

**Comparative Analysis of the Leading Methods for Optimizing Operating Room Efficiency  
and Cost Effectiveness**

by

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Matthew Kravitz, MHA

University of Pittsburgh, 2022

## **Abstract**

Healthcare systems exist in a constant stage of transformation. With increasing pressure to prioritize high-quality care with low-cost, operating rooms within health systems become increasingly targeted for improvement. Operating rooms have become a focal point for providing financial stability since they are the staple for generating payments for the hospital. A hospital that maximizes the efficiency of the operating room will reap the benefits for the healthcare system. Providers are working strenuously to see high volumes of patients, and administrators have immense pressure to keep costs low while maintaining optimal outcomes. This requires working together to find methods and strategies that can help operating rooms function with benefit to both parties.

This paper examines the various methods to maximize operating room efficiency from multiple avenues. The different approaches have varying financial impacts and effectiveness depending on the type of hospital. Rural and urban hospitals have different functionalities and need to maximize their operating rooms accordingly. After reviewing the literature on seven methods used to improve the operating room, a comparative analysis will be conducted based on five essential process improvement (KPI) methods for each technique. Upon learning the roles of each KPI method in operating room improvement methodologies, a leading method will be declared for two types of healthcare systems (rural and urban). Overall, to combat the increasing financial crisis

occurring in the United States health system, operating rooms will become the center of attention to maximize the high payments that result from surgical procedures.

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## 1.0 Introduction

Healthcare systems exist in a constant stage of transformation. With increasing pressure to prioritize high-quality care with low-cost, operating rooms within health systems are increasingly targeted for improvement. Providers work strenuously to meet demands for volumes of patients, and administrators face enormous pressure to keep running costs low while maintaining optimal outcomes. This requires that providers and administrators work together to find methods and strategies to help operating rooms function with benefits to both parties.

Healthcare in the United States is unprecedented when healthcare expenditure only increases while not showing the signs of plateauing anytime soon. Healthcare costs in the United States comprised 19.7% of the GDP in 2020. Four years ago, this was 17.7% of the GDP in 2016 (Yang Jenny). Healthcare expenditure also produces an estimated 25% of this expenditure as solely waste (Shrank, William H, et al.). Waste cost in healthcare is the excessive spending that could be avoided attributed to system aspects such as overtreatment, care failure, care coordination failure, etc. Healthcare institutions should implement operational methods to improve processing and efficiency to tackle these expenditure and waste problems.

One primary target for addressing this problem is operating room revenue. The operating room is one of the largest revenue sources for a health system and one of the highest expenditures. Nationwide, operating rooms(ORs) account for 70% of a hospital's annual revenue and 40% of total expenditures, with an average cost of \$37 per minute for each OR (OpenAnesthesia). Accordingly, operating room management is a crucial focus for targeting improvements to ensure room optimization for costs, quality of care, and safety for patients. Numerous opportunities to improve OR processes exist. Through selecting the highest-reviewed literature, seven methods for

optimization were evaluated, including surgical equipment process improvement, machine learning scheduling: case duration, high-risk modeling, machine learning space optimization in PACU, morning start time adherence, computer model surgical scheduling: block, and parallel induction design and concurrency.

### **1.1 Introduction to Surgical Equipment Process Improvement**

Surgical equipment, or surgical instruments, are designed to perform a specific action during a surgical procedure or operation in a healthcare setting. Surgical equipment is used to modify or provide access to view biological tissue. Surgical equipment has been developed over the past few centuries alongside technology to become a vital component for conducting surgeries successfully. Surgical equipment costs in ORs have become a high burden for hospitals. Global Operating Room Equipment Market, which measures the need for surgical equipment among healthcare systems, accounted for \$24,192 million in 2016 and is estimated to reach \$33,308 million by 2023, registering a compound annual growth rate of 4.5% from 2017 to 2023 (Dumont and Shaikh). Surgical equipment is expensive, but also integral to the successful conduction of an operating room procedure. Surgeries are bound to the equipment available to assist in providing an effective surgery. However, besides a patient for surgery, surgery equipment can be vital to the foundation for many delays in the OR setting. If the surgical equipment is not processed correctly, the surgery cannot be conducted on time or adequately, resulting in delays. Additionally, streamlining the amount of surgical equipment based on necessity can reduce the waste associated with unneeded surgical equipment.

## **1.2 Introduction to Machine Learning Scheduling: Case Duration**

A significant component of operating room efficiency is the accuracy of predicting case duration. In most health systems, this has historically been done by the surgeons who convey the personal experience with the type of case or through an electronic health record that utilizes the historical mean for the case duration. However, modern technology for scheduling (e.g., machine learning models) may benefit hospital operating rooms. Machine learning, a type of artificial intelligence, is a technique to use computer algorithms on large amounts of data to improve prediction and decision making. This technology creates algorithms that build a model based on sample data given, called training data, that serves the purpose of assisting in making predictions or decisions without being explicitly programmed. Utilizing the artificial intelligence, the case duration for each type of case would be estimated using empirical data, improving accuracy, and ensuring exact time slots given without posing a risk of waste or delays (Bellini, Valentina, et al.).

## **1.3 Introduction to High-Risk Modeling**

High-risk modeling is a tool used to predict patients who present cancellation or delay risk on the day of surgery. High-risk modeling provides large potential for machine learning technology to maximize operating room capabilities. It can be used to identify cases with a high risk of cancellations. Cancellations come at an extreme cost to medical centers and healthcare systems. In the United States, last-minute surgery cancellations and no-shows cost healthcare institutions millions of dollars each year. A study at Tulane University Medical Center determined that 6.7% of the scheduled surgeries in 2009 were canceled, which produced a total sum of 1 million dollars in lost revenue. Approximately 30% of the procedures canceled were attributed to

patients not arriving on time for the procedure. Also, the study found that an additional 33% of the procedures were canceled due to a hospital-related mistake or issue (*Same-day surgery cancellations cost Hospitals Millions*). Most of the costs incurred from canceled procedures stem from "opportunity costs" since hospitals cannot move or change the patients to another time due to unavailability in operating block time. The revenue loss varies based on specialty and is displayed below:

#### **Variation in the cost of surgery cancellations**

- Neurosurgeries: \$5,962 to cancel.
- Urology: \$4,758 to cancel.
- Otolaryngology: \$4,623 to cancel.
- Thoracic: \$4,208 to cancel.
- Ophthalmology: \$2,927 to cancel.
- Radiology: \$2,787 to cancel.
- Orthopedic: \$2,779 to cancel.
- Plastic: \$2,260 to cancel.
- General surgery: \$1,965 to cancel; and
- Pediatrics: \$1,325 to cancel.

*(Same-day surgery cancellations cost Hospitals Millions)*

#### **1.4 Introduction to Machine Learning Space Optimization in PACU**

Another application of machine learning would be to support complex models for using multiple spaces at once. A common problem among hospitals is when patients are admitted into the Post-Anesthesia Care Unit (PACU) rooms to recover from surgery. There is a constant transition from the operating room to the PACU, but an efficiency loss is often recorded between

the OR and PACU. A lot of this can be attributed to the congestion of the PACU. If there is no bed available in the PACU, the patient must stay in the OR until one is free. This drives delays and other burdening issues to operating and maintaining the schedule. Machine learning space optimization technology is a tool designed to coordinate better the patient's transition from the OR to the PACU. Utilizing machine learning space optimization technology in the PACU would allow coordination between post-anesthesia care units and the operating room to streamline patient transportation (Fairley, Michael, et al.).

### **1.5 Introduction to Operating Room Morning Start Times Adherence**

Starting the first procedure scheduled for the day on time plays a significant role in determining how the operating room will effectively function for the remainder of the day. The inability to start on time affects the overall mood and the ability to perform the cases effectively and efficiently. Early mornings are where delays are the most impactful since the delay in the first case also affects the delays of all future cases. The issue behind a late start has implications that are more drastically seen in other delays. Delaying start times for surgeries result in a cascade of wait times for surgeons, patients, wasted resources and are a significant issue to tackle in healthcare organizations.

## **1.6 Introduction to Computer Modeling Surgical Scheduling: Block Time**

Allocating the necessary block time to surgeons and selecting the days on which to schedule elective cases is vital to maximizing the use of the operating room. Hospitals are trying to maximize profits due to the burdening costs of healthcare. Consequently, to impact patient care costs in the OR suite, OR managers must maximize "labor productivity" by staffing the bare minimum staff needed to attend to patients. Labor is a fixed cost since the staffing does not fluctuate daily according to the number of patients cared for. To care for patients while employing as few staff as possible, the manager of the OR must maximize utilization through matching block times.

One standard method used to adequately meet elective cases with staff availability is allocating the correct "block-time," also known as OR time, to surgeons. To maximize the OR utilization, the block times need to be filled with the most significant number of cases possible. Two essential aspects to serving the block times exist for hospitals. First, the appropriate block time allocated to surgeons needs to be determined. Secondly, a method for determining how to choose the day to schedule a patient for surgery must also be selected (Dexter, F et al.).

## **1.7 Introduction to Parallel Induction Operating Room Design and Optimal Concurrency**

Another source of operating room efficiency loss is when anesthesia physicians have high amounts of non-utilized time. When operating rooms are not undergoing surgeries, it is a continual loss of revenue for the hospital if sufficient patient cases exist for that day. A design that is beneficial and crucial to adapt is parallel induction design. A similar design is a setup where two

operating rooms for a surgeon are set up next to each other for easy access. This method has anesthesiologists, and, at times, nurse anesthetists stationed at rooms where the surgeries occur in parallel induction rooms allowing anesthetizing to occur simultaneously to improve efficiency and costs. Operating patients in a parallel fashion is beneficial due to maintaining costs at a stable rate, but also treating them with higher efficiency (Friedman, David M, et al.).

Concurrency is a term used to describe the number of patient rooms under an anesthesiologist. A concurrency of one is the traditional: one anesthesiologist per room. However, hospitals aim to increase concurrency to improve efficiency and revenue. The costs of anesthesiologists make up a large portion of the operating room costs, with an average salary of \$404,000 in the United States (“Anesthesiologist Salary.”) Maximizing the efficiency and oversight of anesthesiologists provide an excellent opportunity to improve the revenue involved with having anesthesiologists staffed at the hospital. Aiming for and maintaining optimal concurrency is vital to ensure adequate patient care and avoid physician burnout. Having too high of a concurrency comes with an equally high risk (Posner, K L, and P R Freund). The anesthesiologist is stretched thin when too much oversight, significantly increasing patient error chances. Moreover, if an anesthesiologist has too high concurrency, the physician faces burnout and dissatisfaction with the job.

## **2.0 Surgical Equipment Process Improvement**

A research article that dove into the sources for operating room delays found a significant reason for the delay in the operating room attributed to the unavailability of instruments (Cichos, Kyle H, et al.). Improving surgical equipment processing is a challenging, yet effective tactic, to tackle delays in healthcare systems. The foundation of these improvements becomes embedded in the lean methodology to ensure successful implementation. Before engaging in manners specific to everyone's healthcare institution basic principles should be enforced.

The collaborative input and discussion should involve facility leaders, OR staff members, and the sterile processing department personnel. Using these key department members should focus on accountability at the individual level. Placing accountability on the employee level ensures that instruments are cleaned according to the manufacturer's guidance, appropriate regulations, and facility policies. Focusing on information about the instrument decontamination process, from the point of use to sterilization, allows for appropriate implementation of the necessary process steps. Sterile processing department leaders should develop policies and procedures for decontamination of surgical instruments and the various accountabilities for the process steps. The lean thinking principle steps are laid out below:

### **1. Specify value**

- a. Define the value from the customers perspective and express value in terms of a specified product.

### **2. Map the value stream**

- a. Map all steps included, value and non-value added, involving the product or service to the customer.



### **3. Establish flow**

- a. Ensuring a continuous movement of products, services, and information from the beginning to end of the process.

### **4. Implement pull**

- a. Upstream process is only activated when the downstream process signals the need.

### **5. Work to perfection**

- a. Continuous evaluation of waste so all aspects produce value for the customer.  
Utilize the principles repeatedly (Cichos, Kyle H, et al.).

When reviewing the surgical equipment, surgeons and providers should evaluate critical aspects of the surgical process pathway, including the cleaning times, room turnover times, instruments usage counts, tray weight, holes in tray wrapping, wet trays, and the time invested in optimizing each tray. Utilizing the lean methodization, the leading disruptors should be targeted and calculated to determine an optimal procedure. According to an optimization project centered around this idea, the average instrument usage recorded before the lean optimization was 23.4% (Cichos, Kyle H, et al.). Unused and unnecessary equipment was involved, which generated higher delays. After this optimization, determining the minimum instruments needed to conduct a surgery produced an average instrument usage of 54.2%. By adhering to these lean methods, this study removed 433 of 792 devices, 55% of the instruments from the 11 instrument tray sets needed for major surgeries at the hospital. This produced an overall reduction of 3520 agents. Reducing the devices allowed faster sterilization time, OR instrument tray arrival, and procedure set-up. Annual cost savings were \$270,976 (20%) savings (Cichos, Kyle H, et al.).

Another example is a 2018 study in which surgical equipment was not routinely used in the surgery tray during operations (Dyas et al.). The hospital leaders evaluated head and neck

instrument trays to determine the number, weights, utilization rates, and trays in the new surgical equipment chosen for surgeries. This process reduced the weights and numbers of surgical equipment by 27 lbs. and \$28,000. There were numerous reports of unmeasured improvements in the surgery room and costs. The unmeasured savings amounted to decreased instrument wear, lower replacement frequency, faster operating room setup, and reduced decontamination costs (Dyas et al.). Optimizing surgical trays can reduce cost, physical strain, preparation time, decontamination time, and processing time. Streamlining trays is an effective strategy for hospitals to reduce costs and increase operating room efficiency.

## **2.1 Machine Learning Scheduling: Case Duration**

A pilot study compared the traditional predictive case method with a predicted case duration model of machine learning (Bellini, Valentina, et al.). The case duration was defined as the time between the patient entering the operating room and the time they exited. The proprietary machine learning model used data, including patient demographics, pre-surgical milestones, and hospital logistics. The pilot study concluded a 70% improvement in overall scheduling inaccuracy and a 7-minute difference between the predicted case duration and the actual case duration. Having surgeons and electronic health records book patients scheduling durations can be improved by using similar machine learning models in the pilot study (Bellini, Valentina, et al.).

## **2.2 High-Risk Modeling**

Tulane Medical Center did an analysis study on the cost of cancellations in 2009 to understand the true impact of this issue. Cancellations occurred at 6.7%, with an annual fee of one million dollars. A 2019 study aimed to use artificial intelligence to navigate this disruption in scheduled appointments. Machine learning programs assess algorithms to determine which patients are more likely to cancel and promote plans to enact if the cancellation of that patient were to occur. Reducing cancellations will prevent a loss in revenue while also maximizing the number of patients treated at a hospital (*Same-day surgery cancellations cost Hospitals Millions*).

## **2.3 Machine Learning Space Optimization**

A study determined a significant bottleneck event occurring at the PACU, resulting in substantial delays and coordination issues impacting care delivery. This hospital center, Lucile Packard Children's Hospital Stanford, used a machine learning model to reduce operating room delays, which led to a 76% reduction in PACU holds by supporting an effective active room schedule (Fairley, Michael, et al.).

## **2.4 Operating Room Morning Start Times Adherence**

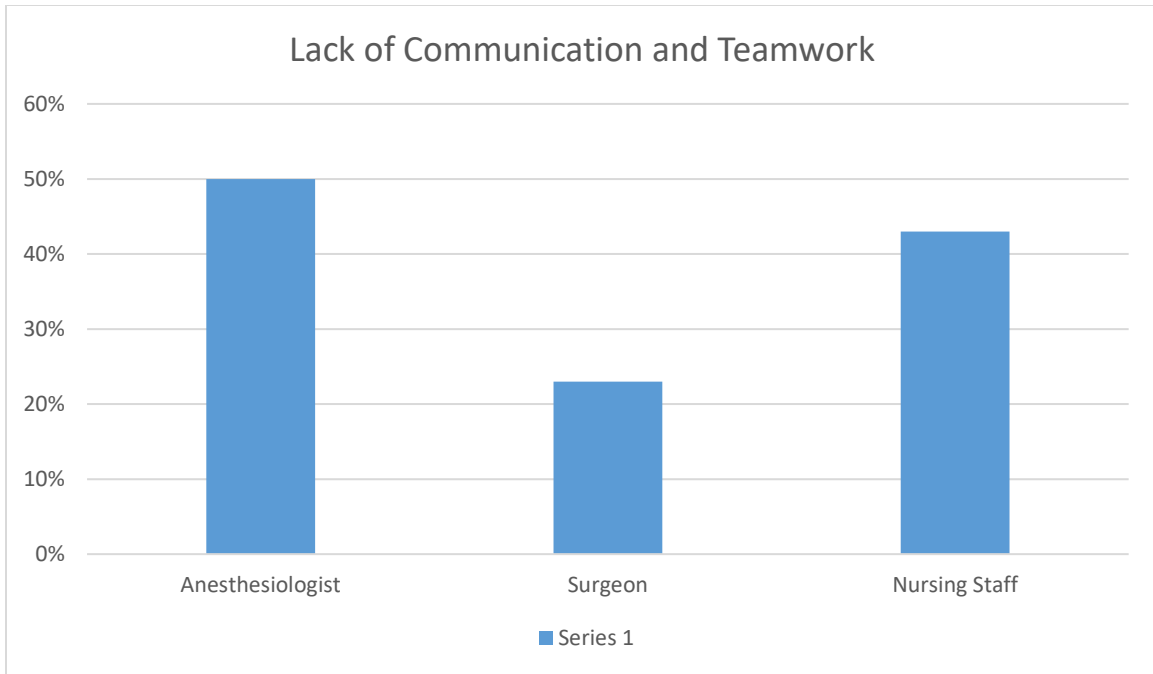
A study found a common reason for delayed starts was with the hospital itself. Most of the delays were related to the anesthesiologists and surgeons being unavailable or the failure to have

a patient ready on time. To determine the most common delays from the provider's perspective, a questionnaire was distributed to all residents, anesthesia, and operational staff to record their type five reasons for delays. A multifaceted and multidisciplinary approach was implemented, which increased on-time starts from about 6% to 60% over nine months. Start times were determined by defining the operation as occurring only once anesthesia had begun. The operational definition varies from that within-study which is when the moment of incision has occurred. Calculating the "delay in start time" was determined by subtracting the start time of the incision from the official start time.

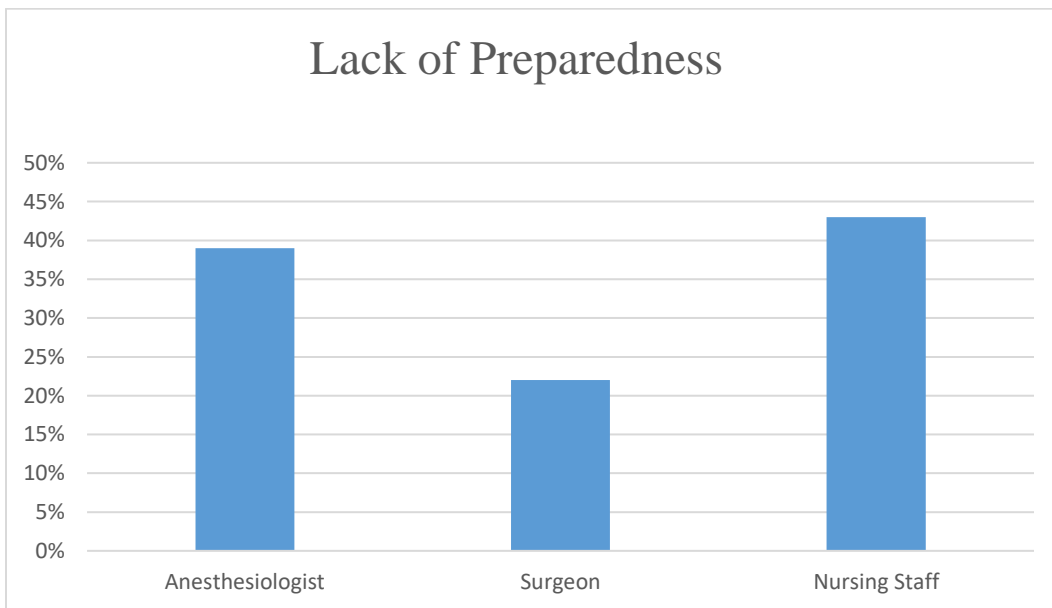
The most common complaints about delays according to the study questionnaire, were:

- Limited availability of trained supporting staff
- Lack of teamwork
- Communication gap
- Improper planning
- Time spent in patient positioning, monitor attachment, cautery application, securing intravascular access, the establishment of invasive monitoring
- Non-compliance with PAC orders
- Surgery residents arriving late
- Equipment problems and malfunction
- Waiting for consultation of various specialties to start cases
- Lack of timely OR preparation

Breaking down the responses according to various staff components was documented as well:



**Figure 1. Lack of Communication and Teamwork (Wright et al.)**



**Figure 2. Lack of preparedness (Wright et al.)**

The reporting was broken down into three respondent job types: Anesthesiologist, Surgeon, and Nursing Staff. Regarding approaching the issue surrounding the delays, an eight-step system was implemented, which entailed the Kotter's eight steps to transforming organizations: "establish a sense of urgency, form a powerful guiding coalition, create a vision, communicate the vision, empower others to act on the vision, plan for and create short-term wins, consolidate improvement and produce more change and institute new approaches." (Wright et al.)

Following Kotter's eight-step process focuses on creating urgency in an organization and utilizing this start to develop a culture of togetherness to make a positive change that benefits everyone involved (Gupta, Babita, et al.). This study detailed low resistance and a surprising acceptance when the teams for solving these issues were generated. If an organization has accurate on-time starts, following this process may be beneficial to creating better operating room efficiency.

## **2.5 Computer Modeling Surgical Scheduling: Block Time**

A study used computer simulation to model the OR schedule. The method for computer modeling included different ways, such as estimation of the date for surgery, case durations, lengths of time patients wait for surgery, hours of block time each day, and the number of blocks each week. There were two essential parameters to generate OR maximization: the method used to decide what day a patient would have surgery and the average length of time patients wait to have the surgery. The method used to determine the day of surgery is contingent on the surgeon and patient availability. The most effective way for utilizing the operating room **was by** maximizing the allocated block time for the elective cases based on expected total hours of elective

subjects, scheduling patients into the first available date (provided open block time is available within four weeks), and otherwise, scheduling patients in "overflow" time outside of the block time (Dexter, F et al.).

Programming the computer simulations required calculating the maximum the number of patients that would request to be scheduled for a surgery per week to obtain the proper algorithm to predict scheduling. The maximum is the number of cases the surgeons can complete with their scheduled block time surgery. The number of hours for block time given to the surgeons is equivalent to the product of the two-simulation parameter: planning OR block time to surgeons and scheduling patients into the specified block time. Using the average number of patients per week, the computer randomly generates the time until the next patient requests to schedule surgery. Upon developing the patient scheduling call timing, case duration, and determining whether the blocks have been utilized effectively, the calculation regarding the technique is accurate within .4% when compared to the actual surgeries once conducted.

To replicate an accurate computer predictive model, the allocation of block time and scheduling methods must occur in sequence. A surgeon's practice will determine the parameters, case duration, scheduling algorithm, and average patient surgery wait time will determine the minimum amount of operating room time (U) that the practice or hospital can achieve. This minimum amount of working room time can never be 100% due to the inability to have perfect scheduling efficiency and effectiveness. The equation calculates the total block time is  $5(H) \times (1 + U)$ . "H" represents the number of total hours forecasted by a surgeon each week. For example, if the maximum potential OR hours that a surgeon can reach is 70% with an average of 12 hours of elective surgeries per week, then the surgeon would have a minimum allocation of  $(12h) \times (1 + .30) = 15.6$  hours needed to complete all elective surgeries in the block time (Dexter, F et al.).

This model effectively predicts block time requirements, but it gives control of the surgical date to the OR suite, away from the surgeon and patient. The most impactful parameter that will affect the OR utilization will be the average length of time patients will wait before the surgery. The study found that OR time is maximized by allocating elective case block time based on the following: expected total hours of elective cases, scheduling patients into the first available date provided open block time is available within four weeks, and otherwise scheduling patients in overflow time outside of the block time. If this computer scheduling model is not following the expected block time allocation parameters, then an overflow of patients will occur outside the scheduled block times.

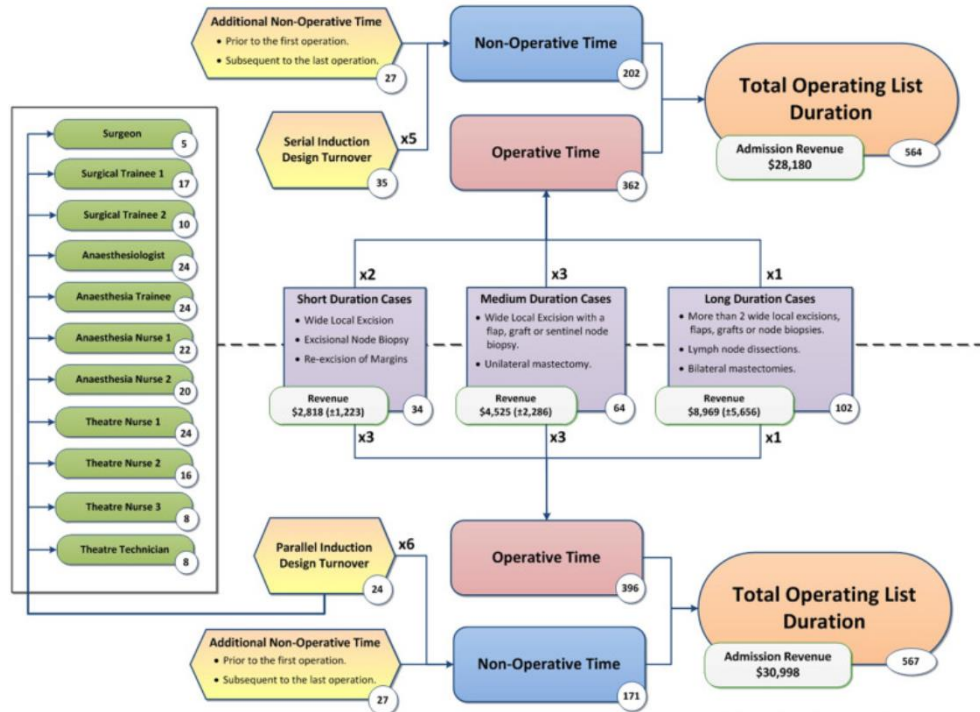
## **2.6 Parallel Induction Operating Room Design and Optimal Concurrency**

The methodology regarding this optimization method is based upon Time-Driven Activity-Based Costing (TDABC), which is the process improvement counterpart to establish itself using time and capacity cost rates to allocate resource costs. Utilizing process maps alongside TDABC develops an adequate and extensive assignment of resources to tasks, leading to the implementation of a parallel induction design. Parallel induction or “parallel processing” occurs by recruiting additional anesthesia providers to induce anesthesia in adjacent induction rooms. The installation takes place while another surgical case is ending. The induction design reduces the non-operative time between consecutive operating points through maximized alignment of preoperative anesthetic processes; with that of the operating room set up such that preparations for the commencement of surgery can begin close to immediately after completion of a prior surgical case.



The normalized procedure practice is called the serial induction design. With this type of setup, the operating room turnover is completed before the next patient enters the operating room, where the anesthesia would then be administered to that patient. Parallel induction techniques would only be best suited for high-volume tertiary hospitals; otherwise, current serial induction may be more suitable. Hospitals considering similar installations will need to ensure that additional personnel, economic justification, and extra nursing care can be provided.

According to TDABC model procedural input, developing personnel costs requires dichotomizing and integrating hypothetical case-mix historical data to generate the typical operating list. This study concluded that operating duration was reduced by 55 minutes under a parallel induction design with a marginal increase (1.6%) in personnel costs (Friedman et al.). This design facilitates an additional short-duration surgical case, leading to an additional revenue stream of \$2818 per day and \$0.73 M per annum per operating room. Although anesthesiologists are being used for parallel spaces, it was found that patient satisfaction and safety were not negatively impacted (Basto et al.). This model for anesthetizing patients creates better efficiency and higher revenue at no cost to patients' quality of experience. With this being stated, the number of patients being seen per anesthesiologist should be considered.



**Figure 3. Operating Procedural List (Basto et al.; permission for re-use)**

The figure showcases the operating list time and personnel costs associated with TDABC. The process mapping was designed and modeled based on the documented process times, procedural categorization based on surgical complexity, and designation of the typical case-mix based on the historical inpatient data. The variability in the non-operative time was calculated based on the transition from allocation to serial or parallel induction. This was based on the estimated personnel utilization of the induction system and the procedural category for parallel induction design. The average admission revenue was captured only by the WIES values on single-day admissions.

Given the need to operate at a higher case rate, additional personnel costs will be considered to compensate for the parallel induction design. However, even with the other providers needed, this will be only confined to hiring additional nurse anesthetists. Despite many benefits and

improvements in operating room efficiency, a few aspects of the parallel induction design need to be considered. Although the operating room would have a mandatory need for the presence of attending and resident anesthesiologists, hospitals would see a distribution of these anesthesiologists among consecutive patients, which would neutralize the costs to a similar level as serial induction. In the system studied, the need for multiple physicians for a singular patient occurred rarely. The rarity of this occurrence led to a minimal impact on teaching and education in this context. Hospitals that have a significant teaching emphasis should consider this. This model for anesthetizing patients creates better efficiency and higher revenue at no cost to patients' quality of experience. With this being stated, the number of patients being seen per Anesthesiologist should be considered.

Optimal concurrency was from 1.6 to 2.2 cases per attending anesthesiologist. Productivity had a positive correlation with a conjunction. With these levels of coincidence, the productivity levels ranged from 10 to 17 hours per anesthesiologist on a clinical day. Regarding patient safety, the patient injury rate decreased with increased productivity levels, but the critical incident rate increased. Changes in operational inefficiency, escalation of care, and human error rates were not statistically significant (Posner KL and Freund PR). Therefore, 1.6 to 2.2 concurrency greatly benefits a hospital operating department. One consideration is that the critical incident rate may increase.

The study used anesthesia records to monitor clinical activity at the administration level to determine the optimal staffing for a hospital's anesthesia department. According to the CQI reports on anesthesia care, the continuous quality improvement program is outlined to analyze the surgery's adverse events or outcomes. The quality of anesthesia care was broken down using five

indicators: rate of critical incidents (adverse event but no adverse outcome), patient injury, escalation of care, operational inefficiencies, and human error.

In an operating room, under anesthesia, all anesthesia members contribute to the productivity of the surgery; however, only the attending anesthesiologist oversees multiple cases concurrently. Productivity is calculated monthly by dividing total attending hours by the sum of the attending anesthesiologist's clinical days spent actively working. Through this methodology, there is the ability to measure both the increasing caseload and the intensity of the workload of attending anesthesiologists that contribute to a decrease in slack time (room turnover, empty rooms, late starts, increased supervisory time). Determining concurrency was calculated by measuring the number of cases the attending anesthesiologist supervises that overlap during the same time. For example, if an anesthesiologist runs two cases during the same period, the concurrency will equal two.

The monthly productive rates for a clinical day were monitored. Monthly productivity is measured by the hours billed per attending anesthesiologist per clinical day. The solid line references the concurrency of two where the attending anesthesiologist concurrently supervises two cases. There was a strong correlation between coexistence and productivity. The anesthesiologist's productivity increased from 11.2 ( $\pm 0.55$ ) in year 1 to 15.1 ( $\pm 1.0$ ) in year 6 ( $P < 0.001$ ) fig.2. There was a positive correlation between the concurrency of case supervision and productivity levels ( $r = 0.838$ ;  $P < 0.001$ ). The average monthly coincidence ranged from 1.6 to 2.2 and produced the most optimal levels.

Patient injury and critical incidents are essential to consider when increasing concurrency. The study analyzed the estimated rates of crucial incidents and patient injury at each productivity level. It was found that the patient injury rate decreased from 134 per 10,000 cases to 38 per 10,000

cases ( $P = 0.002$ ), while the critical incident rate increased from 36 per 10,000 cases to 92 per 10,000 cases ( $P = 0.001$ ) between the lowest and highest levels of productivity.

Over a 6-yr period of changing staffing patterns and increasing anesthesia productivity in our academic medical center, most quality indicators of anesthesia care quality did not appear to decrease. On the contrary, rates of patient injury were lower at higher productivity and concurrency levels, suggesting an overall improvement in patient safety. Rates of human error were relatively constant. Operational inefficiency and escalation of care rates did not increase at higher productivity levels. Operational inefficiencies decreased at higher concurrency levels, suggesting that the increased workload of the attending anesthesia staff did not have accompanying hidden monetary costs for the patient, anesthesia service, or hospital. These results reflect a sufficient level of attending anesthesia staff and support personnel for our anesthesia service's caseload and case intensity.

### **3.0 Comparative Analysis**

After exploring numerous methods to improve operating room functionality, the most beneficial ways need to be based on hospital needs. The term “most beneficial” will also depend on the type of medical institution in consideration. Before discussing the leading method, the two major hospitals (rural/community and urban/academic medical centers) must be examined.

#### **3.1 Rural Hospitals**

Rural hospitals are healthcare institutions with federal designation due to the reliance on federal and state payers due to financial instability. These hospitals are in parts of the United States, where less than 19% of the population resides. Distinct communities that makeup areas around rural hospitals include farming, small businesses, agricultural suppling, and other high physical intensity employment. Potential patients of rural hospitals may have difficulty affording, traveling, and accessing healthcare.

Rural hospitals face a barrier to increase revenue due to low patient volume. The lower volume of cases drives an inability of the hospital to cover fixed operating costs. Additionally, rural areas have a challenging payer mix with a population that heavily relies on Medicare and Medicaid population. In 2017, 56% percent of the revenues for rural hospitals were comprised of Medicare and Medicaid payments. However, the low reimbursement associated with these federal programs adds a boundary to surviving financially when they have reimbursed 87 cents for every dollar spent caring for these patients. Moreover, rural areas tend to house a population that is older,

sicker, and poorer than the national average. For example, the national average for individuals over 65 is 14%, whereas rural populations have an 18% makeup (*Rural Health Information Hub*). Rural hospitals, as a result, tend to have higher chronic illness rates seen in its hospital. Lastly, a significant workforce shortage in rural hospitals produces a chronic challenge and expense for these institutions. Rural hospitals take care of 20% of the population; however, only 10% of physicians practice in these areas (*Rural Health Information Hub*). Considering the significant challenges, all the issues point to the financial instability that drives rural hospital issues.

### **3.2 Urban Hospitals**

Urban hospitals are larger health institutions in metropolitan-city areas in the United States. These hospitals tend to be three times the size of rural hospitals and possess four times the number of Medicare discharges. Additionally, urban hospitals have three times the utilization rate compared to their rural counterpart. Urban hospitals have higher numbers in patient volume, revenue, specialties, and overall financial stability. Increasing revenue for hospitals tends to focus on improving the efficiency of cases to maximize operating room utilization. Urban hospitals' obstacles to delivering care stem from managing high volume and complexity levels, while also maximizing the efficiency of operations. Urban hospitals are tasked with managing increased volumes to handle the high number of patients who live in the area and the complexity of the cases that spend many specialties. In Urban hospitals, 62% of individuals seen in-patient at the hospital have surgery performed, whereas that number drops to 36% for rural hospitals. In addition to high volumes of surgeries at urban hospitals, urban hospitals perform three times as many surgeries as rural hospitals. Not only does the hospital handle high volumes, but also high complexity. The

higher complexity of cases requires coordination and scheduling accuracy to be communicated across all specialties and surgeons (Hall and Owings).

### **3.3 KPI Operating Room Metrics**

Five Key Performance Improvement (KPI) metrics will be used to assess the effectiveness of the strategies for maximizing operating room efficiency. The first KPI is process standardization which outlines the steps for individuals to complete a specific task or process. A plan must be generated and followed to maximize the results in the operating room. Typically, this KPI reinforces the expectations of the OR process to promote teamwork with the correct materials while minimizing the fatigue and having a reduction in human mistakes.

The second KPI is process consistency which is closely related to process standardization. These KPIs focus on having predictability which is crucial to optimizing the surgery schedule, allocation of resources, and flow of medical staff. Process consistency identifies the consistency and inconsistency of steps that make up the operating room process.

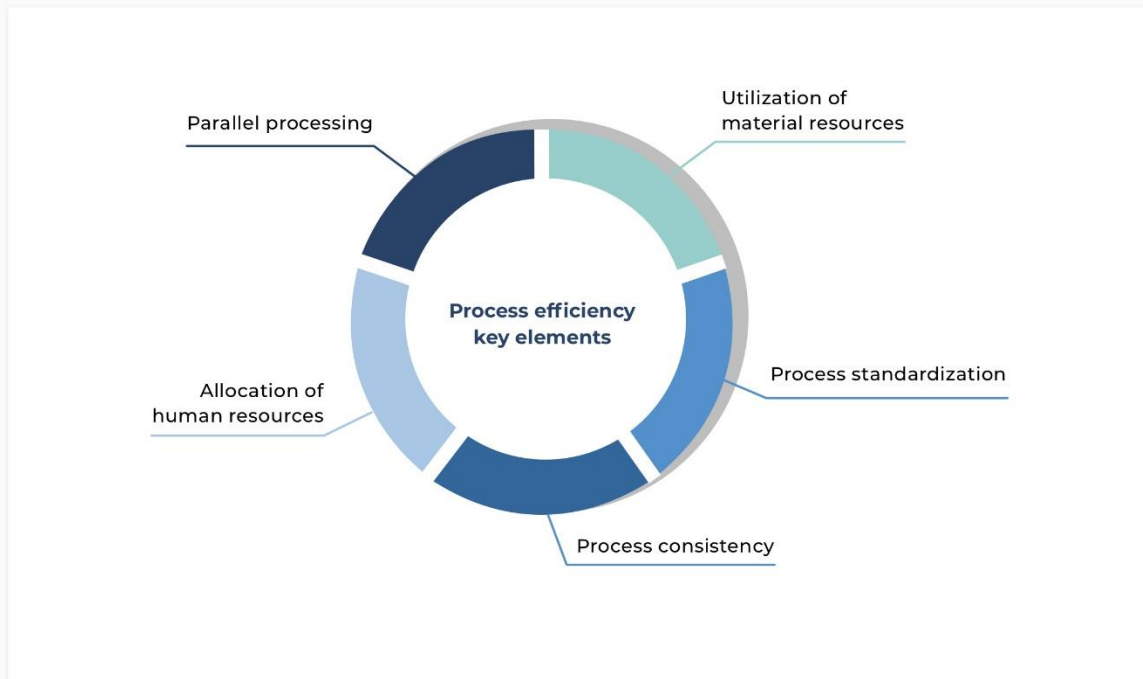
The third KPI metric is parallel processing, which involves identifying operating room processes that can occur in parallel to maximize both the patient and material flow. Running feasible methods similarly will increase overall process efficiency and the number of cases seen.

The fourth KPI metric centers around the allocation of human resources. The metric will have a unified goal to ensure all surgical team members are aligned in their roles, tasks, timing, expectations, and responsibilities. Successfully allocating human resources will prevent omitted steps and provide the functions needed for the procedure to occur correctly and effectively. The



surgical team focused on allocating human resources will be the surgeon, nurses, surgical tech staff, and an anesthesiologist.

Lastly, the fifth KPI metric focuses on the utilization of material resources. The ability to enforce this metric will eliminate waste by optimizing resources used in the operating room to generate a cost-effective environment. Utilization of material resources includes the team members inside and outside the operating room that contribute to the total cost of surgery. This surgery team involved will be the most critical success factor in the execution of the surgery. To maximize the utilization of materials, the process and environment must be designed to allow for optimal team performance. Material resources include the human capital needed for the operating room (Jeroen).



**Figure 4. KPI Operating Room Metrics**

### 3.4 Leading Method Result

Considering a rural hospital, financial stability should be the core focus of these institutions. The methods should include high amounts of cost savings whenever possible. Considering the KPI metrics listed, the two metrics that should be regarded as the most important, according to the mentioned needs of a rural hospital (figure 5), are the utilization of material resources and the allocation of human resources. These two metrics will focus on eliminating waste and being extremely cost-effective. However, these priorities will shift for an urban center hospital. With large volumes of patients and better financial stability, the key focus should be improving efficiency, i.e., increasing the number of cases seen daily. Increasing the daily case rate will increase revenue and offset the fixed cost of having numerous operating rooms open throughout the day. The most impactful KPIs for urban hospitals will be process consistency and standardization. The table below showcases the relative impact of each KPI metric on the type of hospital based on their specific need. When selecting the best method, the KPI metrics with a high level of impact were chosen as the essential metrics.

	Process Standardization	Process Consistency	Parallel Processing	Allocation of Human Resources	Utilization of Material Resources
Urban Hospital	High	High	Medium	Medium	Low
Rural Hospital	Medium	Low	Medium	High	High

**Figure 5. KPI Impact Level (Rural vs. Urban)**

The leading methodology for urban and rural hospitals was determined by assigning the KPI metrics to each method. After posting KPI metrics to each technique, the impact of figure 5 for each hospital was considered.

	Surgical Equipment Process Improvement	Parallel Induction Design and Concurrency	Machine Learning Scheduling: Case Duration	Morning Start Time Adherence	Space Optimization in PACU	High Risk Model	Computer Modeling Surgical Scheduling: Block Time
Process Standardization	Green	Red	Red	Green	Red	Red	Red
Process Consistency	Red	Red	Green	Green	Red	Red	Green
Parallel Processing	Red	Green	Red	Green	Green	Red	Red
Allocation of Human Resources	Red	Green	Red	Red	Red	Red	Red
Utilization of Material Resources	Green	Green	Red	Red	Red	Green	Red

**Figure 6. KPI Operating Room Efficiency Metrics for Methods**

Figure 6 shows the application of the KPI metric to the methodologies presented throughout this paper. The green signifies an operating room strategy that falls under the KPI metric, whereas a red signifies it does not fall under the category. Through this metric analysis, the rural hospital system would benefit the most through the parallel induction design and concurrency strategies since it is the only method to have both KPI metrics that would have a “high” impact. Parallel induction and concurrency reduce the number of human resources needed in the hospital. As previously stated, staffing shortages of physicians are the most prominent in rural areas. Implementing a parallel design with maximized concurrency reduces the staffing needed and saves high costs on anesthesia staffing. According to the metric analysis for urban hospitals, morning start time adherence will benefit these institutions since this is the only method to have KPI metrics (process consistency and process standardization) that have a “high” impact.

Although there are leading methods chosen for each type of hospital, it must be acknowledged that some methods may co-occur with each other. This paragraph will recognize the methodologies that may be considered together. Machine learning scheduling for case duration

occurs within computer modeling surgical scheduling for block time. The case duration makes up the formula to assign block times, so the case duration machine learning method must be utilized if a hospital is to maximize block time. Additionally, surgical equipment process improvement can be a component of improving morning start time adherence. Ensuring proper surgical equipment processing allows for the first surgery case to occur on time with the availability of surgical tools. Another method that can co-occur in the high-risk modeling is computer surgical scheduling for block time. By predicting accurate cancellations and assigning risk values for patients, block time for surgeries can better be assigned to accompany backup patients for potential cancellations. Also, block time can be utilized with parallel induction design to ensure cases line up during the same time for the anesthesiologists to use the method.

## 4.0 Conclusion

There are many opportunities for administrators and providers to work together to improve operating room costs and efficiency. The pressure on both ends demands a need to collaborate to implement improvement strategies that have shown success in various healthcare systems. There are many tactics to improve operating room efficiency at a hospital; these include surgical equipment process improvement, machine learning scheduling: case duration, high-risk modeling, machine learning space optimization in PACU, morning start time adherence, computer model surgical scheduling: block, and parallel induction design and concurrency. After using five KPI metrics for improving operating room efficiency, rural hospitals' leading method is implementing a parallel induction design with maximized concurrency. On the other hand, urban hospitals should focus on morning start time adherence to best impact the efficiency of these institutions.

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