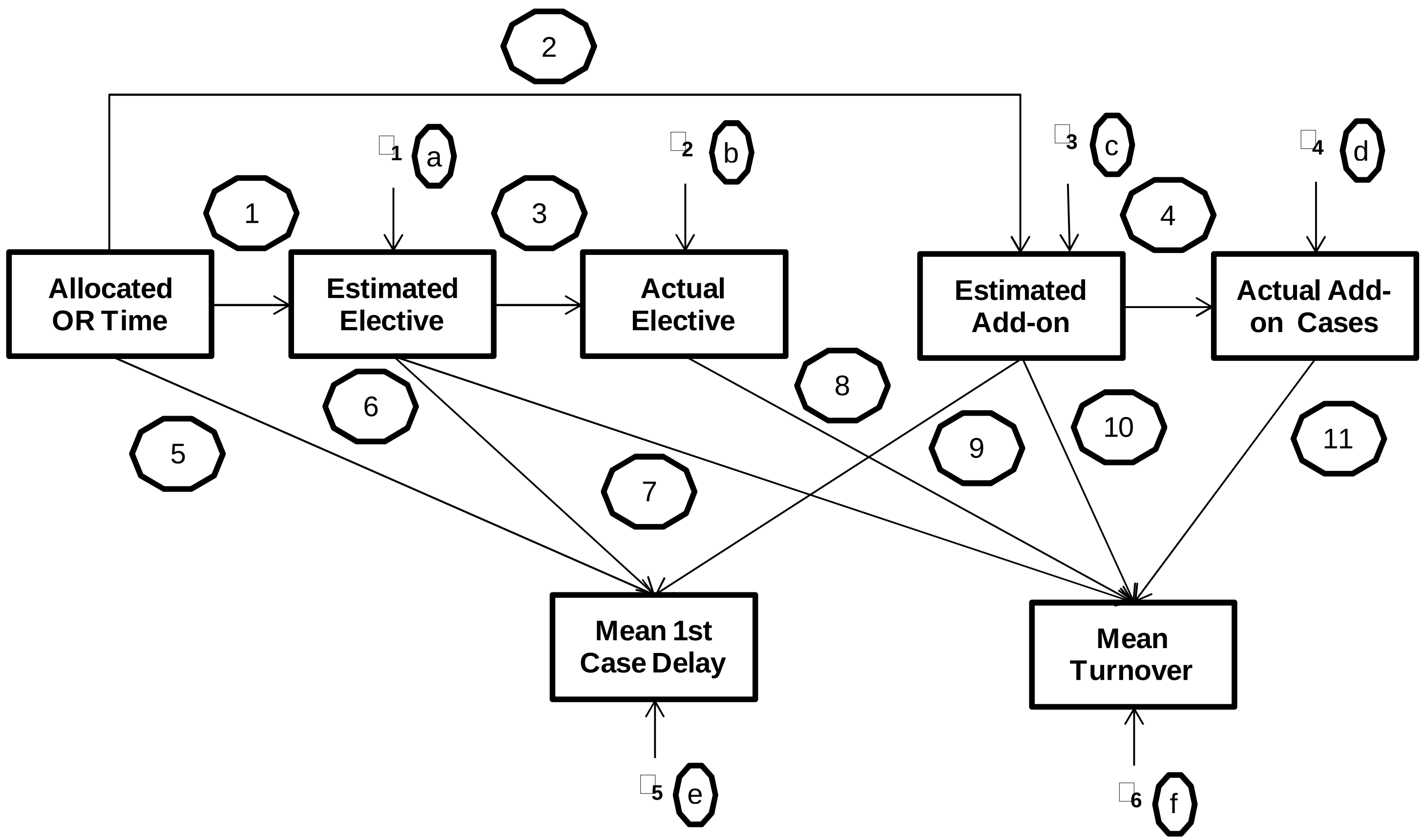
Table 12: Percentiles for Defined Variables in the Behavioral Study

Defined Variables	10%	25%	50%	75%	90%	Mean
Allocated OR time (hr)	35	40	40	40	40	39
Estimated (total) duration of elective cases (hr)	12	15	20	24	27	19
Actual (total) duration of elective cases (hr)	15	17	21	26	29	22
Estimated (total) duration of add-on cases (hr)	0	0	0	2	3	1
Actual (total) duration of add-on cases (hr)	0	0	0	1	3	1
Mean first case start tardiness (min)	0	2	5	12	17	7
Mean turnover times (min)	26	32	40	47	55	40

As reported previously, mean turnover times were correlated among days (Dexter et al. 2005), and this was built into the analysis. In 1999, Dexter et al. (Dexter et al. 1999), used structural equation modeling to model variability in underutilized OR time. We modified the path diagram to better study the psychological biases. The final path diagram used for parameter estimation is shown in Figure 19. The following five paragraphs give a detailed description of the path diagram and the reasons for the path selections. The development of the path diagram was a step in the structural equation modeling used to test our hypotheses.

On Wednesdays, when less OR time was allocated, fewer elective cases and add-on cases were scheduled. This is represented in the path diagram by the arrow going out from "Allocated OR time" to "Estimated duration of elective cases" and to "Estimated duration of add-on cases". These paths make sense, because the availability of OR time can influence how many hours of case are added to the day's schedule (Dexter et al. 1999).

Figure 19: Path Diagram of the Structural Equation Modeling



When less OR time was allocated, it might matter whether first cases of the day start on-time, because the OR staff might perceive that a delayed start of the day might cause them to finish late (Dexter et al. 2009). Thus, a path from “Allocated OR time” to “Mean first case start tardiness” was added.

The estimated (total) duration of elective cases linearly influenced the actual (total) duration of elective cases in the model (Figure 19) (Dexter et al. 1999). Likewise, the estimated (total) duration of add-on cases influenced the actual (total) duration of add-on cases (Dexter et al. 1999). The Kendall’s τ_b rank correlations did not show a significant relation between the mean first case start tardiness and mean turnover times, nor between the estimated (total) duration of elective cases and the estimated (total) duration of add-on cases (both $P > 0.28$). Since the studied facility had copious under-utilized OR time, we did not include these paths.

The other paths included were for hypothesis testing (i.e. the estimated and actual duration of cases to mean turnover times and mean first case start tardiness). We had two paths from the estimated (total) durations of both elective and add-on cases to mean turnover times. OR staff perceptions of the workload might have been based on the estimated (total) duration of cases. As the day proceeded, staff behavior might also have been impacted by the actual (total) duration of cases. For example, when a case ended much earlier than planned, there was plenty of time for the staff to set up the room for the next case. They might work not as fast. On the other hand, when a case took longer than scheduled, the staff might speed up to reduce the tardiness of start of the next cases in the OR.

The analyses could have been performed with the number of cases instead of with the estimated (total) duration of cases (Figure 19). By scatter plot and Pearson linear correlation coefficient ($r = 0.72$), the two were substitutable. To choose, we calculated the Kendall’s τ_b rank correlations with the mean first case start tardiness and mean turnover times (Wachtel and Dexter 2010). Because the correlations between the estimated (total) duration of elective cases and mean turnover times and mean first case start tardiness were larger than those with the number of cases, we used the estimated (total) duration of cases for our analysis. By doing so, we biased our results toward detecting a relationship between OR workload and turnover times (i.e., biased to be contrary to our hypothesis).

The parameters of the structural equation model (Figure 19) were estimated to emulate the observed covariance matrix among the defined variables (Raykov and Marcoulides 2000, Schumacker and Lomax 2010). The distribution–free, weighted least squares method was used for parameter estimation because several of the variables were not normally distributed (Lomax 1989). LISREL 8.8 student version (Scientific Software International, Inc., Lincolnwood, IL) was used to generate the covariance matrix and estimate parameters.

Goodness of fit of the statistical model was assessed several ways, as recommended for structural equation models (Schumacker and Lomax 2010). The chi-square test along with its P-value, root mean square error of approximation (RMSEA), and goodness-of-fit index (GFI)/ adjusted goodness-of-fit index (AGFI) were the methods that we used to evaluate the model performance (Schumacker and Lomax 2010). The chi-square test and its P-value indicate how different the observed and implied covariance matrices is. A small P-value suggests a poor model fit (Schumacker and Lomax 2010). RMSEA estimates lack of fit compared to the saturated model (perfect model). A value of 0.05 or less indicates a good fit, and a value of 0.08 represents an acceptable model (Dexter et al. 1999, Schumacker and Lomax 2010). The GFI/AGFI are similar to the R-squared/adjusted R-squared in regression. They measure the amount of variance in the observed covariance matrices predicted by the reproduced matrices. A GFI/AGFI that is larger than 0.95 suggests a good model (Schumacker and Lomax 2010).

From 2008 through the studied year, the studied facility had no ongoing quality improvement or monitoring program focused on reducing turnover times. However, there was a project focused on reducing first case start tardiness. The latter could negatively affect the generalizability of our findings to other facilities. However, there was no public incentive or financial reward for individuals or OR groups, making the influence limited. Nonetheless, the estimated relationships for mean first case start tardiness must be considered secondary to those for turnover time.

Besides the primary analysis, we ran two sensitivity analyses. There were only two housekeeping teams at the studied facility. When there were more than two cases finished close to simultaneously, turnover(s) was delayed, waiting for the next available housekeeping team. This sharing of resources made the turnovers longer (Dexter et al. 2009). To isolated influences of more than two simultaneous turnovers, we first re-calculated the mean turnover times, excluding turnovers including any 1-minute period with more than two simultaneous turnovers. Second, instead of excluding turnover times longer than 90 minutes for the calculation of the daily mean turnover time, we excluded those turnovers longer than 60 minutes.

5.3 Results

The allocated OR time was significantly larger than optimum (Table 14), satisfying the condition for the behavioral study. Although five ORs were open daily, four ORs were sufficient (see Discussion). For each day of the week, there was little over-utilized OR time (from 0.01 ± 0.03 [standard error] hr to 0.06 ± 0.24 hr per OR per day) (Table 14).

The structural equation model demonstrated reasonable fit based on the chi-square test P = 0.47 (greater than 0.05). The root mean square error of approximation was 0.01 (unitless) (smaller than 0.05). Both the goodness-of-fit index and the adjusted goodness-of-fit index were larger than 0.95 (0.99 and 0.98, respectively). The coefficients parameter estimates and their P-values are given in Table 15.

Table 13: Difference in the Inefficiency of Use of Operating Room (OR) Time between Actual and Optimum Allocation of OR Time

	Allocation of OR Time			
Day of Week	**Actual**	**Optimum**	**OR Inefficiency Difference Mean ± SE (%)**	**Over-utilized OR Time per OR (hr)**
Monday	5 ORs × 8 Hrs	3 ORs × 8 Hrs + 1 OR × 10 Hrs	21.11 ± 0.24	0.06 ± 0.24
Tuesday	5 ORs × 8 Hrs	4 ORs × 8 Hrs	37.87 ± 0.10	<0.01
Wednesday	5 ORs × 7 Hrs	4 ORs × 7 Hrs	33.58 ± 0.24	0.03 ± 0.16
Thursday	5 ORs × 8 Hrs	4 ORs × 8 Hrs	34.99 ± 0.27	0.01 ± 0.03
Friday	5 ORs × 8 Hrs	4 × 8 Hrs	38.87 ± 0.24	0.01 ± 0.07

There was a substantial range in the estimated (total) duration of elective cases (e.g., 10th percentile 12 hr versus 90th percentile 27 hr, Table 13). A decrease by 1 hr in the estimated (total) duration of elective cases caused the mean turnover times to *decrease* by 0.41 ± 0.21 minutes (P=0.05) (Table 15). Decreases in the actual (total) duration of cases, either of elective cases or of add-on cases, did not result in significant decreases (changes) in mean turnover times (P=0.37 and P=0.89, respectively, Table 15). The two sensitivity analyses' results match this finding of no managerially relevant *increase* from decreases in the estimated (total) duration of elective cases. Observed decreases in mean turnover times in these two analyses were 0.17 ± 0.24 minutes (P=0.46) and 0.16 ± 0.16 minutes (P=0.31), respectively (Table 16) (Wachtel and Dexter 2010).

Table 14: Outputs of Primary Structural Equation Modeling

		ORAll[11]	EstELEC[12]	EstADD[13]	ActELEC[14]	ActADD[15]	1ST[16]	TOT[17]
ORAll	**Coefficient**	-	0.6932	0.0141	-	-	0.0047	-
	SE	-	0.1218	0.0238	-	-	0.0025	-
	P-value	-	<.0001	0.5520	-	-	0.0570	-
EstELEC	**Coefficient**	-	-	-	0.8785	-	0.0033	0.0068
	SE	-	-	-	0.0382	-	0.0013	0.0035
	P-Value	-	-	-	<.0001	-	0.0084	0.0531
EstADD	**Coefficient**	-	-	-	-	0.7959	0.0014	0.0209
	SE	-	-	-	-	0.0371	0.0066	0.0296
	P-value	-	-	-	-	<0.0001	0.8338	0.4793
ActELEC	**Coefficient**	-	-	-	-	-	-	0.0031
	SE	-	-	-	-	-	-	0.0034
	P-value	-	-	-	-	-	-	0.3689
ActADD	**Coefficient**	-	-	-	-	-	-	-0.0053
	SE	-	-	-	-	-	-	0.0365
	P-value	-	-	-	-	-	-	0.8853

Each 1 hr decrease in the estimated (total) duration of elective cases caused the mean first case start tardiness to *decrease* by 0.2 ± 0.1 minutes (P=0.01). In the studied facility, 69% of the workdays (170 of 246) were of 5 ORs (i.e., first cases of the day). We saw only four first cases for the rest of the days because of the overall low estimated (total) duration of elective cases. The mean estimated (total) duration of elective cases on the days of four first cases was 16.1 ± 0.5 hr vs. 21.8 ± 0.4 hr for the days of five first cases. When there was less workload, there were fewer numbers of first cases of the day. Thus, there was no fifth OR to wait for the

[11]. OR allocation
[12]. Estimated elective case duration
13. Estimated add-on case duration
14. Actual elective case duration
15. Actual add-on case duration
16. Mean first case start tardiness
17.Mean turnover time

anesthesiologist with three inductions to do, resulting in smaller mean tardiness (Epstein and Dexter 2012).

Table 15: Key Outputs of the Sensitivity Analyses of the Structural Equation Modeling

		Exclude Simultaneous TOTs > 2		Exclude TOTs > 60 Min	
		1ST	TOT	1ST	TOT
EstELEC	Coefficient	0.0033	0.0029	0.0032	0.0027
	SE	0.0012	0.0040	0.0013	0.0027
	P-value	0.0074	0.4639	0.0146	0.3149
EstADD	Coefficient	0.0018	0.0208	0.0027	0.0063
	SE	0.0067	0.0356	0.0068	0.0211
	P-value	0.7881	0.5587	0.6931	0.7660
ActELEC	Coefficient	-	0.0038	-	0.0036
	SE	-	0.0038	-	0.0030
	P-value	-	0.3192	-	0.2253
ActADD	Coefficient	-	-0.0056	-	0.0111
	SE	-	0.0429	-	0.0285
	P-value	-	0.8964	-	0.6959

5.4 Discussion

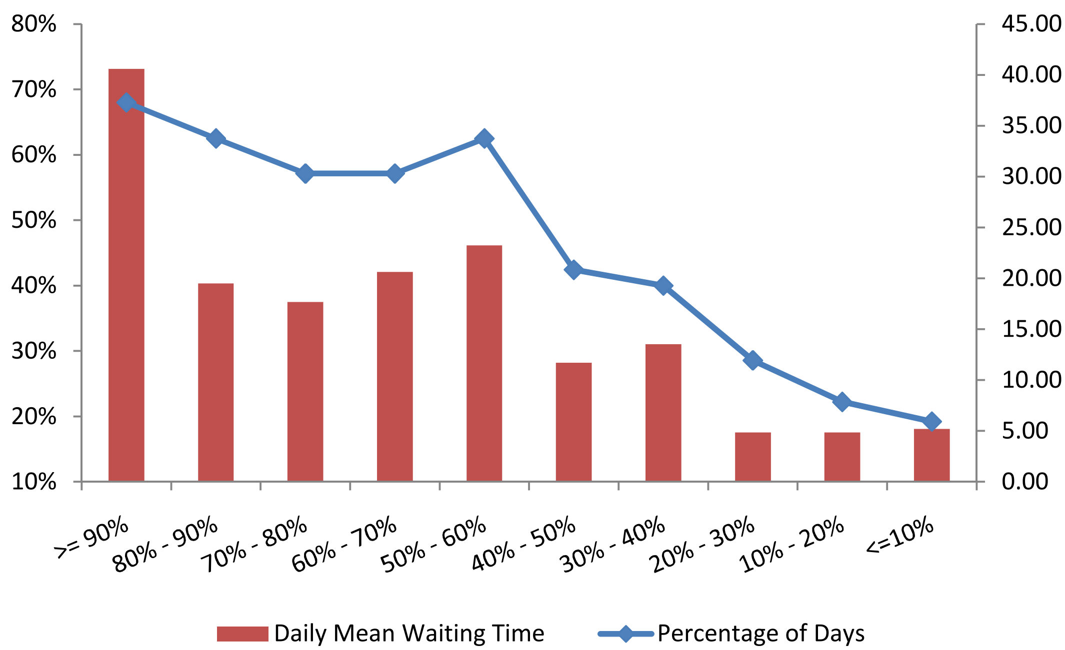
We studied the overall (ensemble) behavior of OR staff at a facility with virtually no over-utilized OR time. We analyzed allocated OR time first, because rational (and biased) decision-making is sensitive to this parameter (Dexter et al. 2001, McIntosh et al. 2006, Stepaniak et al. 2009). As hypothesized, the mean turnover times were negligibly impacted by the estimated (total) duration of elective cases. OR staff kept a constant work pace for non-operative times, except for a slight slowing when there were more than two simultaneous turnovers. The staff overall did not slow down to fill the time when less busy. This negative finding was not caused by there being only small differences in the estimated (total) duration of elective cases among days, as this variable varied markedly (Table 14). Rather, the behavior was consistent with the bias of most staff to maintain their clinical work per unit time during the hours to which they were assigned (Dexter et al. 2007a, Dexter et al.2007b). As summarized in the Introduction, knowing that this bias applies commonly overall among many individuals is important for different facilities with some under-utilized and some over-utilized time, because the consequence is that electronic displays providing information without evidence-based recommendations will result in decisions that are worse than decisions made at random (Dexter et al. 2007a, Dexter et al. 2009, Wachtel and Dexter 2009). The fact that the study was made of the overall behavior of the population (community) of OR nurses, anesthesiologists, etc., is important because many managerial decisions are spatially and temporally distributed. Changing the behavior involves the use of multiple displays (e.g., electronic whiteboards and pagers).

Results were insensitive to the heterogeneity among days in the hours of add-on cases (i.e., OR staff behavior was not significantly influenced by the add-on cases). One likely reason is that most turnover times take place during the morning (Dexter et al. 2009), whereas most add-on cases are performed during the afternoon. Another reason is that for surgical suites with optimum allocated OR time, the substantial OR workload from add-on cases has already been included in the allocated OR time; thus, the probability of substantial over-utilized OR time caused by add-on cases is not high. At the studied facility with an extra first case of the day start, this was even more so.

We analyzed the allocated OR time first to make sure that the hypothesis test would be done in a rational condition. In addition, in our structural equation modeling, add-on case factors were included (Table 15), and none of them was statistically significant with respect to the mean turnover time and mean first case start tardiness. Our results do not depend on the types of facilities as the psychological bias was observed in other facilities in previous studies (Dexter et al. 2007b, Ledolter et al. 2010). The results confirmed the bias during regularly scheduled OR hours and complement previous studies.

Some readers may have considered it obvious from their experience that most clinicians would work each day non-stop, rather than slowing down when there were fewer cases. For example, in a Swedish qualitative research study, perceptions of efficiency included “doing what must be done to achieve good workflow” and “working with preserved quality of care as fast as possible.” (Arakelian et al. 2011). Such prior expectations both reinforce the strength of our statistical findings and highlight the striking importance of their consequences. First, paying anesthesiologists substantially more to work late does not result in their working slower and thereby increasing compensation (see footnote **Error! Bookmark not defined.**†) (Masursky et al. 2009). Making the same observation from a different hospital was important, because basic human nature (test) is to do that which increases the compensation of the people doing the work. Second, for a facility like the one studied with little or no over-utilized OR time, the use of electronic information displays throughout a surgical suite would not have return on investment. That would not be true if OR staff often increased non-operative time on days with fewer estimated (total) duration of cases. Third, for a different facility with more than 8 hr of cases regularly in some ORs and different hours of cases performed in different ORs, the behavior is (highly) suboptimal without recommendations (Marcon and Dexter 2007). Again, the reason is that although clinicians’ behavior to increase clinical work per unit time when assigned is reasonable for decisions involving one OR at a time, that does not apply to decisions involving multiple ORs (e.g., anesthesiologists supervising several nurse anesthetists, moving of cases, scheduling of add-on cases, etc.) (Dexter et al. 2007a, Dexter et al. 2007b, Dexter et al. 2009, Wachtel and Dexter 2009). The two sensitivity analyses focused on the managerially irrelevant, but (barely) statistically significant, change in mean turnover times. As described previously (Dexter et al. 2009), we calculated the percentage of days with more than two simultaneous turnovers. On days with more cases scheduled (i.e., more turnovers), there were more resulting delays in turnovers caused by there being only two available housekeeping teams (Figure 20). Waiting for an available housekeeping team made the turnover times longer than usual (Dexter et al. 2009). When we eliminated the influence of the simultaneous turnovers, the impacts of the estimated (total) duration of elective cases on mean turnover times became less. As hypothesized, from another perspective, OR staff's work pace was not influenced by OR workload.

Figure 20: Percentage of Days with Simultaneous Turnovers Greater than 2 and Daily Mean Wait Time from the Turnovers



To achieve a reduction in costs, the management of the studied facility could have run one fewer OR daily and changed allocated OR time (Dexter et al. 2001, Epstein and Dexter 2002). The way to optimize OR cost efficiency was not to reduce turnover times or ensure on-time start of the workday, but to re-allocate OR hours and to reduce the under-utilized OR hours (McIntosh et al. 2006). However, randomized clinical trials have found that when there are four ORs with different surgeons each with at least 8 hr of cases, productivity was increased by running five ORs (Torkki et al. 2005, Marjamaa et al. 2009). When running three ORs with more than 8 hr of cases, running four ORs also increased productivity (Hanss et al. 2005). Furthermore, running more ORs increases first cases starts which reduces tardiness from scheduled start times for surgeons (Wachtel and Dexter 2009a, Wachtel and Dexter 2009b, Wachtel and Dexter 2010). Therefore, although the choice of five ORs reduced the efficiency of use of OR time, the tactical decision of running an extra OR might have been rational. Regardless, the number of ORs open was a tactical decision made before the OR time was allocated, and was thus incorporated in our calculation of allocated OR time (Dexter and Macario 2002, McIntosh et al. 2006).

5.5 Conclusion

In summary, we explored the OR staff's behavior at a facility with allocated OR time that was optimal conditioned on a pre-determined number of ORs. Over-utilized OR time was rare. The staff was scheduled to work for at least 8 hr. Given such a system, staff behavior did not respond to the change in workload. The staff did not increase non-operative time on days with fewer scheduled hours of cases. The results show that the predicted psychological bias that OR staff work overall to increase clinical work per unit time during the hours they are assigned also applies during regularly scheduled OR hours.

CHAPTER 6 CONCLUSIONS

6.1 Conclusions

In this dissertation, we reviewed the current research conducted in operating room management in general and operating room utilization in particular. One of the key assumptions in existing literature is that surgeons can schedule cases on any workday they select to do the surgery, which is not applicable to many of the healthcare systems in the world. Given an inflexible allocated OR time, the application of previous theories (e.g. frequently allocated OR time) is limited. Thus, research is needed to provide useful information to OR managers for such facilities to optimize the performance.

In Chapter 2, we used data from a facility with fixed allocated OR time to identify the most important factors that influence utilization. We identified several factors that are hypothesized to impact the utilization. Then, stepwise regression and best subset were applied to rank the importance of factors. Simulation model was built to validate conclusions from the statistical analysis and provided us with additional information on patient wait time on the day of surgery. From the analysis, the scheduled OR utilization, the accuracy of case duration prediction, the hours of cancellations and the hours of add-on cases were the most important factors identified from all the models.

Based on the results from Chapter 2, we focused our research efforts to the scheduling and prediction of case duration as they were the key factors identified to influence the OR utilization. As there is naturally high variability in case duration, there is no way to precisely tell when the ORs are closed but to predict the probability of the duration of surgery lists fall into a range. We introduced Type IV Pearson distribution to approximate the duration of surgery lists of multiple cases whose duration assumed to be log-normally distributed and validated its accuracy. The results indicated that this model performed much better than the t-distribution used in most of current research. It helped the OR manager to analyze the duration of surgery lists and arrange the surgery lists to meet the performance targets.

In Chapter 4, an iterative operational simulation approach was proposed to identify the bottlenecks (i.e. tardiness of case start) on the day of surgery. The model runs in such a way that every time the most important reason for tardiness of case start defined by delay risk is distinguished from the other reasons and eliminated. The process continues until a desired performance in over-utilized OR time and cancellation rate is achieved. A case study illustrated the application of the proposed approach. This method can improve the performance in both over-utilized OR time and cancellation, but the effectiveness of the approach is subjected to the influences of scheduling policy and the variability of case duration. An optimum allocated OR time and small variability of case duration have this approach achieve its best benefits.

The effectiveness of the implementation of methodology is subject to OR staff's behavior. There have been studies implying that OR staff perceives efficiency as to complete work as soon as possible. This would result sub optimal performance of OR. The Chapter 5 of our dissertation studied if such a bias also exists for OR suites with hardly any over-utilized OR time to isolate the bias we were interested in studying from other bias. We used structural equation modeling to test our hypothesis that OR staff's work pace was not influenced by the workload as both mean turnover time and mean first case start tardiness were not statistically significant influenced by the fluctuation of OR workload. The bias is common in OR facilities; thus, OR management system needs to provide specific commands to OR staff instead of just displaying information to prevent the psychological bias.

6.2 Future Research

The research conducted in Chapter 2 to identify the distribution of the duration of surgery lists performed much better than currently applied t-distribution; however a portion of surgery lists could not be evaluated by the Type IV Pearson distribution as the lists contained at least one case that had no or only one historical case duration. By including data from multiple facilities/extending the data collection range, the problem remained. Thus, methods that can derive distribution parameter estimates from no or one historical case duration would be extremely helpful to make the Type IV Pearson distribution function to its full capacity.

Another thing is that although the Type IV Pearson distribution provided better estimates, there was still 5% deviation on the average to the true percentiles, which is an indicator that there is further improvement space in finding a distribution that represents the true distribution of surgery lists. By Monte Carlo Simulation, we found out that the inaccuracy was resulted from the partially met log-normal distribution assumption of individual case duration. As there is no universal distribution for each individual case duration, a distribution that is robust to the sum of different type of distributions needs to be explored to better approximate the real distribution of the duration of surgery lists.

Finally, our study as well as majority of current OR research focus only on OR. As we know that the success of OR depends on upstream processes such as clinics and downstream processes such as ICU and wards. A smooth of workflow among all the involved units is the key to the success of OR. The information exchange, the tracking of patients and the dynamic decision support in the system is most critical to facilitate the coordination among different units, especially for a health care system that has multiple locations and patients can be transferred from one facility to another. However, as the current OR information systems lack the ability to extract information in a real-time manner, there is always a latency in decision making, which would result in suboptimal OR performance. The OR operations shall be able to be boosted to another level if a system that provides real-time decision making capability can be implemented to assist OR managers in making timely decisions.

APPENDIX A: ACTUAL UTILIZATION AND PREDICTED UTILIZATION FROM STEPWISE REGRESSION AND BEST SUBSET MODELS

Table 16: Actual Utilization and Predicted Utilization from Models for May

Date	Act Util	Stepwise	Best Subset
5/1/2009	58%	58%	57%
5/4/2009	67%	71%	73%
5/5/2009	81%	74%	73%
5/6/2009	69%	58%	57%
5/7/2009	96%	77%	76%
5/8/2009	72%	79%	78%
5/11/2009	65%	66%	68%
5/12/2009	76%	80%	82%
5/13/2009	95%	86%	88%
5/14/2009	100%	97%	100%
5/15/2009	73%	70%	67%
5/18/2009	92%	87%	89%
5/19/2009	81%	79%	80%
5/20/2009	80%	75%	75%
5/21/2009	96%	88%	89%
5/22/2009	88%	79%	77%
5/26/2009	69%	63%	63%
5/27/2009	70%	71%	72%
5/28/2009	93%	80%	80%
5/29/2009	99%	98%	99%

Table 17: Actual Utilization and Predicted Utilization from Models for June

Date	Act Util	Stepwise	Best Subset
6/1/2009	82%	70%	70%
6/2/2009	66%	66%	66%
6/3/2009	69%	74%	74%
6/4/2009	66%	77%	77%
6/5/2009	77%	78%	78%
6/8/2009	96%	96%	96%
6/9/2009	70%	63%	63%
6/10/2009	76%	78%	78%
6/11/2009	66%	70%	70%
6/12/2009	63%	70%	70%
6/15/2009	72%	70%	70%
6/16/2009	72%	77%	77%
6/17/2009	94%	95%	95%
6/18/2009	84%	87%	87%
6/19/2009	83%	79%	79%
6/22/2009	54%	61%	61%
6/23/2009	56%	55%	55%
6/24/2009	78%	71%	71%
6/25/2009	90%	91%	91%
6/26/2009	88%	85%	85%
6/29/2009	78%	75%	75%
6/30/2009	68%	63%	63%

Table 18: Actual Utilization and Predicted Utilization from Models for July

Date	Act Util	Stepwise	Best Subset
7/6/2009	74%	79%	79%
7/7/2009	61%	61%	61%
7/8/2009	79%	74%	74%
7/9/2009	88%	85%	85%
7/10/2009	86%	87%	87%
7/13/2009	74%	77%	77%
7/14/2009	74%	72%	72%
7/15/2009	63%	57%	57%
7/16/2009	85%	79%	79%
7/17/2009	83%	77%	77%
7/20/2009	81%	81%	81%
7/21/2009	88%	93%	93%
7/22/2009	91%	78%	78%
7/23/2009	104%	96%	96%
7/24/2009	88%	78%	78%
7/27/2009	87%	88%	88%
7/28/2009	54%	51%	51%
7/29/2009	66%	74%	74%
7/30/2009	107%	109%	109%
7/31/2009	58%	62%	62%

Table 19: Actual Utilization and Predicted Utilization from Models for August

Date	Act Util	Stepwise	Best Subset
8/3/2009	73%	78%	78%
8/4/2009	62%	61%	61%
8/5/2009	39%	43%	43%
8/6/2009	68%	79%	79%
8/7/2009	47%	54%	54%
8/10/2009	50%	64%	64%
8/11/2009	70%	83%	83%
8/12/2009	42%	51%	51%
8/13/2009	55%	61%	61%
8/14/2009	61%	61%	61%
8/17/2009	58%	61%	61%
8/18/2009	56%	57%	57%
8/19/2009	78%	61%	61%
8/20/2009	67%	77%	77%
8/21/2009	77%	97%	97%
8/24/2009	58%	66%	66%
8/25/2009	68%	50%	50%
8/27/2009	67%	48%	48%
8/28/2009	78%	87%	87%
8/31/2009	66%	71%	71%

Table 20: Actual Utilization and Predicted Utilization from Models for September

Date	Act Util	Stepwise	Best Subset
9/1/2009	76%	67%	68%
9/2/2009	55%	68%	68%
9/3/2009	94%	97%	98%
9/4/2009	90%	88%	87%
9/8/2009	44%	45%	48%
9/9/2009	66%	72%	73%
9/10/2009	63%	77%	77%
9/11/2009	87%	90%	90%
9/14/2009	41%	47%	48%
9/15/2009	74%	79%	81%
9/16/2009	66%	75%	76%
9/17/2009	81%	91%	91%
9/18/2009	99%	85%	85%
9/21/2009	62%	64%	66%
9/22/2009	90%	73%	74%
9/23/2009	65%	73%	74%
9/24/2009	65%	72%	73%
9/25/2009	78%	75%	75%
9/28/2009	54%	60%	61%
9/29/2009	75%	79%	79%
9/30/2009	48%	54%	55%

APPENDIX B: STATISTICS OF OR UTILIZATION OF FOUR CASE DURATION DISTRIBUTIONS FROM SIMULATIONS

Table 21: Simulated Utilization for Case Duration Type 1

Utilization of Case Type 1

Scheduled Utilization	50% 1st Delay 1	50% 1st Delay 2	90% 1st Delay 1	90% 1st Delay 2
50%	55% ± 0.09%	55% ± 0.09%	55% ± 0.09%	55% ± 0.09%
63%	70% ± 0.11%	70% ± 0.11%	70% ± 0.11%	70% ± 0.11%
75%	84% ± 0.11%	84% ± 0.11%	84% ± 0.11%	84% ± 0.11%
88%	95% ± 0.06%	95% ± 0.06%	95% ± 0.06%	93% ± 0.06%
100%	98% ± 0.03%	97% ± 0.03%	97% ± 0.03%	95% ± 0.03 %

Table 22: Simulated Utilization for Case Duration Type 2

Utilization Case Type 2

Scheduled Utilization	50% 1st Delay 1	50% 1st Delay 2	90% 1st Delay 1	90% 1st Delay 2
50%	54% ± 0.23%	54% ± 0.23%	54% ± 0.23%	54% ± 0.23%
63%	67% ± 0.22%	67% ± 0.22%	67% ± 0.22%	67% ± 0.22%
75%	79% ± 0.20%	79% ± 0.20%	79% ± 0.20%	78% ± 0.20%
88%	89% ± 0.15%	88% ± 0.15%	88% ± 0.15%	87% ± 0.15%
100%	95% ± 0.09%	94% ± 0.09%	94% ± 0.09%	93% ± 0.09 %

Table 23: Simulated Utilization for Case Duration Type 3

Utilization Case Type 3

Scheduled Utilization	50% 1st Delay 1	50% 1st Delay 2	90% 1st Delay 1	90% 1st Delay 2
50%	49% ± 0.13%	49% ± 0.3%	49% ± 0.3%	49% ± 0.13%
75%	74% ± 0.15%	74% ± 0.15%	74% ± 0.15%	74% ± 0.15%
100%	94% ± 0.13%	93% ± 0.13%	94% ± 0.13%	92% ± 0.13%
125%	97% ± 0.05%	96% ± 0.05%	96% ± 0.05%	94% ± 0.05%

Table 24: Simulated Utilization for Case Duration Type 4

Utilization Case Type 4

Scheduled Utilization	50% 1st Delay 1	50% 1st Delay 2	90% 1st Delay 1	90% 1st Delay 2
50%	46% ± 0.28%	46% ± 0.28%	46% ± 0.28%	46% ± 0.28%
75%	68% ± 0.26%	68% ± 0.26%	68% ± 0.26%	67% ± 0.26%
100%	84% ± 0.18%	84% ± 0.18%	84% ± 0.18%	83% ± 0.18%
125%	89% ± 0.13%	88% ± 0.13%	89% ± 0.13%	87% ± 0.13%

APPENDIX C: STATISTICS OF OR INEFFICIENCY OF FOUR CASE DURATION DISTRIBUTIONS FROM SIMULATIONS

Table 25: Simulated Inefficiency of Use of OR Time for Case Duration Type 1

Inefficiency Case Type 1 (in Minutes)

Scheduled Utilization	50% 1st Delay 1	50% 1st Delay 2	90% 1st Delay 1	90% 1st Delay 2
50%	215 ± 0.5	215 ± 0.5	215 ± 0.5	215 ± 0.5
63%	144 ± 0.5	144 ± 0.5	144 ± 0.5	144 ± 0.5
75%	78 ± 0.5	79 ± 0.5	79 ± 0.5	81 ± 0.5
88%	52 ± 0.6	60 ± 0.6	60 ± 0.6	74 ± 0.6
100%	120 ± 1	132 ± 1	135 ± 1	157 ± 1

Table 26: Simulated Inefficiency of Use of OR Time for Case Duration Type 2

Inefficiency Case Type 2 (in Minutes)

Scheduled Utilization	50% 1st Delay 1	50% 1st Delay 2	90% 1st Delay 1	90% 1st Delay 2
50%	230 ± 1.1	231 ± 1.1	231 ± 1.1	232 ± 1.1
63%	177 ± 1.4	178 ± 1.4	178 ± 1.4	180 ± 1.4
75%	139 ± 1.7	142 ± 1.7	142 ± 1.7	147 ± 1.7
88%	130 ± 2.3	136 ± 2.3	136 ± 2.3	145 ± 2.3
100%	162 ± 2.9	170 ± 2.9	171 ± 2.9	186 ± 2.9

Table 27: Simulated Inefficiency of Use of OR Time for Case Duration Type 3

Inefficiency Case Type 3 (in Minutes)				
Scheduled Utilization	**50% 1st Delay 1**	**50% 1st Delay 2**	**90% 1st Delay 1**	**90% 1st Delay 2**
50%	246 ± 0.6	246 ± 0.6	246 ± 0.6	246 ± 0.6
75%	125 ± 0.7	126 ± 0.7	126 ± 0.7	128 ± 0.7
100%	74 ± 0.6	86 ± 0.6	82 ± 0.6	104 ± 0.6
125%	228 ± 1.4	244 ± 1.4	240 ± 1.4	269 ± 1.4

Table 28: Simulated Inefficiency of Use of OR Time for Case Duration Type 4

Inefficiency Case Type 4 (in Minutes)				
Scheduled Utilization	**50% 1st Delay 1**	**50% 1st Delay 2**	**90% 1st Delay 1**	**90% 1st Delay 2**
50%	274 ± 1.6	275 ± 1.6	275 ± 1.6	277 ± 1.6
75%	203 ± 2.3	206 ± 2.3	205 ± 2.3	210 ± 2.3
100%	189 ± 3.3	195 ± 3.3	192 ± 3.3	203 ± 3.3
125%	323 ± 4.4	330 ± 4.4	327 ± 4.4	341 ± 4.4

APPENDIX D: STATISTICS OF MEAN PATIENT WAIT TIME OF FOUR CASE DURATION DISTRIBUTIONS FROM SIMULATIONS

Table 30: Case Average Wait Time for Case Duration Type 21

Case Average Wait Time (Minutes) - Case Type 1

Delays	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
% Delay 1	18 ± 0.24	28 ± 0.33	38 ± 0.41	48 ± 0.46	59 ± 0.52	69 ± 0.57	79 ± 0.62
% Delay 2	5 ± 0.25	33 ± 0.36	43 ± 0.43	53 ± 0.48	63 ± 0.54	74 ± 0.59	84 ± 0.63
% Delay 1	24 ± 0.25	34 ± 0.33	44 ± 0.41	54 ± 0.46	65 ± 0.52	75 ± 0.57	85 ± 0.62
% Delay 2	1 ± 0.27	43 ± 0.35	53 ± 0.42	63 ± 0.47	74 ± 0.53	84 ± 0.58	94 ± 0.62

Table 29: Case Average Wait Time for Case Duration Type 2

Case Average Wait Time (Minutes) - Case Type 2

Delays	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
0% Delay 1	17 ± 0.69	27 ± 0.95	38 ± 1.18	49 ± 1.33	61 ± 1.55	72 ± 1.71	85 ± 1.89
0% Delay 2	5 ± 0.64	32 ± 0.93	43 ± 1.20	54 ± 1.35	66 ± 1.57	76 ± 1.72	89 ± 1.90
0% Delay 1	24 ± 0.71	33 ± 0.97	44 ± 1.20	54 ± 1.35	66 ± 1.57	77 ± 1.73	89 ± 1.90
0% Delay 2	1 ± 0.62	42 ± 0.98	53 ± 1.22	62 ± 1.37	74 ± 1.59	85 ± 1.75	97 ± 1.93

Table 31: Case Average Wait Time for Case Duration Type 3

Case Average Wait Time (Minutes) - Case Type 3				
Delays	**Case 2**	**Case 3**	**Case 4**	**Case 5**
50% Delay 1	13 ± 0.39	19 ± 0.52	26 ± 0.65	33 ± 0.72
50% Delay 2	20 ± 0.43	26 ± 0.57	32 ± 0.69	39 ± 0.76
90% Delay 1	19 ± 0.41	24 ± 0.55	31 ± 0.67	37 ± 0.74
90% Delay 2	32 ± 0.47	37 ± 0.61	43 ± 0.73	49 ± 0.73

Table 32: Case Average Wait Time for Case Duration Type 4

Case Average Wait Time (Minutes) - Case Type 4				
Delays	**Case 2**	**Case 3**	**Case 4**	**Case 5**
50% Delay 1	16 ± 1.31	33 ± 1.76	53 ± 2.18	69 ± 2.45
50% Delay 2	23 ± 1.34	38 ± 1.79	56 ± 2.20	72 ± 2.47
90% Delay 1	20 ± 1.34	36 ± 1.78	55 ± 2.19	70 ± 2.46
90% Delay 2	32 ± 1.38	45 ± 1.82	61 ± 2.24	76 ± 2.51

APPENDIX E: POM-OR PERFORMANCE FOR EACH SIMULATION RUN ON OVER-UTILIZED OR TIME

Table 33: Mean Over-utilized OR Time from Simulation

	Mean Over-utilized OR Time						
	OR 1	**OR2**	**OR3**		**OR 1**	**OR2**	**OR3**
Baseline	24.1 ± 0.4	58.4 ± 0.17	30.6 ± 0.2	**15**	21.6 ± 2.1	55.7 ± 1.3	27.6 ± 1.3
1	22.1 ± 2.1	56.2 ± 1.4	28.0 ± 1.2	**16**	22.5 ± 2.2	55.3 ± 1.3	27.3 ± 1.3
2	22.0 ± 1.9	57.8 ± 1.4	28.8 ± 1.2	**17**	22.2 ± 2.2	54.9 ± 1.3	27.2 ± 1.3
3	22.1 ± 1.9	57.7 ± 1.3	28.7 ± 1.2	**18**	22.2 ± 2.3	54.5 ± 1.3	27.3 ± 1.3
4	22.5 ± 2.0	58.0 ± 1.3	28.8 ± 1.2	**19**	21.3 ± 2.0	54.4 ± 1.3	27.0 ± 1.3
5	22.4 ± 1.9	58.0 ± 1.4	28.8 ± 1.2	**20**	21.7 ± 2.1	54.5 ± 1.3	26.9 ± 1.3
6	22.1 ± 1.9	57.7 ± 1.4	28.5 ± 1.2	**21**	21.3 ± 2.1	54.4 ± 1.3	26.6 ± 1.3
7	22.4 ± 1.9	57.5 ± 1.3	28.7 ± 1.3	**22**	21.8 ± 2.1	54.1 ± 1.3	27.0 ± 1.3
8	21.9 ± 1.9	57.0 ± 1.3	28.8 ± 1.3	**23**	21.7 ± 2.1	54.0 ± 1.3	27.1 ± 1.3
9	22.0 ± 1.9	56.6 ± 1.3	28.5 ± 1.3	**24**	22.0 ± 2.2	53.7 ± 1.3	27.0 ± 1.4
10	21.5 ± 2.0	56.3 ± 1.3	28.4 ± 1.3	**25**	22.0 ± 2.2	53.5 ± 1.4	27.1 ± 1.4
11	22.1 ± 2.1	56.2 ± 1.3	28.0 ± 1.3	**26**	22.0 ± 2.2	53.6 ± 1.4	27.1 ± 1.4
12	21.9 ± 2.1	55.9 ± 1.3	27.2 ± 1.3	**27**	22.0 ± 2.2	53.8 ± 1.4	26.8 ± 1.4
13	21.7 ± 2.1	55.6 ± 1.3	27.8 ± 1.3	**Ideal**	22.0 ± 2.3	50.2 ± 1.4	24.6 ± 1.3
14	20.8 ± 2.0	55.7 ± 1.3	27.4 ± 1.3				
50% Variance Baseline	N/A	36.7 ± 0.8	15.8 ± 0.8	**50% Variance Ideal**	N/A	26.5 ± 0.8	10.7 ± 1.2

APPENDIX F: POM-OR PERFORMANCE FOR EACH SIMULATION RUN ON CANCELLATION

Table 34: Number of Cancellations from Simulation

	Cancellations						
	OR 1	**OR2**	**OR3**		**OR 1**	**OR2**	**OR3**
Baseline	0	82	5	**15**	0	69	3
1	0	78	4	**16**	0	70	3
2	0	78	3	**17**	0	69	3
3	0	77	3	**18**	0	70	3
4	0	76	3	**19**	0	70	3
5	0	76	3	**20**	0	70	3
6	0	77	3	**21**	0	69	3
7	0	76	3	**22**	0	71	3
8	0	76	3	**23**	0	68	3
9	0	75	3	**24**	0	68	3
10	0	75	3	**25**	0	67	3
11	0	75	3	**26**	0	67	3
12	0	73	3	**27**	0	67	3
13	0	71	3	**Ideal**	0	53	3
14	0	69	3				
50% Variance Baseline	0	5	0	**50% Variance Ideal**	0	1	0

APPENDIX G: SEQUENCE OF TARDINESS ELIMINATION FROM POM-OR

Table 35: Ranks of Delay Reasons for Baseline Model and POM-ORS for OR1

Baseline		POM-ORS	
Case ID	**Delay Description**	**Case ID**	**Delay Description**
1	SURGEON LATE	1	SURGEON LATE
2	SURGEON LATE	1	ANESTHESIA SET UP
1	INCORRECT OR NO CONSENT	1	INCORRECT OR NO CONSENT
1	ANESTHESIA SET UP	2	SURGEON LATE
2	ANESTHESIA SET UP	2	ANESTHESIA SET UP
2	PRE-OP LAB WORK	1	PRE-OP LAB WORK
1	PRE-OP LAB WORK	2	INCORRECT OR NO CONSENT
3	INCORRECT OR NO CONSENT	3	INCORRECT OR NO CONSENT
3	PRE-OP LAB WORK	3	PRE-OP LAB WORK
3	ANESTHESIA SET UP	2	PRE-OP LAB WORK
2	INCORRECT OR NO CONSENT	3	ANESTHESIA SET UP
1	ROOM/EQUIPMENT SET UP	3	SURGEON LATE
2	ROOM/EQUIPMENT SET UP	1	ROOM/EQUIPMENT SET UP
1	OR STAFF NOT AVAILABLE	1	OR STAFF NOT AVAILABLE
3	SURGEON LATE	1	OTHER DEPARTMENT DELAY
3	ROOM/EQUIPMENT SET UP	2	ROOM/EQUIPMENT SET UP
1	OTHER DEPARTMENT DELAY	2	OR STAFF NOT AVAILABLE
2	OR STAFF NOT AVAILABLE	1	ANESTHESIA PRE-EVAL/RECHECK
1	EQUIPMENT NOT AVAILABLE	1	EQUIPMENT NOT AVAILABLE
3	OTHER DEPARTMENT DELAY	2	EQUIPMENT NOT AVAILABLE
1	ANESTHESIA PRE-EVAL/RECHECK	2	ANESTHESIA PRE-EVAL/RECHECK
3	ANESTHESIA PRE-EVAL/RECHECK	2	OTHER DEPARTMENT DELAY
3	OR STAFF NOT AVAILABLE	3	ROOM/EQUIPMENT SET UP
2	ANESTHESIA PRE-EVAL/RECHECK	3	OR STAFF NOT AVAILABLE
2	EQUIPMENT NOT AVAILABLE	3	OTHER DEPARTMENT DELAY

2	OTHER DEPARTMENT DELAY	3	EQUIPMENT NOT AVAILABLE
3	EQUIPMENT NOT AVAILABLE	3	ANESTHESIA PRE-EVAL/RECHECK

Table 36: Ranks of Delay Reasons for Baseline Model and POM-ORS for OR2

Baseline		**POM-ORS**	
Case ID	**Delay Description**	**Case ID**	**Delay Description**
4	SURGEON LATE	4	SURGEON LATE
4	ANESTHESIA SET UP	4	ANESTHESIA SET UP
4	PRE-OP LAB WORK	5	INCORRECT OR NO CONSENT
5	INCORRECT OR NO CONSENT	5	ANESTHESIA SET UP
5	ANESTHESIA SET UP	6	ANESTHESIA SET UP
4	INCORRECT OR NO CONSENT	6	PRE-OP LAB WORK
6	ANESTHESIA SET UP	6	SURGEON LATE
7	PRE-OP LAB WORK	5	PRE-OP LAB WORK
6	SURGEON LATE	4	PRE-OP LAB WORK
7	ANESTHESIA SET UP	9	PRE-OP LAB WORK
10	PRE-OP LAB WORK	4	INCORRECT OR NO CONSENT
7	SURGEON LATE	7	ANESTHESIA SET UP
9	PRE-OP LAB WORK	7	SURGEON LATE
9	ANESTHESIA SET UP	8	SURGEON LATE
10	SURGEON LATE	9	ANESTHESIA SET UP
5	SURGEON LATE	6	INCORRECT OR NO CONSENT
5	PRE-OP LAB WORK	9	SURGEON LATE
9	SURGEON LATE	7	PRE-OP LAB WORK
8	SURGEON LATE	8	INCORRECT OR NO CONSENT
9	INCORRECT OR NO CONSENT	9	INCORRECT OR NO CONSENT
6	PRE-OP LAB WORK	7	INCORRECT OR NO CONSENT
6	OR STAFF NOT AVAILABLE	5	SURGEON LATE
6	INCORRECT OR NO CONSENT	8	ANESTHESIA SET UP
8	ANESTHESIA SET UP	10	PRE-OP LAB WORK
8	INCORRECT OR NO CONSENT	8	PRE-OP LAB WORK
7	INCORRECT OR NO CONSENT	10	SURGEON LATE

5	ROOM/EQUIPMENT SET UP	10	ANESTHESIA SET UP

Table 37: Ranks of Delay Reasons for Baseline Model and POM-ORS for OR3

Baseline		**POM-ORS**	
Case ID	**Delay Description**	**Case ID**	**Delay Description**
11	ANESTHESIA SET UP	11	ANESTHESIA SET UP
11	SURGEON LATE	11	SURGEON LATE
13	SURGEON LATE	13	SURGEON LATE
11	INCORRECT OR NO CONSENT	12	ANESTHESIA SET UP
12	ANESTHESIA SET UP	13	ANESTHESIA SET UP
11	PRE-OP LAB WORK	12	INCORRECT OR NO CONSENT
12	SURGEON LATE	12	SURGEON LATE
12	PRE-OP LAB WORK	13	INCORRECT OR NO CONSENT
13	ANESTHESIA SET UP	11	INCORRECT OR NO CONSENT
12	INCORRECT OR NO CONSENT	11	PRE-OP LAB WORK
13	PRE-OP LAB WORK	12	PRE-OP LAB WORK
13	INCORRECT OR NO CONSENT	13	PRE-OP LAB WORK
11	ROOM/EQUIPMENT SET UP	11	OR STAFF NOT AVAILABLE
11	EQUIPMENT NOT AVAILABLE	12	OR STAFF NOT AVAILABLE
11	OR STAFF NOT AVAILABLE	13	OR STAFF NOT AVAILABLE
11	OTHER DEPARTMENT DELAY	13	OTHER DEPARTMENT DELAY
12	OR STAFF NOT AVAILABLE	11	ROOM/EQUIPMENT SET UP
13	ROOM/EQUIPMENT SET UP	13	ROOM/EQUIPMENT SET UP
13	ANESTHESIA PRE-EVAL/RECHECK	12	ROOM/EQUIPMENT SET UP
12	ROOM/EQUIPMENT SET UP	11	ANESTHESIA PRE-EVAL/RECHECK
12	OTHER DEPARTMENT DELAY	11	EQUIPMENT NOT AVAILABLE
12	ANESTHESIA PRE-EVAL/RECHECK	13	ANESTHESIA PRE-EVAL/RECHECK
11	ANESTHESIA PRE-EVAL/RECHECK	12	EQUIPMENT NOT AVAILABLE
12	EQUIPMENT NOT AVAILABLE	13	EQUIPMENT NOT AVAILABLE
13	OR STAFF NOT AVAILABLE	12	OTHER DEPARTMENT DELAY
13	EQUIPMENT NOT AVAILABLE	12	ANESTHESIA PRE-EVAL/RECHECK
13	OTHER DEPARTMENT DELAY	11	OTHER DEPARTMENT DELAY

APPENDIX H: PERCENTILE VALUES OF THE DISTRIBUTION OF THE DURATION OF SURGERY LISTS WITH 10 HISTORICAL CASES

Table 38: Percentile Values of the Distribution of the Duration of Surgery Lists from Type IV Pearson Distribution

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
1/3/2011	OR04	362	372	381	390	399	409	421	437	464	391
1/3/2011	OR07	296	316	330	344	356	370	385	403	431	380
1/4/2011	OR01	312	340	361	381	401	422	447	479	530	403
1/4/2011	OR03	381	401	417	430	444	458	473	492	521	395
1/4/2011	OR08	255	270	281	292	302	312	324	339	361	335
1/5/2011	OR03	164	178	189	200	210	221	234	249	274	163
1/5/2011	OR08	231	243	252	261	269	277	286	298	315	318
1/6/2011	OR03	268	305	335	362	391	421	457	503	577	337
1/7/2011	OR02	176	192	204	215	226	238	252	269	297	370
1/7/2011	OR03	341	358	370	381	392	404	418	434	460	455
1/7/2011	OR07	199	217	231	244	257	270	286	305	335	300
1/10/2011	OR02	207	220	230	239	248	257	268	281	301	339
1/10/2011	OR04	365	375	384	392	401	411	423	439	466	385
1/11/2011	OR01	445	464	478	491	503	515	529	546	571	450
1/11/2011	OR08	251	264	274	283	292	300	310	322	340	290
1/12/2011	OR04	222	244	262	278	295	313	333	359	400	319
1/12/2011	OR07	193	209	222	233	245	257	271	289	317	200
1/13/2011	OR07	175	191	204	216	228	240	255	273	302	234
1/14/2011	OR04	162	180	195	208	222	236	253	275	308	227
1/14/2011	OR07	459	485	505	523	541	560	581	608	648	417
1/18/2011	OR08	216	224	231	237	242	248	255	262	273	240
1/19/2011	OR03	248	264	277	288	300	311	325	341	366	427
1/20/2011	OR04	356	378	394	408	422	437	455	476	510	360

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
1/21/2011	OR01	318	339	355	370	384	399	417	438	471	345
1/21/2011	OR02	162	178	190	201	212	223	237	255	282	342
1/21/2011	OR03	208	224	237	249	260	272	286	303	329	181
1/24/2011	OR02	501	530	552	571	590	610	632	659	698	615
1/24/2011	OR04	346	363	375	387	398	411	425	443	473	373
1/25/2011	OR01	448	495	532	566	600	636	678	730	810	560
1/25/2011	OR03	289	309	324	338	352	366	382	402	433	272
1/25/2011	OR04	414	444	467	488	509	531	556	589	640	407
1/25/2011	OR08	334	345	354	361	368	375	383	392	406	357
1/26/2011	OR01	69	82	94	105	116	129	145	166	201	55
1/26/2011	OR07	219	235	248	259	270	282	295	313	340	335
1/27/2011	OR04	325	353	375	395	415	436	459	489	535	442
1/28/2011	OR01	408	434	454	471	488	506	527	552	589	350
1/28/2011	OR02	179	194	207	218	229	240	254	271	299	207
1/28/2011	OR03	191	211	226	240	254	269	286	308	340	199
1/28/2011	OR07	242	259	272	284	296	308	323	342	371	250
1/31/2011	OR04	259	276	289	301	314	327	343	363	396	285
1/31/2011	OR07	220	237	250	262	274	286	300	317	344	245
2/1/2011	OR08	388	405	418	429	440	452	465	480	503	378
2/3/2011	OR04	302	332	356	377	399	421	447	479	528	447
2/4/2011	OR03	470	513	547	579	610	643	682	730	806	444
2/4/2011	OR07	166	179	189	199	208	219	230	246	271	174
2/4/2011	OR08	315	341	362	381	400	420	443	471	515	288
2/7/2011	OR07	265	279	290	300	309	319	329	343	363	330
2/8/2011	OR03	242	261	275	289	302	316	332	352	384	373
2/8/2011	OR04	376	384	391	397	403	410	418	428	445	450
2/8/2011	OR08	325	338	348	357	365	374	384	396	413	293
2/9/2011	OR03	297	316	330	344	357	370	386	405	434	393

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
2/9/2011	OR04	220	242	258	274	290	306	326	351	390	280
2/9/2011	OR07	156	169	179	189	198	207	219	233	255	280
2/10/2011	OR03	319	359	391	422	454	489	531	586	676	467
2/11/2011	OR07	319	344	363	380	398	417	439	466	508	328
2/11/2011	OR08	263	280	294	305	317	329	342	359	383	277
2/14/2011	OR02	363	380	392	404	415	426	439	455	478	390
2/14/2011	OR03	350	379	402	424	446	471	500	538	600	378
2/14/2011	OR04	336	353	366	377	389	401	416	434	464	447
2/15/2011	OR08	243	259	272	283	293	305	318	334	358	217
2/16/2011	OR02	236	250	260	269	278	288	299	312	334	277
2/16/2011	OR03	170	184	194	203	212	221	232	246	266	264
2/16/2011	OR04	214	241	262	281	301	322	346	378	428	337
2/16/2011	OR08	320	339	353	366	378	391	406	425	454	369
2/17/2011	OR03	250	269	284	298	311	325	341	361	391	277
2/17/2011	OR04	418	450	475	498	521	545	574	610	666	485
2/18/2011	OR04	259	282	300	317	335	354	376	405	452	355
2/18/2011	OR07	287	308	325	340	354	370	387	409	442	421
2/18/2011	OR08	277	294	307	319	331	344	359	378	408	208
2/22/2011	OR06	219	238	252	266	279	293	310	331	363	265
2/22/2011	OR08	245	255	262	268	274	281	288	296	308	258
2/23/2011	OR03	231	249	263	275	287	299	313	331	356	380
2/23/2011	OR07	186	202	215	227	239	251	265	283	309	251
2/23/2011	OR08	109	116	122	126	131	136	142	149	159	126
2/24/2011	OR03	382	416	444	470	496	526	560	606	680	441
2/24/2011	OR04	158	171	182	192	203	214	228	245	274	317
2/28/2011	OR04	344	355	365	374	383	393	406	422	449	405
3/1/2011	OR03	289	313	330	347	363	379	399	422	458	355
3/1/2011	OR04	206	221	233	243	254	266	279	297	326	225

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
3/2/2011	OR02	75	85	94	102	110	119	130	144	167	200
3/2/2011	OR04	244	262	276	290	305	321	340	365	408	286
3/2/2011	OR08	189	204	217	228	239	251	264	282	309	200
3/3/2011	OR02	452	470	484	496	509	521	536	553	579	495
3/4/2011	OR03	233	249	261	272	283	295	309	326	354	267
3/4/2011	OR08	336	355	370	384	397	411	427	448	480	271
3/7/2011	OR04	336	352	365	377	389	401	416	435	465	423
3/7/2011	OR07	176	190	200	210	220	230	241	255	276	230
3/8/2011	OR03	166	182	194	205	216	227	241	257	283	258
3/8/2011	OR04	303	327	346	363	380	398	418	444	485	385
3/8/2011	OR08	379	398	412	425	438	451	465	482	508	349
3/9/2011	OR04	259	284	303	321	339	358	379	407	449	465
3/9/2011	OR08	173	181	187	193	199	204	211	219	230	200
3/10/2011	OR01	255	281	301	320	339	360	383	412	458	240
3/10/2011	OR04	202	224	242	258	274	291	310	335	374	287
3/10/2011	OR07	234	253	267	280	293	306	321	340	367	415
3/11/2011	OR03	221	239	252	265	277	290	304	322	349	256
3/11/2011	OR04	223	244	260	275	289	304	322	344	377	213
3/11/2011	OR07	156	171	183	193	204	216	229	246	273	245
3/11/2011	OR08	176	191	203	214	225	237	251	269	299	219
3/14/2011	OR04	203	220	232	244	256	268	283	302	332	440
3/15/2011	OR08	328	347	362	375	388	401	416	434	461	305
3/16/2011	OR04	167	177	186	193	201	209	218	229	248	248
3/16/2011	OR08	250	267	281	293	305	317	332	350	378	343
3/17/2011	OR01	254	277	296	312	329	346	366	391	429	450
3/17/2011	OR03	222	239	252	264	275	287	301	317	342	279
3/17/2011	OR04	360	380	395	409	422	437	453	475	508	443
3/18/2011	OR04	206	223	237	250	263	277	293	313	344	270

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
3/18/2011	OR07	192	207	219	229	239	250	263	279	305	272
3/18/2011	OR08	200	208	213	218	223	228	234	241	250	197
3/21/2011	OR02	365	385	401	415	428	442	457	476	503	480
3/21/2011	OR03	424	448	466	482	498	514	533	555	589	501
3/21/2011	OR04	343	363	378	392	406	420	437	458	492	460
3/21/2011	OR08	183	196	207	216	226	235	246	260	280	255
3/22/2011	OR03	451	470	485	498	511	525	540	558	585	487
3/23/2011	OR07	99	109	117	125	132	140	149	161	181	147
3/24/2011	OR04	354	380	399	417	434	451	472	497	536	488
3/24/2011	OR07	187	203	216	227	239	251	266	285	315	220
3/25/2011	OR01	346	380	407	431	455	480	509	545	601	288
3/25/2011	OR04	221	236	248	259	270	282	295	313	342	330
3/25/2011	OR07	445	470	489	507	524	542	563	589	629	440
3/25/2011	OR08	194	201	206	211	216	221	226	233	243	260
3/28/2011	OR03	360	379	394	408	421	435	450	469	498	483
3/28/2011	OR04	391	410	423	436	448	461	476	495	526	447
3/28/2011	OR08	191	207	220	232	244	256	270	287	314	230
3/29/2011	OR02	377	396	411	424	436	449	464	481	507	400
3/29/2011	OR04	431	459	480	500	519	539	561	590	633	601
3/29/2011	OR08	244	258	268	277	286	295	305	318	336	290
3/30/2011	OR01	261	277	290	301	312	325	339	358	388	297
3/31/2011	OR04	224	239	251	263	275	288	304	325	361	365
4/1/2011	OR02	164	177	187	196	205	215	226	242	266	185
4/1/2011	OR03	141	155	166	177	187	198	210	226	250	185
4/4/2011	OR06	478	509	532	553	573	594	617	646	688	645
4/4/2011	OR07	245	260	272	283	293	304	316	331	353	232
4/4/2011	OR08	140	150	157	164	171	178	186	196	210	187
4/5/2011	OR04	143	155	165	174	184	194	207	224	252	147

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
4/6/2011	OR06	189	208	222	236	250	264	281	302	335	190
4/7/2011	OR01	338	366	388	409	430	454	482	519	579	537
4/7/2011	OR02	387	404	416	427	438	449	461	476	498	450
4/7/2011	OR03	440	459	473	486	498	511	526	544	570	626
4/7/2011	OR04	369	395	415	432	449	468	488	514	553	460
4/7/2011	OR07	375	405	429	450	472	495	521	554	605	410
4/8/2011	OR04	180	204	223	240	258	277	300	328	373	250
4/11/2011	OR04	516	550	576	600	623	648	676	711	764	510
4/11/2011	OR07	261	278	291	303	314	326	340	358	386	427
4/11/2011	OR08	156	167	175	182	190	197	206	216	231	217
4/13/2011	OR01	457	482	500	517	533	549	568	592	628	429
4/13/2011	OR04	411	437	458	478	497	518	542	574	624	392
4/14/2011	OR04	615	637	654	669	685	701	721	745	783	632
4/14/2011	OR07	213	239	259	277	296	315	338	368	413	284
4/15/2011	OR07	327	346	361	375	388	403	420	441	474	328
4/15/2011	OR08	191	203	213	221	229	238	247	259	276	196
4/18/2011	OR02	602	624	640	655	669	683	699	718	745	685
4/18/2011	OR03	292	316	335	352	369	387	408	435	476	341
4/18/2011	OR04	341	356	368	379	389	401	415	432	461	495
4/19/2011	OR06	149	161	170	178	186	194	204	216	234	150
4/20/2011	OR04	286	310	328	344	361	378	398	423	462	310
4/20/2011	OR06	177	193	206	218	230	243	257	276	304	160
4/20/2011	OR07	118	129	137	145	153	161	170	183	203	165
4/20/2011	OR08	120	127	131	135	139	143	148	153	162	170
4/21/2011	OR04	628	655	676	694	712	730	752	779	821	583
4/22/2011	OR03	265	281	293	303	313	324	336	351	373	324
4/22/2011	OR04	272	293	310	326	341	358	377	401	437	380
4/22/2011	OR07	357	382	400	417	434	452	472	497	536	274

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
4/22/2011	OR08	245	259	270	279	288	298	308	321	340	365
4/25/2011	OR03	572	599	622	644	669	696	731	778	860	675
4/26/2011	OR01	358	380	397	412	427	443	461	484	519	462
4/26/2011	OR02	268	283	295	305	315	326	337	352	374	260
4/26/2011	OR08	200	208	214	220	225	231	237	244	255	194
4/27/2011	OR01	529	561	586	608	630	653	679	712	762	482
4/27/2011	OR04	374	394	409	422	435	449	465	486	518	385
4/28/2011	OR01	124	136	145	154	163	172	183	197	220	262
4/29/2011	OR01	177	194	206	217	229	241	255	272	300	190
4/29/2011	OR07	324	346	363	379	394	411	430	454	491	340
4/29/2011	OR08	335	357	374	390	405	422	440	463	499	340
5/2/2011	OR01	534	583	621	656	690	727	770	823	905	670
5/2/2011	OR03	426	457	484	509	536	567	604	655	740	608
5/2/2011	OR04	390	408	422	434	447	460	475	494	524	398
5/2/2011	OR08	147	157	165	173	180	189	198	211	230	195
5/3/2011	OR08	284	299	310	320	330	340	352	366	386	278
5/4/2011	OR04	347	366	380	392	405	418	434	453	485	272
5/4/2011	OR08	202	214	222	230	238	246	254	265	281	217
5/5/2011	OR04	479	502	520	536	553	571	592	619	664	486
5/5/2011	OR07	260	291	317	341	365	392	424	465	530	285
5/6/2011	OR03	152	167	179	190	200	212	225	242	269	163
5/6/2011	OR04	282	308	329	347	366	386	409	438	482	335
5/6/2011	OR07	245	265	280	294	308	322	339	361	394	270
5/6/2011	OR08	272	288	301	312	322	333	346	361	383	330
5/9/2011	OR01	285	304	319	333	346	359	375	395	425	370
5/9/2011	OR03	375	396	412	426	440	455	471	491	520	354
5/9/2011	OR07	169	182	193	203	213	224	236	251	275	220
5/10/2011	OR08	531	547	558	568	578	588	598	611	629	420

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
5/11/2011	OR02	270	293	311	327	343	360	380	404	442	233
5/11/2011	OR04	260	283	300	315	331	347	366	390	427	340
5/12/2011	OR01	438	472	500	525	551	579	612	654	722	280
5/12/2011	OR07	211	224	235	244	253	262	272	285	305	200
5/13/2011	OR07	476	508	532	554	575	598	623	655	702	430
5/16/2011	OR01	171	189	203	216	230	244	260	281	314	195
5/16/2011	OR04	364	382	396	408	420	433	448	467	497	497
5/18/2011	OR02	124	136	146	154	163	172	183	197	219	235
5/19/2011	OR02	346	361	373	383	392	402	413	427	447	435
5/20/2011	OR03	193	206	216	224	233	242	252	265	285	288
5/20/2011	OR07	185	194	200	206	213	220	228	239	257	245
5/20/2011	OR08	252	266	276	286	296	306	318	334	357	366
5/23/2011	OR04	365	380	392	402	413	424	437	455	483	360
5/24/2011	OR02	339	356	368	380	390	401	413	428	450	475
5/24/2011	OR04	149	164	175	185	196	207	220	236	261	190
5/25/2011	OR07	499	524	542	558	574	590	608	630	662	480
5/26/2011	OR02	341	357	369	379	389	399	411	425	445	398
5/26/2011	OR03	263	287	305	322	340	358	380	407	449	410
5/27/2011	OR08	247	256	263	269	275	281	287	295	306	327
5/31/2011	OR04	295	314	329	342	355	369	384	403	431	330
6/1/2011	OR02	131	140	147	154	161	168	177	188	207	193
6/2/2011	OR02	382	397	409	419	429	439	450	463	483	429
6/2/2011	OR03	203	226	245	263	281	301	324	355	404	293
6/3/2011	OR02	154	166	176	185	194	203	213	227	247	182
6/6/2011	OR04	392	421	443	463	483	505	529	559	605	444
6/6/2011	OR06	362	388	408	426	443	462	482	508	546	405
6/7/2011	OR04	163	176	187	197	206	216	228	243	266	275
6/7/2011	OR08	278	294	307	319	331	343	358	377	406	430

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
6/8/2011	OR04	459	485	505	522	540	558	579	606	647	530
6/10/2011	OR08	224	234	242	249	255	262	269	278	291	276
6/13/2011	OR03	366	393	415	434	454	475	499	529	578	414
6/13/2011	OR04	592	617	635	652	669	687	707	733	774	695
6/13/2011	OR06	390	418	439	459	478	498	521	550	594	415
6/14/2011	OR04	261	277	289	300	311	322	335	351	375	340
6/15/2011	OR07	153	166	176	186	196	206	218	234	259	112
6/15/2011	OR08	174	183	190	197	203	209	216	224	237	220
6/17/2011	OR04	271	290	304	317	330	344	360	379	409	305
6/20/2011	OR04	215	227	237	246	255	266	279	295	323	250
6/20/2011	OR08	172	184	194	202	210	219	229	241	260	305
6/21/2011	OR08	190	204	216	226	236	246	258	273	295	337
6/22/2011	OR01	229	246	258	270	281	294	308	327	357	283
6/22/2011	OR08	181	190	198	204	211	217	224	233	246	190
6/23/2011	OR03	206	220	231	241	250	260	271	285	307	243
6/27/2011	OR02	356	372	384	395	405	416	427	442	463	555
6/27/2011	OR03	305	325	341	355	369	384	400	420	449	394
6/27/2011	OR04	358	372	382	392	402	413	426	443	471	415
6/28/2011	OR08	379	403	421	438	454	471	489	513	547	335
6/30/2011	OR01	289	323	350	376	403	432	466	512	584	465
6/30/2011	OR02	526	535	542	548	554	561	568	577	591	658
6/30/2011	OR03	339	360	377	392	407	422	439	461	493	420
7/1/2011	OR03	370	396	416	435	453	473	497	526	574	516
7/1/2011	OR08	356	379	397	413	428	444	462	485	518	545
7/5/2011	OR04	255	267	277	285	294	302	313	325	346	328
7/6/2011	OR01	253	266	277	286	295	305	316	329	349	250
7/6/2011	OR07	168	176	183	189	194	200	207	216	230	250
7/7/2011	OR04	357	379	396	410	425	440	457	479	514	600

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
7/8/2011	OR04	288	306	321	334	347	360	375	394	423	339
7/8/2011	OR07	83	90	95	100	106	112	120	131	148	470
7/11/2011	OR03	376	404	425	444	463	483	506	534	578	432
7/11/2011	OR04	439	460	476	491	505	521	540	564	602	463
7/13/2011	OR02	138	147	154	161	168	175	184	195	214	190
7/13/2011	OR04	357	374	387	398	410	423	437	456	485	450
7/13/2011	OR08	172	191	207	221	236	251	269	292	328	358
7/14/2011	OR03	477	502	520	537	552	569	587	610	643	542
7/14/2011	OR07	265	291	311	329	347	367	390	420	468	365
7/15/2011	OR03	178	192	203	213	223	233	244	259	281	152
7/18/2011	OR03	191	207	219	230	240	252	264	281	305	362
7/18/2011	OR04	255	270	282	292	303	315	329	347	376	458
7/18/2011	OR06	292	319	340	360	379	399	423	453	499	343
7/18/2011	OR07	352	380	401	421	440	460	482	510	552	390
7/19/2011	OR01	248	276	299	321	343	367	395	431	489	438
7/19/2011	OR04	393	419	438	455	472	490	509	533	569	470
7/20/2011	OR01	227	246	260	273	286	300	316	336	368	363
7/20/2011	OR03	399	421	437	452	466	481	498	519	549	557
7/21/2011	OR04	392	421	444	465	485	506	530	559	604	660
7/21/2011	OR07	268	285	298	310	321	333	346	363	387	313
7/22/2011	OR01	242	269	292	313	335	359	387	424	483	315
7/22/2011	OR07	322	343	359	374	389	405	423	445	480	415
7/25/2011	OR03	296	310	320	329	338	348	360	374	395	560
7/25/2011	OR07	302	318	330	341	351	363	375	390	413	390
7/28/2011	OR02	246	263	276	288	300	312	325	342	366	344
7/29/2011	OR01	245	261	274	285	296	308	322	339	365	330
7/29/2011	OR03	142	157	168	178	189	200	213	229	255	409
7/29/2011	OR04	136	147	156	163	171	180	189	202	221	175

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
7/29/2011	OR07	252	269	283	296	309	322	337	357	388	265
8/1/2011	OR02	379	399	415	429	443	457	472	491	518	380
8/1/2011	OR03	447	476	498	518	537	558	580	608	650	630
8/3/2011	OR04	235	250	261	272	283	294	308	326	354	235
8/5/2011	OR07	273	294	309	323	337	352	369	389	421	395
8/8/2011	OR04	387	408	424	438	452	467	483	504	537	455
8/9/2011	OR04	340	361	377	391	405	420	436	457	487	340
8/9/2011	OR08	313	333	349	363	377	391	408	429	462	466
8/11/2011	OR04	381	396	407	418	429	440	453	471	500	495
8/12/2011	OR07	394	421	441	460	478	497	518	545	586	463
8/15/2011	OR04	350	380	403	424	444	466	491	521	567	415
8/16/2011	OR02	179	196	209	221	232	245	259	278	306	175
8/17/2011	OR02	118	128	136	144	151	159	169	182	202	307
8/17/2011	OR07	156	172	183	194	205	217	231	250	281	180
8/17/2011	OR08	189	200	207	214	221	228	236	245	259	206
8/18/2011	OR06	385	415	438	459	479	500	524	553	597	493
8/18/2011	OR07	253	268	280	290	300	311	323	338	361	393
8/19/2011	OR07	378	404	424	443	461	481	503	531	575	425
8/19/2011	OR08	113	120	125	130	135	140	145	152	162	202
8/22/2011	OR04	350	381	404	426	447	469	494	526	573	460
8/22/2011	OR08	123	137	148	158	168	178	190	206	230	210
8/23/2011	OR06	169	186	200	212	225	239	255	276	308	250
8/23/2011	OR08	230	247	260	272	284	297	313	333	364	320
8/24/2011	OR01	406	445	477	505	534	565	600	645	715	590
8/24/2011	OR04	224	241	255	267	279	292	307	327	359	333
8/25/2011	OR04	347	361	372	382	393	404	417	434	462	458
8/26/2011	OR06	110	120	127	135	142	150	159	170	188	145
8/26/2011	OR07	254	273	289	303	318	333	351	374	410	342

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
8/29/2011	OR06	317	344	364	383	402	421	444	472	515	400
8/31/2011	OR01	239	259	274	288	301	315	332	353	386	280
9/1/2011	OR03	242	255	266	275	284	293	304	317	337	350
9/2/2011	OR01	280	310	334	357	379	404	432	469	526	265
9/2/2011	OR06	101	111	120	128	136	144	154	167	186	289
9/2/2011	OR07	339	360	377	392	408	424	443	467	504	390
9/6/2011	OR08	356	379	398	414	431	449	469	494	533	400
9/7/2011	OR07	142	157	170	181	193	205	220	239	269	205
9/8/2011	OR04	336	356	370	384	397	411	426	447	479	370
9/9/2011	OR02	332	348	361	373	384	396	410	428	455	380
9/9/2011	OR07	365	389	407	424	440	457	477	501	539	455
9/9/2011	OR08	209	218	224	230	236	242	248	256	268	237
9/12/2011	OR03	142	152	160	167	175	183	192	204	222	178
9/12/2011	OR04	356	386	409	430	451	472	497	527	573	440
9/13/2011	OR02	173	187	199	209	219	230	242	258	282	280
9/13/2011	OR08	317	335	348	360	372	385	400	419	447	380
9/14/2011	OR03	177	190	201	210	219	230	241	257	282	200
9/15/2011	OR01	195	210	221	231	241	251	263	277	299	317
9/15/2011	OR05	96	109	120	130	141	153	167	185	215	132
9/16/2011	OR04	171	186	197	208	218	229	241	257	281	358
9/16/2011	OR05	129	138	146	152	159	167	175	187	205	267
9/16/2011	OR07	192	211	227	241	255	270	288	311	346	287
9/16/2011	OR08	293	305	314	322	329	337	345	355	370	350
9/19/2011	OR01	282	306	325	342	359	376	396	421	458	300
9/19/2011	OR04	360	385	403	421	438	455	476	502	542	422
9/19/2011	OR06	100	114	124	134	143	154	166	182	206	224
9/20/2011	OR01	288	306	320	332	345	357	372	389	415	326
9/20/2011	OR04	232	249	262	273	284	296	310	326	351	224

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
9/20/2011	OR08	364	389	408	426	443	461	481	506	544	370
9/21/2011	OR04	301	324	342	358	375	392	412	438	479	345
9/22/2011	OR03	300	319	334	347	360	374	389	408	436	474
9/23/2011	OR07	235	254	269	283	297	311	328	349	381	385
9/26/2011	OR02	378	390	399	407	415	423	432	444	461	415
9/26/2011	OR04	356	377	392	406	420	435	452	473	506	515
9/27/2011	OR01	436	470	497	521	544	569	597	633	687	525
9/27/2011	OR04	359	381	397	411	426	441	457	478	510	438
9/27/2011	OR08	344	359	371	381	391	402	413	427	447	395
9/28/2011	OR02	380	393	403	412	420	429	439	451	469	380
9/28/2011	OR07	249	270	286	301	316	332	350	374	409	440
9/28/2011	OR08	202	218	230	241	252	264	278	295	323	322
9/29/2011	OR01	174	194	210	226	242	259	280	306	348	237
9/29/2011	OR04	360	377	391	403	414	427	442	461	491	436
9/30/2011	OR03	435	459	478	495	512	530	550	576	615	359
9/30/2011	OR04	229	244	256	267	278	289	302	318	342	212
9/30/2011	OR07	331	354	372	388	404	421	440	465	501	449
10/4/2011	OR08	268	280	290	298	306	315	324	336	352	345
10/5/2011	OR02	141	151	158	165	172	179	188	200	219	160
10/5/2011	OR03	170	186	198	210	221	234	248	267	297	172
10/5/2011	OR05	119	136	149	162	175	188	204	225	259	233
10/5/2011	OR07	242	258	271	282	293	305	318	335	361	403
10/5/2011	OR08	153	166	176	186	195	206	218	234	259	372
10/6/2011	OR04	348	362	374	384	394	406	419	437	465	410
10/6/2011	OR06	176	191	203	213	224	235	247	263	287	410
10/7/2011	OR07	373	395	412	427	443	459	477	501	537	362
10/12/2011	OR01	318	338	353	366	380	394	410	431	463	365
10/12/2011	OR04	226	239	249	259	269	280	293	310	338	336

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
10/13/2011	OR02	384	413	435	455	475	496	519	547	590	625
10/13/2011	OR05	357	374	388	400	411	424	439	458	488	425
10/14/2011	OR01	400	431	455	477	499	522	548	581	633	510
10/14/2011	OR08	204	219	231	242	253	264	276	292	315	340
10/17/2011	OR03	400	420	436	449	463	477	492	511	539	423
10/18/2011	OR01	298	315	329	341	353	365	379	396	422	295
10/18/2011	OR03	336	368	393	416	440	465	495	533	595	412
10/18/2011	OR04	471	494	512	529	545	561	581	604	641	460
10/19/2011	OR02	325	341	354	365	377	390	405	423	453	340
10/19/2011	OR05	95	110	122	133	145	157	172	192	225	90
10/19/2011	OR08	258	270	279	287	295	304	314	326	346	330
10/20/2011	OR03	198	218	233	248	262	277	295	317	351	287
10/20/2011	OR06	207	223	235	246	257	268	280	296	319	245
10/21/2011	OR01	184	197	207	216	225	234	245	258	279	210
10/21/2011	OR07	279	299	315	329	343	358	376	397	431	282
10/24/2011	OR02	377	391	402	411	420	429	440	452	471	400
10/24/2011	OR04	310	326	339	350	361	374	388	406	435	380
10/24/2011	OR07	360	398	428	456	483	513	547	591	660	580
10/26/2011	OR03	167	183	196	208	220	233	248	266	294	348
10/26/2011	OR05	291	313	331	347	363	381	401	427	468	324
10/26/2011	OR07	190	203	213	222	232	242	254	269	294	250
10/27/2011	OR01	532	566	591	614	636	659	685	717	764	720
10/28/2011	OR02	185	202	214	226	238	250	264	282	310	274
10/28/2011	OR08	307	328	345	360	374	390	407	428	460	333
10/31/2011	OR04	307	322	333	344	355	366	380	397	426	468
10/31/2011	OR06	282	302	318	332	345	360	376	396	426	315
11/1/2011	OR02	378	392	402	412	420	430	440	452	471	360
11/1/2011	OR08	219	230	238	245	252	259	267	277	291	245

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
11/2/2011	OR03	170	184	195	206	216	227	240	256	280	185
11/2/2011	OR06	246	262	275	287	298	310	324	341	366	256
11/2/2011	OR07	119	130	140	148	156	165	175	189	210	210
11/2/2011	OR08	206	217	225	233	241	249	258	271	290	340
11/3/2011	OR01	164	178	189	199	209	220	232	249	275	170
11/3/2011	OR05	334	353	367	380	392	405	420	440	471	410
11/3/2011	OR06	215	227	236	244	252	261	270	281	299	373
11/4/2011	OR03	112	120	127	133	139	146	154	165	183	146
11/7/2011	OR02	462	486	504	520	535	552	570	593	627	631
11/7/2011	OR04	334	351	364	376	388	400	415	434	464	405
11/7/2011	OR08	148	160	170	178	186	195	205	217	236	200
11/8/2011	OR03	236	253	267	280	292	305	319	338	365	340
11/9/2011	OR02	145	154	161	167	174	181	190	201	220	178
11/9/2011	OR04	202	215	226	235	245	256	269	286	314	225
11/9/2011	OR08	291	306	316	326	335	345	356	370	392	361
11/10/2011	OR05	218	236	250	263	276	290	306	328	362	313
11/10/2011	OR06	510	529	544	557	569	582	596	614	640	473
11/14/2011	OR02	298	316	329	341	353	366	381	399	428	473
11/15/2011	OR03	197	208	216	224	231	239	248	260	278	402
11/15/2011	OR08	362	376	386	395	404	413	422	434	451	388
11/16/2011	OR04	222	235	245	254	264	275	288	304	332	265
11/16/2011	OR05	123	141	156	169	183	199	216	240	276	128
11/16/2011	OR08	186	197	205	212	219	227	236	248	267	350
11/17/2011	OR04	374	388	399	408	417	426	436	448	467	428
11/18/2011	OR08	227	244	257	269	280	293	307	325	354	265
11/21/2011	OR01	273	300	322	342	362	384	410	443	495	450
11/21/2011	OR02	155	168	177	186	195	204	214	227	246	123
11/21/2011	OR03	163	182	197	210	224	239	255	277	310	281

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
11/21/2011	OR06	177	193	205	217	228	240	254	270	296	168
11/21/2011	OR07	224	241	255	267	279	291	305	323	349	329
11/22/2011	OR08	444	465	481	496	512	528	548	574	615	475
11/23/2011	OR02	160	173	182	191	200	209	220	234	255	245
11/23/2011	OR03	172	188	200	211	222	234	247	264	289	189
11/28/2011	OR05	468	495	516	535	555	575	599	630	678	460
11/29/2011	OR03	199	217	231	243	256	269	283	302	330	249
11/29/2011	OR04	485	503	516	528	540	552	565	582	607	495
12/1/2011	OR01	298	317	331	344	357	370	385	404	434	370
12/1/2011	OR04	377	393	406	417	429	441	455	473	503	430
12/5/2011	OR03	299	319	334	347	361	375	390	409	438	292
12/5/2011	OR04	349	370	386	401	415	430	447	469	502	343
12/5/2011	OR06	165	181	194	205	216	228	242	259	286	205
12/5/2011	OR08	104	114	122	129	137	145	154	166	185	177
12/6/2011	OR03	412	431	445	457	470	483	497	516	543	377
12/6/2011	OR08	368	383	394	404	413	422	433	445	463	395
12/7/2011	OR01	315	342	362	380	398	417	439	466	508	256
12/7/2011	OR03	355	378	396	412	427	443	461	484	517	426
12/7/2011	OR05	100	110	119	127	136	146	158	174	202	114
12/7/2011	OR08	305	324	338	351	364	378	394	414	445	380
12/9/2011	OR07	181	195	205	215	225	235	248	264	289	244
12/9/2011	OR08	259	277	292	305	318	332	347	366	394	270
12/12/2011	OR04	446	476	500	521	542	564	590	621	669	345
12/12/2011	OR08	159	173	184	195	205	215	227	242	265	205
12/13/2011	OR04	213	227	238	247	257	267	278	293	314	364
12/14/2011	OR08	263	279	292	303	314	325	338	355	380	443
12/15/2011	OR04	266	285	299	312	325	340	356	377	411	350
12/15/2011	OR05	141	163	180	197	213	232	253	283	332	241

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
12/16/2011	OR04	377	397	412	426	439	454	470	490	521	459
12/16/2011	OR07	465	498	523	546	569	592	619	652	703	405
12/16/2011	OR08	308	329	346	362	378	395	415	441	482	403
12/19/2011	OR08	137	149	159	168	176	186	196	210	230	184
12/20/2011	OR08	304	320	332	343	354	365	377	392	414	285
12/21/2011	OR08	340	360	376	390	404	419	436	458	491	408
12/22/2011	OR06	204	217	227	236	244	254	264	277	297	262
12/28/2011	OR08	144	151	156	161	166	171	176	182	192	135
12/30/2011	OR07	259	276	289	300	312	324	338	355	382	328

Table 39: Percentile Values of the Distribution of the Duration of Surgery Lists from T-distribution

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
1/3/2011	OR04	381	389	395	400	405	410	414	420	428	391
1/3/2011	OR07	327	338	346	353	359	366	372	380	391	380
1/4/2011	OR01	361	378	390	400	410	420	430	443	460	403
1/4/2011	OR03	406	420	430	438	446	454	462	472	486	395
1/4/2011	OR08	282	289	295	300	304	309	314	319	327	335
1/5/2011	OR03	181	193	201	208	214	221	228	236	247	163
1/5/2011	OR08	251	258	263	268	272	276	280	285	293	318
1/6/2011	OR03	305	339	363	384	403	423	444	468	502	337
1/7/2011	OR02	202	213	220	227	233	239	246	253	264	370
1/7/2011	OR03	369	379	386	392	397	403	409	415	425	455
1/7/2011	OR07	230	242	250	257	263	270	277	285	297	300
1/10/2011	OR02	223	233	240	246	252	257	263	270	280	339
1/10/2011	OR04	384	392	398	402	407	412	417	422	430	385
1/11/2011	OR01	469	482	491	498	505	513	520	529	542	450
1/11/2011	OR08	274	280	285	289	293	297	301	306	313	290

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
1/12/2011	OR04	259	273	283	292	300	308	317	327	341	319
1/12/2011	OR07	221	231	239	246	252	258	265	273	283	200
1/13/2011	OR07	194	207	215	223	230	237	245	254	266	234
1/14/2011	OR04	184	198	208	216	224	232	241	250	264	227
1/14/2011	OR07	523	533	540	546	552	557	563	570	580	417
1/18/2011	OR08	230	235	238	241	244	247	249	253	258	240
1/19/2011	OR03	276	285	292	298	304	309	315	322	332	427
1/20/2011	OR04	385	398	408	417	424	432	441	451	464	360
1/21/2011	OR01	339	357	370	381	391	401	412	425	443	345
1/21/2011	OR02	189	199	207	213	219	225	232	239	250	342
1/21/2011	OR03	236	246	253	259	265	271	277	284	294	181
1/24/2011	OR02	534	555	570	583	595	608	621	636	657	615
1/24/2011	OR04	372	382	390	396	402	408	415	422	433	373
1/25/2011	OR01	506	544	571	594	615	637	660	687	724	560
1/25/2011	OR03	325	335	343	350	356	362	368	376	386	272
1/25/2011	OR04	473	487	497	506	514	523	532	542	556	407
1/25/2011	OR08	355	360	364	367	369	372	375	379	384	357
1/26/2011	OR01	84	98	109	118	126	135	144	154	169	55
1/26/2011	OR07	247	257	264	271	276	282	288	295	305	335
1/27/2011	OR04	364	383	397	408	419	430	441	455	474	442
1/28/2011	OR01	436	456	471	483	495	506	519	533	553	350
1/28/2011	OR02	201	212	220	227	233	239	246	254	265	207
1/28/2011	OR03	226	237	245	251	257	263	270	278	288	199
1/28/2011	OR07	277	286	293	298	304	309	314	321	330	250
1/31/2011	OR04	279	293	303	312	320	328	337	347	361	285
1/31/2011	OR07	250	259	266	272	278	283	289	296	306	245
2/1/2011	OR08	421	428	434	439	443	448	453	458	466	378
2/3/2011	OR04	348	367	380	392	402	413	425	438	457	447

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
2/4/2011	OR03	555	579	596	610	624	638	653	670	694	444
2/4/2011	OR07	189	198	205	210	215	221	226	233	241	174
2/4/2011	OR08	369	382	391	399	406	414	422	431	443	288
2/7/2011	OR07	289	297	303	307	312	317	322	327	335	330
2/8/2011	OR03	274	286	294	301	308	315	322	330	342	373
2/8/2011	OR04	386	394	399	404	408	412	417	422	430	450
2/8/2011	OR08	350	356	360	364	367	371	374	379	385	293
2/9/2011	OR03	330	340	348	355	361	368	374	382	393	393
2/9/2011	OR04	255	268	278	287	295	302	311	321	334	280
2/9/2011	OR07	173	183	190	196	202	208	214	222	232	280
2/10/2011	OR03	365	401	428	451	472	493	515	542	579	467
2/11/2011	OR07	361	377	388	398	407	416	425	436	452	328
2/11/2011	OR08	294	304	310	316	322	327	333	340	350	277
2/14/2011	OR02	384	396	404	411	418	424	431	440	451	390
2/14/2011	OR03	384	407	424	438	452	465	479	496	519	378
2/14/2011	OR04	362	373	380	387	393	399	405	413	423	447
2/15/2011	OR08	271	280	287	292	297	302	308	314	323	217
2/16/2011	OR02	252	262	270	276	283	289	295	303	313	277
2/16/2011	OR03	187	197	204	210	215	221	226	233	243	264
2/16/2011	OR04	255	272	285	295	305	315	326	338	355	337
2/16/2011	OR08	360	368	374	380	385	390	395	401	409	369
2/17/2011	OR03	273	288	298	307	316	324	333	343	358	277
2/17/2011	OR04	479	494	504	513	522	530	540	550	565	485
2/18/2011	OR04	307	319	328	335	342	349	356	365	377	355
2/18/2011	OR07	330	340	348	355	361	367	374	382	392	421
2/18/2011	OR08	312	321	327	332	337	342	347	353	362	208
2/22/2011	OR06	251	263	271	278	285	292	299	308	319	265
2/22/2011	OR08	262	267	271	273	276	279	282	285	290	258

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
2/23/2011	OR03	251	265	275	283	291	299	307	317	331	380
2/23/2011	OR07	207	219	228	236	244	251	259	268	280	251
2/23/2011	OR08	117	122	126	130	133	136	140	144	149	126
2/24/2011	OR03	440	465	484	500	515	530	546	565	591	441
2/24/2011	OR04	180	189	196	202	207	213	219	226	235	317
2/28/2011	OR04	364	373	379	384	389	393	399	405	413	405
3/1/2011	OR03	329	343	352	360	368	376	384	394	407	355
3/1/2011	OR04	229	239	246	253	258	264	271	278	288	225
3/2/2011	OR02	89	98	105	111	116	122	127	134	143	200
3/2/2011	OR04	273	286	296	304	312	319	328	337	351	286
3/2/2011	OR08	216	226	233	240	245	251	257	264	274	200
3/3/2011	OR02	472	486	496	504	513	521	529	540	554	495
3/4/2011	OR03	260	269	276	281	287	292	298	305	314	267
3/4/2011	OR08	378	387	393	398	403	408	413	419	427	271
3/7/2011	OR04	362	373	380	387	393	399	405	413	424	423
3/7/2011	OR07	192	203	211	217	224	230	237	245	256	230
3/8/2011	OR03	185	197	206	214	221	228	235	244	256	258
3/8/2011	OR04	345	357	366	373	380	387	395	404	416	385
3/8/2011	OR08	418	426	432	437	441	446	451	456	464	349
3/9/2011	OR04	288	307	321	333	344	355	367	381	400	465
3/9/2011	OR08	186	191	195	198	201	203	207	210	215	200
3/10/2011	OR01	290	310	324	336	347	359	371	385	404	240
3/10/2011	OR04	230	247	259	269	278	288	298	310	327	287
3/10/2011	OR07	258	271	281	289	297	304	313	322	335	415
3/11/2011	OR03	242	255	265	274	281	289	298	308	321	256
3/11/2011	OR04	258	270	278	286	292	299	306	315	327	213
3/11/2011	OR07	182	192	199	205	211	217	223	230	240	245
3/11/2011	OR08	203	213	220	227	232	238	244	252	262	219

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
3/14/2011	OR04	230	240	247	254	260	266	272	280	290	440
3/15/2011	OR08	366	375	381	386	391	396	401	407	416	305
3/16/2011	OR04	180	189	195	200	205	209	215	221	229	248
3/16/2011	OR08	284	294	300	306	311	317	322	329	338	343
3/17/2011	OR01	283	301	314	325	335	346	357	370	387	450
3/17/2011	OR03	243	255	264	272	279	286	294	302	315	279
3/17/2011	OR04	386	400	410	418	426	434	443	453	467	443
3/18/2011	OR04	229	242	253	261	269	277	286	296	310	270
3/18/2011	OR07	218	228	234	240	246	251	257	264	273	272
3/18/2011	OR08	214	218	220	223	225	227	230	232	236	197
3/21/2011	OR02	391	405	414	423	431	438	447	457	470	480
3/21/2011	OR03	464	477	486	494	502	509	517	527	540	501
3/21/2011	OR04	373	385	394	402	409	417	425	434	446	460
3/21/2011	OR08	201	210	217	223	228	234	240	247	256	255
3/22/2011	OR03	476	489	499	507	514	522	530	539	553	487
3/23/2011	OR07	110	120	126	132	137	143	148	155	164	147
3/24/2011	OR04	385	403	416	427	437	448	458	471	489	488
3/24/2011	OR07	213	223	231	237	243	249	256	263	274	220
3/25/2011	OR01	395	419	435	450	463	476	491	507	530	288
3/25/2011	OR04	250	258	264	270	275	279	285	291	299	330
3/25/2011	OR07	507	516	523	528	534	539	545	552	561	440
3/25/2011	OR08	207	210	213	216	218	220	222	225	229	260
3/28/2011	OR03	394	404	412	418	424	430	437	444	455	483
3/28/2011	OR04	416	428	437	445	452	459	466	475	487	447
3/28/2011	OR08	212	224	233	240	247	254	261	270	282	230
3/29/2011	OR02	402	415	424	432	439	446	454	463	476	400
3/29/2011	OR04	486	499	509	517	524	532	540	549	562	601
3/29/2011	OR08	269	276	281	285	289	293	297	302	308	290

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
3/30/2011	OR01	284	295	302	309	315	321	328	335	346	297
3/31/2011	OR04	241	256	267	276	285	294	303	314	329	365
4/1/2011	OR02	182	192	199	204	210	215	221	228	237	185
4/1/2011	OR03	158	169	177	184	190	197	204	212	223	185
4/4/2011	OR06	540	552	561	568	574	581	588	597	608	645
4/4/2011	OR07	265	276	284	290	297	303	309	317	328	232
4/4/2011	OR08	152	159	164	169	173	177	182	187	195	187
4/5/2011	OR04	164	172	179	184	189	194	200	206	215	147
4/6/2011	OR06	211	225	236	244	252	261	269	280	294	190
4/7/2011	OR01	375	398	415	430	443	457	471	488	512	537
4/7/2011	OR02	408	419	427	434	441	447	454	462	473	450
4/7/2011	OR03	472	482	490	496	502	508	514	521	532	626
4/7/2011	OR04	402	420	432	443	453	463	474	486	504	460
4/7/2011	OR07	417	438	454	467	479	491	504	519	541	410
4/8/2011	OR04	221	235	246	255	263	271	280	290	305	250
4/11/2011	OR04	577	594	606	616	625	635	645	657	674	510
4/11/2011	OR07	292	301	307	313	318	323	329	336	345	427
4/11/2011	OR08	169	177	182	187	191	196	200	206	214	217
4/13/2011	OR01	490	505	517	526	535	544	554	565	581	429
4/13/2011	OR04	466	478	486	494	501	508	515	524	536	392
4/14/2011	OR04	657	668	675	682	688	694	700	707	718	632
4/14/2011	OR07	255	270	281	290	299	308	317	328	343	284
4/15/2011	OR07	371	380	387	392	398	403	408	415	424	328
4/15/2011	OR08	213	220	225	228	232	236	240	245	251	196
4/18/2011	OR02	639	650	658	665	671	678	685	693	704	685
4/18/2011	OR03	331	346	357	366	374	383	392	403	417	341
4/18/2011	OR04	364	374	382	388	394	399	406	413	423	495
4/19/2011	OR06	164	172	179	184	189	194	199	206	214	150

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
4/20/2011	OR04	316	332	345	355	365	375	385	397	414	310
4/20/2011	OR06	196	209	218	227	234	242	250	259	273	160
4/20/2011	OR07	131	140	147	152	158	163	169	175	185	165
4/20/2011	OR08	128	132	135	138	140	143	146	149	153	170
4/21/2011	OR04	675	688	698	706	713	721	729	738	752	583
4/22/2011	OR03	284	295	303	310	317	323	330	338	349	324
4/22/2011	OR04	311	323	333	341	348	355	363	373	385	380
4/22/2011	OR07	413	423	430	436	442	447	453	460	470	274
4/22/2011	OR08	273	279	284	288	292	295	299	304	311	365
4/25/2011	OR03	631	648	660	670	680	690	700	713	730	675
4/26/2011	OR01	398	409	417	424	431	437	444	452	463	462
4/26/2011	OR02	287	298	305	312	318	324	330	338	349	260
4/26/2011	OR08	213	218	221	224	227	229	232	235	240	194
4/27/2011	OR01	586	601	612	621	630	638	648	659	674	482
4/27/2011	OR04	400	414	423	431	439	446	454	464	477	385
4/28/2011	OR01	139	149	155	161	166	172	177	184	193	262
4/29/2011	OR01	198	210	219	226	233	240	248	257	269	190
4/29/2011	OR07	377	386	393	399	404	409	415	422	431	340
4/29/2011	OR08	382	393	400	407	413	419	425	433	443	340
5/2/2011	OR01	626	651	668	684	698	712	727	745	770	670
5/2/2011	OR03	502	519	532	543	553	563	574	587	604	608
5/2/2011	OR04	415	427	436	443	450	457	465	474	486	398
5/2/2011	OR08	162	169	175	180	184	189	194	199	207	195
5/3/2011	OR08	312	319	324	328	333	337	341	346	353	278
5/4/2011	OR04	372	384	393	401	408	415	423	432	444	272
5/4/2011	OR08	220	227	232	236	240	244	249	254	261	217
5/5/2011	OR04	521	534	544	552	559	567	575	585	598	486
5/5/2011	OR07	302	328	347	363	378	393	409	428	454	285

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
5/6/2011	OR03	172	184	192	199	205	211	218	226	237	163
5/6/2011	OR04	328	344	355	365	374	383	392	403	419	335
5/6/2011	OR07	286	296	303	310	315	321	327	335	345	270
5/6/2011	OR08	304	312	318	323	328	332	337	343	352	330
5/9/2011	OR01	310	324	333	342	349	357	366	375	389	370
5/9/2011	OR03	410	422	430	438	444	451	458	466	478	354
5/9/2011	OR07	185	196	204	211	218	224	231	239	250	220
5/10/2011	OR08	562	568	572	576	580	583	587	591	597	420
5/11/2011	OR02	318	329	337	343	350	356	363	371	382	233
5/11/2011	OR04	292	307	317	326	334	342	351	361	375	340
5/12/2011	OR01	484	511	530	547	562	578	594	614	640	280
5/12/2011	OR07	228	238	244	250	256	261	267	274	283	200
5/13/2011	OR07	546	557	565	572	579	585	592	600	612	430
5/16/2011	OR01	195	209	219	228	235	243	252	262	275	195
5/16/2011	OR04	389	401	410	417	424	431	438	446	458	497
5/18/2011	OR02	137	147	154	159	165	170	176	183	192	235
5/19/2011	OR02	365	375	383	389	395	401	407	414	424	435
5/20/2011	OR03	208	218	225	231	236	242	248	255	265	288
5/20/2011	OR07	195	203	209	214	218	223	228	234	242	245
5/20/2011	OR08	279	286	292	297	301	306	311	316	324	366
5/23/2011	OR04	389	398	405	411	417	423	429	436	445	360
5/24/2011	OR02	360	371	379	386	393	399	406	414	425	475
5/24/2011	OR04	169	180	188	194	200	207	213	221	231	190
5/25/2011	OR07	545	556	564	570	577	583	590	598	609	480
5/26/2011	OR02	361	372	379	385	391	397	404	411	421	398
5/26/2011	OR03	292	311	325	337	348	359	371	384	404	410
5/27/2011	OR08	263	268	271	274	276	279	281	285	289	327
5/31/2011	OR04	320	333	343	351	359	367	375	385	398	330

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
6/1/2011	OR02	142	150	155	160	165	169	174	180	188	193
6/2/2011	OR02	400	411	418	425	431	437	443	451	462	429
6/2/2011	OR03	221	246	264	280	294	309	324	342	368	293
6/3/2011	OR02	168	178	185	192	197	203	210	217	227	182
6/6/2011	OR04	433	452	466	477	488	499	510	524	543	444
6/6/2011	OR06	412	424	433	441	448	455	463	472	484	405
6/7/2011	OR04	180	191	198	204	210	216	222	230	240	275
6/7/2011	OR08	315	322	327	332	336	340	344	350	357	430
6/8/2011	OR04	499	514	525	535	544	553	562	573	589	530
6/10/2011	OR08	242	247	251	254	257	260	263	267	272	276
6/13/2011	OR03	417	432	442	451	459	467	476	487	501	414
6/13/2011	OR04	637	649	657	664	671	677	684	692	704	695
6/13/2011	OR06	443	456	466	474	482	490	498	507	521	415
6/14/2011	OR04	281	293	301	308	315	321	328	336	348	340
6/15/2011	OR07	176	185	192	198	203	208	214	220	230	112
6/15/2011	OR08	189	194	198	201	204	208	211	215	220	220
6/17/2011	OR04	305	315	322	328	334	340	346	353	364	305
6/20/2011	OR04	235	244	251	256	261	266	272	278	287	250
6/20/2011	OR08	187	196	202	208	213	219	224	231	240	305
6/21/2011	OR08	213	222	229	235	240	245	251	258	267	337
6/22/2011	OR01	253	264	272	278	285	291	298	306	317	283
6/22/2011	OR08	196	202	206	209	212	216	219	223	229	190
6/23/2011	OR03	224	234	241	248	254	259	266	273	283	243
6/27/2011	OR02	375	386	394	401	407	414	420	428	439	555
6/27/2011	OR03	340	351	359	366	373	379	386	394	405	394
6/27/2011	OR04	380	389	396	402	407	412	418	425	434	415
6/28/2011	OR08	429	439	447	453	459	465	472	479	490	335
6/30/2011	OR01	335	363	384	401	418	434	451	472	500	465

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
6/30/2011	OR02	536	544	549	553	557	561	565	571	578	658
6/30/2011	OR03	375	388	397	404	412	419	426	435	448	420
7/1/2011	OR03	414	431	443	453	463	472	482	494	511	516
7/1/2011	OR08	404	414	421	427	433	438	444	451	461	545
7/5/2011	OR04	270	280	286	292	297	302	308	315	324	328
7/6/2011	OR01	269	279	286	292	298	304	310	317	327	250
7/6/2011	OR07	177	184	189	193	197	201	206	211	218	250
7/7/2011	OR04	389	402	412	420	428	435	444	453	467	600
7/8/2011	OR04	321	331	338	345	351	357	363	370	381	339
7/8/2011	OR07	90	98	103	108	113	117	122	127	135	470
7/11/2011	OR03	421	437	449	458	468	477	487	498	514	432
7/11/2011	OR04	480	490	497	503	509	514	520	527	537	463
7/13/2011	OR02	150	157	163	168	172	177	182	187	195	190
7/13/2011	OR04	382	393	401	408	414	420	427	435	446	450
7/13/2011	OR08	208	220	229	237	244	251	258	267	280	358
7/14/2011	OR03	519	531	540	548	556	563	571	580	592	542
7/14/2011	OR07	309	325	336	345	354	363	372	383	398	365
7/15/2011	OR03	195	206	214	220	227	233	239	247	258	152
7/18/2011	OR03	210	222	230	238	245	251	259	267	279	362
7/18/2011	OR04	279	289	296	301	307	312	318	325	335	458
7/18/2011	OR06	342	357	368	377	386	395	404	415	430	343
7/18/2011	OR07	384	406	421	434	446	459	472	487	508	390
7/19/2011	OR01	288	311	328	343	356	370	384	401	425	438
7/19/2011	OR04	435	449	459	468	476	485	493	504	518	470
7/20/2011	OR01	253	266	275	282	290	297	305	314	326	363
7/20/2011	OR03	435	447	456	463	470	477	484	493	505	557
7/21/2011	OR04	431	451	465	477	488	500	512	526	545	660
7/21/2011	OR07	289	301	310	317	324	332	339	348	360	313

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
7/22/2011	OR01	283	306	322	336	349	362	376	393	415	315
7/22/2011	OR07	369	379	386	392	398	403	409	416	426	415
7/25/2011	OR03	313	323	331	337	343	349	355	362	373	560
7/25/2011	OR07	333	340	346	351	355	360	365	370	378	390
7/28/2011	OR02	264	278	288	296	304	312	320	330	344	344
7/29/2011	OR01	273	283	290	296	302	307	313	320	330	330
7/29/2011	OR03	162	173	180	187	194	200	207	215	226	409
7/29/2011	OR04	150	159	165	170	175	180	186	192	200	175
7/29/2011	OR07	289	298	305	311	316	322	327	334	344	265
8/1/2011	OR02	400	416	427	437	446	455	465	476	492	380
8/1/2011	OR03	497	513	524	534	543	552	561	573	588	630
8/3/2011	OR04	259	268	276	282	287	293	299	306	316	235
8/5/2011	OR07	309	321	329	336	343	350	357	366	378	395
8/8/2011	OR04	415	429	439	447	455	463	472	482	495	455
8/9/2011	OR04	377	388	396	403	409	416	423	431	442	340
8/9/2011	OR08	356	364	371	376	381	386	391	398	406	466
8/11/2011	OR04	404	414	421	427	433	439	445	452	462	495
8/12/2011	OR07	456	466	474	480	486	492	498	506	516	463
8/15/2011	OR04	387	408	424	437	449	461	474	490	511	415
8/16/2011	OR02	198	211	221	230	238	246	254	264	278	175
8/17/2011	OR02	134	142	147	152	157	162	166	172	180	307
8/17/2011	OR07	170	185	196	206	215	223	233	244	259	180
8/17/2011	OR08	207	212	216	220	223	226	229	233	239	206
8/18/2011	OR06	445	458	467	474	482	489	496	505	518	493
8/18/2011	OR07	279	287	293	299	304	309	314	320	329	393
8/19/2011	OR07	439	451	460	467	474	480	487	496	508	425
8/19/2011	OR08	122	127	130	133	136	139	142	145	150	202
8/22/2011	OR04	389	410	426	439	452	464	477	493	515	460

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
8/22/2011	OR08	141	152	160	166	173	179	186	193	204	210
8/23/2011	OR06	193	206	216	224	232	239	248	257	270	250
8/23/2011	OR08	265	274	280	285	290	295	300	306	315	320
8/24/2011	OR01	452	485	509	529	548	567	588	612	645	590
8/24/2011	OR04	252	262	269	276	282	288	294	301	312	333
8/25/2011	OR04	369	379	386	392	397	403	408	415	425	458
8/26/2011	OR06	121	129	135	140	145	150	155	161	169	145
8/26/2011	OR07	299	309	315	321	327	332	338	345	354	342
8/29/2011	OR06	367	381	391	399	407	415	424	434	448	400
8/31/2011	OR01	267	280	289	297	304	312	320	329	341	280
9/1/2011	OR03	258	268	275	281	287	293	299	306	315	350
9/2/2011	OR01	324	347	364	378	391	404	418	435	458	265
9/2/2011	OR06	114	123	129	135	140	145	151	158	167	289
9/2/2011	OR07	381	394	403	411	418	425	433	442	455	390
9/6/2011	OR08	408	417	424	430	435	441	447	453	463	400
9/7/2011	OR07	147	165	179	190	201	211	222	236	254	205
9/8/2011	OR04	364	377	385	393	400	407	414	423	435	370
9/9/2011	OR02	361	370	377	383	388	393	399	406	415	380
9/9/2011	OR07	421	430	437	443	449	455	461	468	478	455
9/9/2011	OR08	223	228	232	235	237	240	243	247	252	237
9/12/2011	OR03	154	163	169	174	179	184	189	196	204	178
9/12/2011	OR04	394	415	430	443	455	467	480	495	516	440
9/13/2011	OR02	191	202	210	217	223	230	237	244	255	280
9/13/2011	OR08	354	362	368	372	377	382	386	392	400	380
9/14/2011	OR03	201	209	216	221	226	231	236	243	251	200
9/15/2011	OR01	211	223	231	238	245	251	258	267	278	317
9/15/2011	OR05	120	129	135	140	145	150	155	161	170	132
9/16/2011	OR04	190	201	209	216	222	229	235	243	254	358

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
9/16/2011	OR05	141	149	154	159	164	168	173	178	186	267
9/16/2011	OR07	225	238	248	256	264	271	280	289	303	287
9/16/2011	OR08	315	320	324	328	331	334	337	341	346	350
9/19/2011	OR01	307	327	342	354	365	377	389	404	424	300
9/19/2011	OR04	391	409	421	432	442	452	463	476	493	422
9/19/2011	OR06	118	128	136	142	148	154	160	168	178	224
9/20/2011	OR01	311	324	333	341	348	356	364	373	386	326
9/20/2011	OR04	254	266	274	282	288	295	302	310	322	224
9/20/2011	OR08	417	427	434	440	445	451	457	464	474	370
9/21/2011	OR04	346	356	364	370	376	382	388	395	405	345
9/22/2011	OR03	333	344	351	358	364	370	377	385	395	474
9/23/2011	OR07	274	285	292	298	304	310	317	324	334	385
9/26/2011	OR02	393	401	407	413	418	422	428	434	442	415
9/26/2011	OR04	384	398	407	416	424	431	440	449	463	515
9/27/2011	OR01	482	506	524	539	553	567	582	599	624	525
9/27/2011	OR04	397	408	416	423	430	436	443	451	462	438
9/27/2011	OR08	373	380	385	390	394	398	403	408	415	395
9/28/2011	OR02	397	406	412	418	423	428	433	440	449	380
9/28/2011	OR07	281	297	308	318	327	335	345	356	372	440
9/28/2011	OR08	226	237	246	253	260	266	273	282	294	322
9/29/2011	OR01	206	221	233	242	251	260	270	281	296	237
9/29/2011	OR04	386	397	405	412	418	424	431	439	450	436
9/30/2011	OR03	485	495	503	509	515	521	528	535	546	359
9/30/2011	OR04	248	259	267	274	280	286	293	301	312	212
9/30/2011	OR07	382	392	399	405	411	417	423	430	440	449
10/4/2011	OR08	292	298	302	305	308	312	315	319	325	345
10/5/2011	OR02	152	160	166	171	176	180	185	191	199	160
10/5/2011	OR03	188	201	211	220	227	235	244	254	267	172

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
10/5/2011	OR05	150	159	166	171	177	182	188	194	204	233
10/5/2011	OR07	270	279	286	292	298	303	309	316	325	403
10/5/2011	OR08	175	184	190	196	201	206	211	218	226	372
10/6/2011	OR04	370	380	387	393	399	405	411	418	427	410
10/6/2011	OR06	195	206	214	221	228	235	242	250	261	410
10/7/2011	OR07	426	435	441	447	452	457	463	469	478	362
10/12/2011	OR01	345	358	368	376	383	391	399	408	421	365
10/12/2011	OR04	247	256	263	269	274	279	285	292	301	336
10/13/2011	OR02	419	440	456	469	481	494	507	522	544	625
10/13/2011	OR05	383	394	402	409	415	422	429	437	448	425
10/14/2011	OR01	444	465	481	494	506	519	532	547	569	510
10/14/2011	OR08	229	239	245	251	257	262	268	275	284	340
10/17/2011	OR03	434	445	453	460	466	473	480	488	499	423
10/18/2011	OR01	328	338	345	351	357	363	369	376	386	295
10/18/2011	OR03	388	409	424	437	449	461	474	490	511	412
10/18/2011	OR04	501	518	530	541	550	560	570	582	599	460
10/19/2011	OR02	358	367	373	378	383	387	393	399	407	340
10/19/2011	OR05	122	131	138	144	149	154	160	166	175	90
10/19/2011	OR08	281	288	293	297	300	304	308	313	319	330
10/20/2011	OR03	220	236	248	258	267	277	286	298	314	287
10/20/2011	OR06	226	238	246	253	260	267	274	282	294	245
10/21/2011	OR01	201	210	217	223	228	234	240	246	256	210
10/21/2011	OR07	325	334	341	346	352	357	363	369	379	282
10/24/2011	OR02	395	405	411	417	422	428	433	440	449	400
10/24/2011	OR04	334	345	353	359	365	371	378	386	396	380
10/24/2011	OR07	420	442	458	471	483	496	509	524	546	580
10/26/2011	OR03	186	199	209	218	225	233	241	251	265	348
10/26/2011	OR05	335	345	353	359	365	370	377	384	394	324

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
10/26/2011	OR07	213	222	228	234	239	244	249	255	264	250
10/27/2011	OR01	591	608	621	631	641	651	661	674	691	720
10/28/2011	OR02	207	219	227	235	241	248	256	264	276	274
10/28/2011	OR08	349	359	367	373	379	384	391	398	408	333
10/31/2011	OR04	330	340	347	353	359	365	371	378	388	468
10/31/2011	OR06	313	326	336	344	351	359	367	376	390	315
11/1/2011	OR02	396	405	412	417	423	428	434	440	450	360
11/1/2011	OR08	237	242	247	250	254	257	260	265	270	245
11/2/2011	OR03	185	198	207	214	221	229	236	245	258	185
11/2/2011	OR06	272	283	291	297	303	309	316	324	334	256
11/2/2011	OR07	134	143	150	155	161	166	172	179	188	210
11/2/2011	OR08	225	232	237	242	246	250	254	260	267	340
11/3/2011	OR01	183	194	201	208	214	220	227	234	245	170
11/3/2011	OR05	361	373	381	389	395	402	409	417	429	410
11/3/2011	OR06	230	238	245	250	255	260	265	271	280	373
11/4/2011	OR03	121	129	135	140	145	150	155	161	169	146
11/7/2011	OR02	498	513	523	533	541	550	559	569	584	631
11/7/2011	OR04	359	370	378	385	392	398	405	413	424	405
11/7/2011	OR08	165	173	179	184	189	194	199	205	213	200
11/8/2011	OR03	267	276	283	289	295	301	307	314	324	340
11/9/2011	OR02	155	163	170	175	180	185	190	196	204	178
11/9/2011	OR04	224	233	239	245	250	255	261	267	276	225
11/9/2011	OR08	319	326	331	336	340	344	348	353	360	361
11/10/2011	OR05	247	258	266	273	279	285	292	300	311	313
11/10/2011	OR06	547	556	562	568	573	578	583	590	599	473
11/14/2011	OR02	329	339	346	353	359	365	371	378	388	473
11/15/2011	OR03	210	219	225	230	235	240	245	252	260	402
11/15/2011	OR08	390	395	399	402	406	409	412	416	421	388

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
11/16/2011	OR04	243	252	259	264	269	274	280	286	295	265
11/16/2011	OR05	156	166	173	180	185	191	198	205	215	128
11/16/2011	OR08	204	211	216	220	225	229	233	238	245	350
11/17/2011	OR04	391	401	407	413	419	424	430	437	447	428
11/18/2011	OR08	255	266	273	280	286	292	299	306	317	265
11/21/2011	OR01	326	341	352	362	371	379	389	400	415	450
11/21/2011	OR02	169	178	185	190	196	201	207	213	222	123
11/21/2011	OR03	188	202	213	222	230	239	248	258	273	281
11/21/2011	OR06	194	208	217	225	233	241	249	258	272	168
11/21/2011	OR07	253	263	270	276	282	288	294	301	311	329
11/22/2011	OR08	488	497	504	510	515	521	527	534	543	475
11/23/2011	OR02	178	187	194	200	205	210	216	223	232	245
11/23/2011	OR03	189	202	212	220	228	235	243	253	266	189
11/28/2011	OR05	519	532	542	550	558	566	574	584	597	460
11/29/2011	OR03	220	233	242	250	258	266	274	283	296	249
11/29/2011	OR04	507	520	528	536	543	550	558	566	579	495
12/1/2011	OR01	324	336	345	353	360	367	375	383	396	370
12/1/2011	OR04	401	412	420	426	433	439	446	453	464	430
12/5/2011	OR03	323	337	347	356	364	372	381	391	405	292
12/5/2011	OR04	378	392	402	410	418	426	434	444	458	343
12/5/2011	OR06	182	196	206	214	222	230	239	249	262	205
12/5/2011	OR08	116	125	131	137	142	147	152	159	168	177
12/6/2011	OR03	444	454	461	467	473	479	485	492	502	377
12/6/2011	OR08	398	404	408	412	415	418	422	426	432	395
12/7/2011	OR01	357	372	383	392	401	410	420	431	446	256
12/7/2011	OR03	399	411	419	426	432	439	446	454	466	426
12/7/2011	OR05	119	127	133	138	142	147	152	157	165	114
12/7/2011	OR08	346	355	362	367	372	378	383	390	399	380

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
12/9/2011	OR07	205	214	221	227	232	238	244	251	260	244
12/9/2011	OR08	296	305	311	317	322	327	332	339	348	270
12/12/2011	OR04	503	517	527	536	544	552	561	571	585	345
12/12/2011	OR08	178	189	196	202	208	214	220	228	238	205
12/13/2011	OR04	231	241	249	255	260	266	272	279	289	364
12/14/2011	OR08	294	303	309	314	319	324	330	336	345	443
12/15/2011	OR04	290	304	314	323	331	339	347	358	372	350
12/15/2011	OR05	166	183	195	206	215	225	235	247	264	241
12/16/2011	OR04	417	426	433	439	444	449	455	461	471	459
12/16/2011	OR07	540	553	562	570	577	584	592	601	614	405
12/16/2011	OR08	353	364	371	378	384	390	396	404	414	403
12/19/2011	OR08	153	162	169	175	180	185	191	198	207	184
12/20/2011	OR08	335	342	348	352	356	361	365	371	378	285
12/21/2011	OR08	384	394	401	407	412	418	424	431	440	408
12/22/2011	OR06	226	234	239	244	248	252	257	262	269	262
12/28/2011	OR08	155	159	162	165	167	170	172	175	179	135
12/30/2011	OR07	289	298	305	311	316	321	327	334	343	328

Table 40: Empirical Percentile Values of the Distribution of the Duration of Surgery Lists from Monte Carlo Simulation

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
1/3/2011	OR04	362	373	382	391	399	409	421	437	464	391
1/3/2011	OR07	296	316	330	343	356	370	385	404	431	380
1/4/2011	OR01	312	339	360	380	400	422	447	479	529	403
1/4/2011	OR03	380	401	417	431	444	458	474	493	521	395
1/4/2011	OR08	255	270	281	292	302	312	324	339	361	335
1/5/2011	OR03	163	178	189	200	210	221	233	249	274	163
1/5/2011	OR08	231	243	252	261	268	277	286	298	315	318

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
1/6/2011	OR03	268	305	335	363	391	421	458	505	578	337
1/7/2011	OR02	176	191	204	215	226	238	252	270	297	370
1/7/2011	OR03	341	358	370	381	393	404	418	434	460	455
1/7/2011	OR07	199	216	231	244	256	270	285	305	335	300
1/10/2011	OR02	207	220	230	239	248	258	268	281	301	339
1/10/2011	OR04	365	375	384	393	401	411	423	439	465	385
1/11/2011	OR01	445	464	478	490	503	515	529	546	571	450
1/11/2011	OR08	251	264	274	283	291	300	310	322	339	290
1/12/2011	OR04	222	244	262	278	295	313	334	360	402	319
1/12/2011	OR07	193	209	222	233	245	257	272	289	317	200
1/13/2011	OR07	175	191	204	216	228	240	255	274	302	234
1/14/2011	OR04	161	180	195	208	222	237	253	275	308	227
1/14/2011	OR07	459	485	505	523	541	560	580	607	648	417
1/18/2011	OR08	216	224	231	237	243	248	255	262	273	240
1/19/2011	OR03	248	264	277	289	300	312	325	341	366	427
1/20/2011	OR04	355	376	393	408	422	438	455	477	510	360
1/21/2011	OR01	317	339	355	370	384	400	417	439	472	345
1/21/2011	OR02	162	177	189	200	212	224	237	255	282	342
1/21/2011	OR03	208	225	237	249	260	273	286	304	330	181
1/24/2011	OR02	501	530	552	572	591	610	632	659	698	615
1/24/2011	OR04	346	362	375	387	398	411	425	444	473	373
1/25/2011	OR01	448	495	532	566	600	636	678	730	811	560
1/25/2011	OR03	288	308	324	337	351	366	382	402	432	272
1/25/2011	OR04	413	443	467	488	509	531	557	590	640	407
1/25/2011	OR08	334	345	353	361	368	375	383	392	406	357
1/26/2011	OR01	69	82	94	105	116	129	145	166	202	55
1/26/2011	OR07	219	235	247	259	270	282	296	313	340	335
1/27/2011	OR04	325	353	375	395	415	436	460	490	534	442

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
1/28/2011	OR01	408	434	453	471	488	506	527	552	588	350
1/28/2011	OR02	178	194	206	217	229	241	254	272	299	207
1/28/2011	OR03	191	211	226	240	254	269	287	308	341	199
1/28/2011	OR07	242	259	272	284	296	309	323	342	371	250
1/31/2011	OR04	259	275	289	301	314	327	343	364	397	285
1/31/2011	OR07	220	237	250	262	274	286	300	318	345	245
2/1/2011	OR08	388	405	418	429	441	452	465	480	503	378
2/3/2011	OR04	302	332	356	377	399	421	447	479	529	447
2/4/2011	OR03	469	513	547	578	610	643	682	731	808	444
2/4/2011	OR07	166	179	189	199	209	219	231	246	271	174
2/4/2011	OR08	314	341	362	381	400	420	443	472	515	288
2/7/2011	OR07	265	279	290	300	309	319	330	343	363	330
2/8/2011	OR03	242	261	275	288	302	316	332	352	384	373
2/8/2011	OR04	376	385	391	397	404	410	418	428	445	450
2/8/2011	OR08	325	338	348	357	365	374	384	396	413	293
2/9/2011	OR03	297	316	330	343	356	370	386	405	435	393
2/9/2011	OR04	220	241	258	274	289	306	326	351	390	280
2/9/2011	OR07	155	169	179	188	198	208	219	233	255	280
2/10/2011	OR03	318	358	391	422	454	489	531	586	675	467
2/11/2011	OR07	319	343	362	380	398	417	438	465	508	328
2/11/2011	OR08	263	280	294	305	317	329	342	359	383	277
2/14/2011	OR02	362	379	392	404	415	427	439	455	478	390
2/14/2011	OR03	350	379	403	425	447	472	501	538	600	378
2/14/2011	OR04	335	352	365	377	389	402	416	435	465	447
2/15/2011	OR08	243	259	272	282	293	305	318	334	358	217
2/16/2011	OR02	236	249	260	269	278	288	299	313	334	277
2/16/2011	OR03	170	183	194	203	212	222	232	246	266	264
2/16/2011	OR04	214	240	261	281	300	322	347	379	430	337

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
2/16/2011	OR08	320	338	352	366	378	392	407	425	455	369
2/17/2011	OR03	250	269	284	298	311	325	341	361	391	277
2/17/2011	OR04	418	449	474	497	520	545	574	610	667	485
2/18/2011	OR04	259	282	300	318	336	355	377	406	452	355
2/18/2011	OR07	286	308	325	340	354	370	388	409	443	421
2/18/2011	OR08	277	294	307	319	332	344	359	378	407	208
2/22/2011	OR06	219	238	252	266	279	294	310	331	363	265
2/22/2011	OR08	245	255	262	268	274	281	287	296	308	258
2/23/2011	OR03	231	249	262	274	287	299	313	331	357	380
2/23/2011	OR07	186	202	215	227	239	251	265	283	310	251
2/23/2011	OR08	109	116	122	126	131	136	142	149	159	126
2/24/2011	OR03	382	416	444	470	496	525	560	605	678	441
2/24/2011	OR04	157	171	182	192	203	214	227	245	274	317
2/28/2011	OR04	344	356	365	374	383	394	406	422	448	405
3/1/2011	OR03	289	312	330	347	363	379	398	422	458	355
3/1/2011	OR04	205	220	232	243	254	266	280	298	326	225
3/2/2011	OR02	75	85	94	102	110	119	130	144	168	200
3/2/2011	OR04	244	262	276	290	304	320	340	365	408	286
3/2/2011	OR08	188	204	216	228	239	251	265	282	309	200
3/3/2011	OR02	452	470	484	497	509	521	536	553	579	495
3/4/2011	OR03	233	248	261	272	283	295	309	327	354	267
3/4/2011	OR08	336	355	370	384	397	411	427	448	480	271
3/7/2011	OR04	335	352	365	377	389	402	417	435	465	423
3/7/2011	OR07	176	190	201	210	220	230	241	255	277	230
3/8/2011	OR03	166	181	193	204	215	227	241	258	283	258
3/8/2011	OR04	304	327	346	363	380	398	419	445	486	385
3/8/2011	OR08	379	398	412	425	437	451	465	482	508	349
3/9/2011	OR04	259	283	303	321	339	358	380	407	449	465

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
3/9/2011	OR08	173	181	187	193	199	204	211	219	230	200
3/10/2011	OR01	254	280	301	320	339	359	382	412	457	240
3/10/2011	OR04	201	224	241	258	274	291	311	336	376	287
3/10/2011	OR07	234	252	267	280	293	306	321	340	367	415
3/11/2011	OR03	220	238	252	265	277	290	304	322	349	256
3/11/2011	OR04	223	244	260	275	289	304	322	344	378	213
3/11/2011	OR07	156	170	182	193	204	216	229	246	274	245
3/11/2011	OR08	176	191	203	214	225	237	251	269	299	219
3/14/2011	OR04	202	219	232	244	256	269	284	303	332	440
3/15/2011	OR08	328	347	362	375	388	401	416	434	462	305
3/16/2011	OR04	166	177	186	193	201	209	218	230	248	248
3/16/2011	OR08	249	267	280	293	305	317	332	351	379	343
3/17/2011	OR01	254	278	296	312	329	346	366	391	428	450
3/17/2011	OR03	222	239	252	263	275	287	300	317	342	279
3/17/2011	OR04	359	379	394	408	422	437	454	475	508	443
3/18/2011	OR04	206	223	237	250	263	277	293	312	343	270
3/18/2011	OR07	192	207	218	229	239	250	263	280	305	272
3/18/2011	OR08	200	208	213	218	223	228	234	240	250	197
3/21/2011	OR02	365	385	401	415	428	442	457	476	503	480
3/21/2011	OR03	424	448	466	482	498	514	533	555	588	501
3/21/2011	OR04	342	362	378	392	406	421	438	459	492	460
3/21/2011	OR08	183	197	207	216	226	235	246	260	280	255
3/22/2011	OR03	451	470	485	499	511	525	540	558	585	487
3/23/2011	OR07	98	109	117	124	132	140	149	162	181	147
3/24/2011	OR04	354	379	399	417	434	452	473	498	537	488
3/24/2011	OR07	187	202	215	227	238	251	266	285	315	220
3/25/2011	OR01	347	380	407	431	455	481	510	546	602	288
3/25/2011	OR04	221	236	248	259	270	282	295	313	342	330

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
3/25/2011	OR07	445	469	489	506	524	542	563	590	629	440
3/25/2011	OR08	194	201	206	211	216	221	226	233	243	260
3/28/2011	OR03	359	379	394	407	421	434	450	469	498	483
3/28/2011	OR04	390	409	423	436	449	462	477	496	526	447
3/28/2011	OR08	190	207	220	231	243	256	270	287	314	230
3/29/2011	OR02	377	396	411	424	437	450	464	482	507	400
3/29/2011	OR04	431	459	480	500	519	539	562	591	634	601
3/29/2011	OR08	244	257	268	277	286	295	305	317	335	290
3/30/2011	OR01	261	277	290	301	312	325	339	358	388	297
3/31/2011	OR04	224	239	251	263	274	288	303	325	361	365
4/1/2011	OR02	164	177	187	196	205	215	226	241	265	185
4/1/2011	OR03	141	155	166	177	187	198	210	226	249	185
4/4/2011	OR06	478	509	532	553	573	594	617	646	688	645
4/4/2011	OR07	245	260	272	283	294	304	316	331	353	232
4/4/2011	OR08	140	150	157	164	171	178	186	196	210	187
4/5/2011	OR04	143	155	165	175	184	194	207	223	250	147
4/6/2011	OR06	189	208	222	236	250	265	281	303	335	190
4/7/2011	OR01	338	366	388	409	431	454	482	518	578	537
4/7/2011	OR02	387	404	416	428	438	449	462	477	498	450
4/7/2011	OR03	439	458	473	485	498	511	526	543	570	626
4/7/2011	OR04	369	394	414	432	450	468	489	514	552	460
4/7/2011	OR07	375	405	428	450	471	495	520	553	604	410
4/8/2011	OR04	180	203	222	240	258	277	300	328	373	250
4/11/2011	OR04	516	550	577	601	624	649	677	711	763	510
4/11/2011	OR07	261	278	291	302	314	326	340	358	386	427
4/11/2011	OR08	156	167	175	182	190	197	206	216	231	217
4/13/2011	OR01	456	480	499	516	532	549	569	592	627	429
4/13/2011	OR04	409	436	457	477	496	518	543	575	626	392

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
4/14/2011	OR04	614	637	654	670	685	702	721	745	783	632
4/14/2011	OR07	213	238	258	277	296	316	339	368	414	284
4/15/2011	OR07	326	346	361	375	388	403	420	441	474	328
4/15/2011	OR08	191	203	213	221	229	238	247	259	277	196
4/18/2011	OR02	601	624	641	655	669	683	699	717	744	685
4/18/2011	OR03	291	316	335	353	370	388	409	435	476	341
4/18/2011	OR04	340	356	368	379	390	401	415	432	460	495
4/19/2011	OR06	149	161	170	178	186	195	204	216	234	150
4/20/2011	OR04	286	309	327	344	360	378	398	423	461	310
4/20/2011	OR06	177	193	206	218	230	243	257	275	303	160
4/20/2011	OR07	117	128	137	145	153	161	171	183	203	165
4/20/2011	OR08	120	127	131	135	139	143	148	153	162	170
4/21/2011	OR04	627	654	675	694	712	731	752	779	820	583
4/22/2011	OR03	265	281	292	303	313	324	337	352	374	324
4/22/2011	OR04	271	293	310	325	341	358	377	401	437	380
4/22/2011	OR07	357	381	400	417	434	452	472	497	535	274
4/22/2011	OR08	245	259	270	279	288	298	308	321	340	365
4/25/2011	OR03	570	601	625	649	672	699	732	776	856	675
4/26/2011	OR01	357	379	397	412	427	443	461	484	520	462
4/26/2011	OR02	268	283	295	305	315	326	337	352	374	260
4/26/2011	OR08	200	208	214	220	225	231	237	245	255	194
4/27/2011	OR01	529	560	585	608	630	653	679	712	762	482
4/27/2011	OR04	373	393	408	422	436	450	467	487	519	385
4/28/2011	OR01	124	136	145	154	163	173	184	198	219	262
4/29/2011	OR01	177	193	206	217	229	241	255	273	300	190
4/29/2011	OR07	324	345	363	378	394	411	430	454	491	340
4/29/2011	OR08	334	356	374	390	405	421	440	463	499	340
5/2/2011	OR01	535	583	622	656	691	727	770	823	907	670

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
5/2/2011	OR03	425	459	486	511	538	568	603	652	737	608
5/2/2011	OR04	388	407	422	434	447	460	475	494	524	398
5/2/2011	OR08	147	157	165	173	180	189	198	211	230	195
5/3/2011	OR08	283	299	310	320	330	341	352	366	386	278
5/4/2011	OR04	346	364	379	392	405	419	434	454	485	272
5/4/2011	OR08	202	214	222	230	238	246	254	265	281	217
5/5/2011	OR04	479	501	519	536	553	571	593	621	664	486
5/5/2011	OR07	260	291	317	341	366	393	424	465	530	285
5/6/2011	OR03	152	167	178	189	200	212	225	242	268	163
5/6/2011	OR04	282	308	329	348	366	387	410	438	482	335
5/6/2011	OR07	245	264	280	294	308	322	339	361	394	270
5/6/2011	OR08	272	288	301	312	322	334	346	361	383	330
5/9/2011	OR01	284	304	319	332	346	360	376	395	425	370
5/9/2011	OR03	374	396	412	427	441	455	471	491	520	354
5/9/2011	OR07	168	182	193	203	213	223	236	251	275	220
5/10/2011	OR08	531	547	559	569	578	588	598	611	629	420
5/11/2011	OR02	269	292	310	327	343	360	380	404	441	233
5/11/2011	OR04	260	282	300	315	331	348	367	391	428	340
5/12/2011	OR01	438	472	499	525	551	578	611	653	721	280
5/12/2011	OR07	211	225	235	244	253	262	273	285	305	200
5/13/2011	OR07	476	507	531	553	575	598	624	655	703	430
5/16/2011	OR01	171	189	203	216	230	244	261	282	315	195
5/16/2011	OR04	364	381	395	408	420	433	448	467	497	497
5/18/2011	OR02	124	136	145	154	163	173	183	197	219	235
5/19/2011	OR02	346	361	373	383	392	402	413	427	446	435
5/20/2011	OR03	193	206	216	224	233	242	252	265	285	288
5/20/2011	OR07	185	194	201	207	213	220	228	238	256	245
5/20/2011	OR08	252	266	277	286	296	307	319	334	357	366

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
5/23/2011	OR04	365	380	392	403	413	425	438	455	482	360
5/24/2011	OR02	339	356	368	380	390	402	414	429	451	475
5/24/2011	OR04	149	163	175	185	196	207	220	237	262	190
5/25/2011	OR07	499	524	542	559	574	591	609	630	662	480
5/26/2011	OR02	341	357	369	379	389	399	411	424	445	398
5/26/2011	OR03	263	287	305	323	340	358	380	407	449	410
5/27/2011	OR08	247	256	263	269	275	281	287	295	306	327
5/31/2011	OR04	295	314	329	342	355	369	384	403	431	330
6/1/2011	OR02	131	140	147	154	161	168	177	188	207	193
6/2/2011	OR02	382	397	409	419	429	439	450	464	483	429
6/2/2011	OR03	203	227	245	263	281	300	324	354	404	293
6/3/2011	OR02	153	166	176	185	194	203	214	227	248	182
6/6/2011	OR04	391	420	443	463	483	504	528	559	605	444
6/6/2011	OR06	362	388	407	426	443	461	482	508	546	405
6/7/2011	OR04	162	176	187	197	206	216	228	243	266	275
6/7/2011	OR08	278	294	308	319	331	343	358	376	405	430
6/8/2011	OR04	458	484	504	522	540	558	580	606	647	530
6/10/2011	OR08	224	234	242	248	255	262	269	278	291	276
6/13/2011	OR03	365	392	414	434	453	475	499	529	578	414
6/13/2011	OR04	591	616	635	652	669	688	708	733	774	695
6/13/2011	OR06	390	418	440	459	479	499	522	551	594	415
6/14/2011	OR04	261	277	289	300	311	322	335	351	375	340
6/15/2011	OR07	153	166	176	186	196	206	218	234	259	112
6/15/2011	OR08	174	183	190	197	203	209	216	225	237	220
6/17/2011	OR04	271	290	304	318	331	344	360	379	409	305
6/20/2011	OR04	215	227	237	246	256	266	278	295	323	250
6/20/2011	OR08	172	184	193	202	210	219	229	241	260	305
6/21/2011	OR08	190	204	216	226	236	247	258	273	295	337

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
6/22/2011	OR01	228	245	258	269	281	294	308	327	356	283
6/22/2011	OR08	181	190	198	204	211	217	224	233	246	190
6/23/2011	OR03	206	220	231	241	250	260	272	285	307	243
6/27/2011	OR02	355	372	384	394	405	416	427	442	463	555
6/27/2011	OR03	304	325	341	355	369	384	400	420	449	394
6/27/2011	OR04	358	372	383	393	402	413	426	442	470	415
6/28/2011	OR08	379	403	422	438	454	471	490	513	548	335
6/30/2011	OR01	289	323	351	377	403	432	466	510	584	465
6/30/2011	OR02	526	535	542	548	554	561	568	577	591	658
6/30/2011	OR03	338	360	377	392	407	422	440	461	493	420
7/1/2011	OR03	369	395	415	434	453	473	497	527	574	516
7/1/2011	OR08	356	379	397	412	428	444	462	485	518	545
7/5/2011	OR04	254	267	276	285	294	303	313	326	346	328
7/6/2011	OR01	252	266	277	286	295	305	316	329	349	250
7/6/2011	OR07	168	176	183	188	194	200	208	216	230	250
7/7/2011	OR04	356	378	395	410	425	441	458	481	514	600
7/8/2011	OR04	288	306	321	334	347	360	376	395	424	339
7/8/2011	OR07	83	90	95	101	106	113	120	130	148	470
7/11/2011	OR03	376	404	425	444	463	483	506	534	578	432
7/11/2011	OR04	438	459	475	490	505	522	540	564	602	463
7/13/2011	OR02	138	147	155	161	168	175	184	195	214	190
7/13/2011	OR04	356	373	386	398	410	423	437	456	485	450
7/13/2011	OR08	172	191	207	221	236	252	269	293	328	358
7/14/2011	OR03	477	502	520	537	553	569	588	610	643	542
7/14/2011	OR07	264	289	309	328	347	367	390	421	469	365
7/15/2011	OR03	178	192	203	213	223	233	245	259	281	152
7/18/2011	OR03	191	207	219	230	240	252	265	281	305	362
7/18/2011	OR04	254	269	281	292	303	315	329	347	376	458

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
7/18/2011	OR06	291	319	340	359	379	400	423	453	499	343
7/18/2011	OR07	352	380	401	421	440	460	483	510	553	390
7/19/2011	OR01	247	276	299	321	343	367	395	430	489	438
7/19/2011	OR04	394	419	438	455	472	489	509	534	569	470
7/20/2011	OR01	226	245	259	273	286	300	316	337	369	363
7/20/2011	OR03	398	420	437	452	466	481	498	519	550	557
7/21/2011	OR04	391	421	444	465	485	506	530	560	605	660
7/21/2011	OR07	268	285	298	310	322	333	346	363	387	313
7/22/2011	OR01	242	269	292	313	335	359	387	423	484	315
7/22/2011	OR07	321	342	359	374	389	405	423	445	480	415
7/25/2011	OR03	296	309	320	329	338	348	360	374	395	560
7/25/2011	OR07	301	317	330	341	351	362	375	390	413	390
7/28/2011	OR02	246	263	277	288	300	312	325	342	366	344
7/29/2011	OR01	244	261	274	285	296	308	322	339	365	330
7/29/2011	OR03	142	156	168	178	189	200	213	230	256	409
7/29/2011	OR04	135	146	155	163	171	180	189	202	221	175
7/29/2011	OR07	251	269	283	296	309	322	338	357	388	265
8/1/2011	OR02	379	400	415	429	442	456	471	490	518	380
8/1/2011	OR03	447	476	498	518	537	558	580	608	649	630
8/3/2011	OR04	235	250	262	272	283	295	308	326	354	235
8/5/2011	OR07	273	293	309	323	338	353	369	390	421	395
8/8/2011	OR04	386	407	423	438	452	467	484	506	539	455
8/9/2011	OR04	340	361	377	391	406	420	437	457	487	340
8/9/2011	OR08	313	333	349	363	377	392	409	429	462	466
8/11/2011	OR04	380	396	407	418	429	440	454	471	499	495
8/12/2011	OR07	394	420	441	459	477	497	518	545	585	463
8/15/2011	OR04	350	380	403	424	445	467	491	522	568	415
8/16/2011	OR02	179	195	209	220	232	245	259	278	306	175

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
8/17/2011	OR02	118	128	136	144	151	159	169	182	202	307
8/17/2011	OR07	155	171	183	194	205	217	232	251	282	180
8/17/2011	OR08	189	200	207	214	221	228	236	245	259	206
8/18/2011	OR06	385	415	438	458	479	500	524	553	597	493
8/18/2011	OR07	253	268	280	290	300	311	323	338	361	393
8/19/2011	OR07	378	404	424	443	461	480	503	532	575	425
8/19/2011	OR08	113	120	125	130	135	140	145	152	162	202
8/22/2011	OR04	350	380	404	426	447	470	495	526	574	460
8/22/2011	OR08	123	137	148	158	168	178	190	206	230	210
8/23/2011	OR06	169	186	200	213	226	240	256	276	309	250
8/23/2011	OR08	231	247	260	272	284	297	313	333	364	320
8/24/2011	OR01	405	444	476	505	534	565	600	645	715	590
8/24/2011	OR04	223	240	254	266	279	292	308	327	358	333
8/25/2011	OR04	346	361	372	382	393	404	417	433	461	458
8/26/2011	OR06	109	119	127	135	142	150	159	170	188	145
8/26/2011	OR07	254	273	289	304	318	334	352	375	411	342
8/29/2011	OR06	317	344	365	383	402	422	444	473	515	400
8/31/2011	OR01	238	258	274	287	301	316	333	354	386	280
9/1/2011	OR03	242	255	266	275	284	294	304	317	337	350
9/2/2011	OR01	280	310	335	357	379	404	432	469	526	265
9/2/2011	OR06	101	111	120	128	136	144	154	167	187	289
9/2/2011	OR07	339	360	377	392	408	424	443	467	504	390
9/6/2011	OR08	356	379	397	414	431	448	468	493	533	400
9/7/2011	OR07	141	157	169	181	193	206	220	239	269	205
9/8/2011	OR04	334	354	370	384	397	411	427	448	479	370
9/9/2011	OR02	331	348	361	373	384	396	410	428	454	380
9/9/2011	OR07	365	389	407	424	440	458	477	502	538	455
9/9/2011	OR08	209	218	224	230	236	242	249	256	268	237

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
9/12/2011	OR03	142	152	160	167	174	182	192	203	222	178
9/12/2011	OR04	355	386	409	430	450	472	497	528	572	440
9/13/2011	OR02	172	187	198	209	219	230	242	258	282	280
9/13/2011	OR08	317	334	348	360	373	385	400	419	447	380
9/14/2011	OR03	177	190	200	210	220	230	242	257	282	200
9/15/2011	OR01	195	209	221	231	241	251	263	277	299	317
9/15/2011	OR05	95	109	120	130	141	153	167	185	216	132
9/16/2011	OR04	171	186	197	208	218	229	242	257	281	358
9/16/2011	OR05	129	138	146	152	159	167	175	187	205	267
9/16/2011	OR07	191	211	227	241	255	271	288	311	347	287
9/16/2011	OR08	293	305	314	322	329	337	345	355	370	350
9/19/2011	OR01	283	306	325	342	359	376	396	421	458	300
9/19/2011	OR04	360	384	403	420	437	455	476	501	541	422
9/19/2011	OR06	100	113	124	134	143	154	166	182	206	224
9/20/2011	OR01	287	306	320	333	345	357	372	389	415	326
9/20/2011	OR04	232	249	262	273	285	297	310	327	353	224
9/20/2011	OR08	364	389	409	426	444	462	482	506	544	370
9/21/2011	OR04	300	323	341	358	374	392	413	439	480	345
9/22/2011	OR03	300	319	334	347	360	374	389	408	436	474
9/23/2011	OR07	234	254	269	283	297	311	328	349	381	385
9/26/2011	OR02	378	390	399	408	416	424	433	444	461	415
9/26/2011	OR04	355	376	392	407	421	436	453	474	506	515
9/27/2011	OR01	436	470	497	520	544	569	598	633	687	525
9/27/2011	OR04	359	380	396	411	425	440	457	478	509	438
9/27/2011	OR08	344	359	371	381	392	402	413	427	447	395
9/28/2011	OR02	380	393	403	412	420	429	439	451	469	380
9/28/2011	OR07	249	270	286	301	316	332	350	373	409	440
9/28/2011	OR08	202	218	230	241	252	264	278	295	322	322

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
9/29/2011	OR01	173	193	210	226	242	259	279	306	348	237
9/29/2011	OR04	359	377	390	403	415	428	442	461	490	436
9/30/2011	OR03	434	459	478	495	512	530	550	576	616	359
9/30/2011	OR04	229	244	256	267	278	289	302	318	343	212
9/30/2011	OR07	330	353	371	388	404	421	440	464	501	449
10/4/2011	OR08	268	281	290	298	307	315	324	336	352	345
10/5/2011	OR02	141	151	158	165	172	179	188	199	218	160
10/5/2011	OR03	170	185	198	209	221	234	249	267	296	172
10/5/2011	OR05	119	136	149	162	175	189	205	226	261	233
10/5/2011	OR07	241	258	271	282	293	305	318	335	361	403
10/5/2011	OR08	153	166	176	186	195	206	218	234	260	372
10/6/2011	OR04	347	362	374	384	395	406	420	437	465	410
10/6/2011	OR06	176	191	203	214	224	235	247	263	287	410
10/7/2011	OR07	373	395	412	427	443	459	477	501	536	362
10/12/2011	OR01	317	337	352	366	380	394	411	431	463	365
10/12/2011	OR04	226	239	250	260	270	280	293	310	337	336
10/13/2011	OR02	383	413	435	455	475	495	519	548	590	625
10/13/2011	OR05	356	374	387	399	412	425	440	458	488	425
10/14/2011	OR01	399	430	454	477	499	522	548	581	633	510
10/14/2011	OR08	203	219	231	242	253	264	276	292	315	340
10/17/2011	OR03	399	420	435	449	463	477	492	511	539	423
10/18/2011	OR01	298	315	329	341	353	365	379	396	422	295
10/18/2011	OR03	336	367	393	416	439	465	496	534	595	412
10/18/2011	OR04	471	494	512	528	544	562	581	605	641	460
10/19/2011	OR02	325	341	354	365	377	390	405	424	453	340
10/19/2011	OR05	95	110	121	132	144	157	172	192	224	90
10/19/2011	OR08	257	269	279	287	296	304	314	327	346	330
10/20/2011	OR03	198	218	233	247	262	277	295	317	351	287

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
10/20/2011	OR06	207	223	235	246	257	268	280	296	319	245
10/21/2011	OR01	184	197	207	216	225	234	245	259	279	210
10/21/2011	OR07	278	298	314	329	343	358	375	397	431	282
10/24/2011	OR02	377	391	402	411	420	429	440	452	471	400
10/24/2011	OR04	309	325	338	350	362	374	388	407	435	380
10/24/2011	OR07	359	397	428	456	484	514	548	592	660	580
10/26/2011	OR03	167	183	196	208	220	233	248	266	295	348
10/26/2011	OR05	291	313	331	347	363	381	401	427	469	324
10/26/2011	OR07	190	203	213	222	232	242	254	269	293	250
10/27/2011	OR01	532	565	591	614	636	659	685	717	764	720
10/28/2011	OR02	185	201	214	226	238	250	264	282	310	274
10/28/2011	OR08	307	329	345	360	374	390	407	429	460	333
10/31/2011	OR04	306	322	333	344	355	366	380	397	425	468
10/31/2011	OR06	282	302	318	332	345	360	376	396	425	315
11/1/2011	OR02	377	391	402	412	421	430	440	453	471	360
11/1/2011	OR08	219	230	238	245	252	259	267	277	291	245
11/2/2011	OR03	170	184	195	206	216	227	240	256	280	185
11/2/2011	OR06	246	262	275	287	298	310	323	340	366	256
11/2/2011	OR07	118	130	139	147	156	165	176	189	210	210
11/2/2011	OR08	205	217	225	233	241	249	259	271	291	340
11/3/2011	OR01	164	178	189	199	209	220	232	249	275	170
11/3/2011	OR05	333	352	367	380	392	406	421	440	470	410
11/3/2011	OR06	215	227	236	244	252	260	270	281	299	373
11/4/2011	OR03	112	120	127	133	139	146	154	165	183	146
11/7/2011	OR02	462	486	503	520	535	552	570	593	627	631
11/7/2011	OR04	333	351	364	376	388	401	416	434	464	405
11/7/2011	OR08	148	160	169	178	186	195	205	217	236	200
11/8/2011	OR03	236	253	267	280	292	305	319	337	365	340

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
11/9/2011	OR02	144	154	161	168	174	182	190	201	219	178
11/9/2011	OR04	202	215	226	236	246	256	269	286	314	225
11/9/2011	OR08	290	305	316	326	335	345	357	371	392	361
11/10/2011	OR05	218	236	250	263	276	290	307	328	362	313
11/10/2011	OR06	510	529	544	557	569	583	597	614	640	473
11/14/2011	OR02	298	315	329	341	353	366	381	399	428	473
11/15/2011	OR03	197	208	216	224	231	239	249	260	277	402
11/15/2011	OR08	363	376	386	396	404	413	422	434	451	388
11/16/2011	OR04	222	235	245	255	264	275	287	304	331	265
11/16/2011	OR05	123	141	155	169	183	199	217	239	276	128
11/16/2011	OR08	186	196	205	212	220	228	237	248	267	350
11/17/2011	OR04	374	388	398	408	417	426	436	449	467	428
11/18/2011	OR08	226	243	257	269	281	293	308	326	354	265
11/21/2011	OR01	273	300	322	342	362	384	410	443	496	450
11/21/2011	OR02	155	167	177	186	195	204	214	227	246	123
11/21/2011	OR03	163	182	196	210	224	238	255	277	310	281
11/21/2011	OR06	176	192	205	217	228	240	254	270	296	168
11/21/2011	OR07	224	241	255	267	279	291	305	323	349	329
11/22/2011	OR08	443	465	481	497	512	529	548	573	615	475
11/23/2011	OR02	159	172	182	191	200	210	221	235	256	245
11/23/2011	OR03	172	188	200	211	222	234	247	264	289	189
11/28/2011	OR05	468	495	516	536	556	577	601	631	681	460
11/29/2011	OR03	199	217	231	243	256	269	283	302	330	249
11/29/2011	OR04	484	502	516	528	540	552	566	582	608	495
12/1/2011	OR01	297	316	331	344	357	370	386	405	434	370
12/1/2011	OR04	376	393	406	418	429	442	456	474	502	430
12/5/2011	OR03	298	318	334	347	360	374	390	409	437	292
12/5/2011	OR04	348	369	386	401	415	431	448	470	503	343

Date	OR	10%	20%	30%	40%	50%	60%	70%	80%	90%	Actual Duration
12/5/2011	OR06	165	181	194	205	217	229	243	260	286	205
12/5/2011	OR08	104	114	122	129	137	145	154	166	186	177
12/6/2011	OR03	412	430	444	457	470	483	498	516	543	377
12/6/2011	OR08	369	383	394	404	413	422	433	445	463	395
12/7/2011	OR01	315	341	361	380	398	418	440	467	509	256
12/7/2011	OR03	355	378	396	412	427	443	461	484	518	426
12/7/2011	OR05	100	110	119	128	136	146	158	174	201	114
12/7/2011	OR08	304	323	338	351	364	378	394	414	445	380
12/9/2011	OR07	181	194	205	215	225	235	248	264	290	244
12/9/2011	OR08	259	278	292	305	318	332	347	366	394	270
12/12/2011	OR04	446	476	500	522	543	565	590	622	670	345
12/12/2011	OR08	159	173	184	194	204	215	227	242	265	205
12/13/2011	OR04	212	226	237	247	257	267	278	293	315	364
12/14/2011	OR08	262	279	291	303	314	326	339	355	380	443
12/15/2011	OR04	266	284	299	312	326	340	357	378	412	350
12/15/2011	OR05	140	162	179	196	213	232	254	285	334	241
12/16/2011	OR04	377	397	412	426	440	454	470	490	520	459
12/16/2011	OR07	465	498	524	547	569	593	620	653	703	405
12/16/2011	OR08	308	329	346	362	378	395	415	441	482	403
12/19/2011	OR08	137	149	159	168	176	186	196	210	230	184
12/20/2011	OR08	304	320	332	343	354	365	377	392	414	285
12/21/2011	OR08	339	360	376	390	405	420	437	459	492	408
12/22/2011	OR06	204	217	227	236	245	254	264	277	296	262
12/28/2011	OR08	144	151	157	161	166	171	176	182	192	135
12/30/2011	OR07	258	275	288	300	312	324	338	356	382	328

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ABSTRACT

OPERATING ROOM UTILIZATION AND BEHAVIORAL STUDY

by

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August 2012

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Operating Rooms (OR) are the most expensive care units in health care systems. In order for OR theatre to operate in cost efficient way, it is desirable that the ORs exhibit high utilization, while at the same time, maintain a low-level over-utilized OR time. At the operational level, there are many factors that could influence the OR utilization performances. The objective of this study is to develop effective approaches focusing on the most important factors that influence OR utilization to assist OR management in decision making to achieve better utilization and cost efficiency. In the study, model selection and cross-validation methods were used to find the best linear model of OR utilization given different subsets of the factors. As the scheduled utilization and case duration prediction accuracy were identified as the two most statistically significant factors, we then proposed a new distribution to approximate the total duration of surgery lists of multiple cases and compared its accuracy in the estimation of the probability of under- and over-run of surgery lists with the widely applied t-distribution. Monte Carlo simulation was used to validate the appropriateness of the proposed new distribution by comparing the percentiles of the empirical distribution of the duration of surgery lists with those calculated from the proposed distribution. The tardiness of case starts prohibit OR from achieving optimal efficiency, as they causes over-utilized OR time and cancellations. Given limited resources, it is critical for the OR management to prioritize the tackling of tardiness. An

iterative simulation method considering multiple delay reasons at a time was proposed that continuously identifies the top delay risks to facilitate proactive decision making to prevent tardiness from taking place. The effectiveness of this approach was examined through a case study by having different scheduling policies and case duration distributions. In the end, the behavioral pattern of OR staff was explored by constructing a structural equation model. Relationships among different variables and mean turnover time duration were estimated. It was found out that the work pace of OR staff during turnover times was not affected by the OR workload, and proved there was a psychological bias of OR staff to make decisions based on increasing clinical work per unit time during the hours they are assigned. This research complements current OR management study by introducing better and new methods for OR operational decision making.

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Quality Data Analyst Co-op	May 2008 - December 2008

SELECTED PUBLICATIONS

1. J. Wang, F. Dexter, and K. Yang. "Behavioral Study of Daily Mean Turnover Times and First Case of the Day Tardiness of Starts." Accepted Pending Minor Changes, in Review of Anesthesia and Analgesia, San Francisco, CA, 2012.

2. J. Wang and K. Yang. "Using Type IV Pearson distribution to calculate the probabilities of under- and over-run of surgery lists consisting of multiple cases." in Review of European Journal of Anaesthesiology, Geneva, Switzerland, 2012

3. J. Wang, EA. Murat, H. Neemuchwala, and K. Yang. "Proactive Management of Operating Room Resources through Operational Simulation." Manuscript preparation, targeting Health Care Management Science, Secaucus, NJ, 2012