THERE IS NO “I” IN TEAM: IMPACTS OF SURGICAL TEAM DYNAMICS ON OPERATIONAL PERFORMANCE AND CLINICAL OUTCOMES

by

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THERE IS NO "I" IN TEAM: IMPACTS OF SURGICAL TEAM DYNAMICS ON CASE SCHEDULING ERRORS AND POST-OPERATIVE COMPLICATIONS

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This dissertation was prepared under the direction of the candidate's dissertation advisor, Dr. Ravi S. Behara, Department of Information Technology and Operations Management, and has been approved by all members of the supervisory committee. It was submitted to the faculty of the College of Business and was accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

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While the complexities and challenges facing healthcare continue to grow, the focus on improving surgical practices remains constant. Possessing a strong influence over patient referral patterns, public reputation/prominence, and financial performance, surgical practices command heightened attention on operational performance and clinical outcomes. Executive leadership cannot support (nor improve) a surgical practice without comprehending the importance of team dynamics in the operating room (OR) environment.

Previous literature offers mixed and incomplete results on themes of team familiarity and OR efficiency, frequently citing handoffs, late starts, and task disruptions as catalysts for negative performance. Studies routinely use historical interaction counts to measure team familiarity, which often neglect the degree of participation (engagement) across prior experiences. Similarly, counts of handoffs or individuals entering an OR do not offer an accurate assessment of team performance. Guided by historical studies, four hypotheses are presented and argue that enhancing surgical team dynamics yield favorable improvements for operational performance and clinical outcomes. Utilizing data from 9,049 neurologic surgery cases performed at two separate campuses (belonging to the same organization) over a three-year timeframe (March 2019 to November 2021), this study measures surgical team dynamics in a highly complex setting through the lens of case continuity and surgeon familiarity to assess key outputs: case scheduling errors (proxy for operational performance) and post-operative complications within 30-days of surgery (proxy for clinical outcomes).

Based on linear and logistic regression analyses, all four hypotheses are supported. The results showcase how increased case continuity decreases case scheduling errors and post-operative complications. Similarly, surgeon familiarity decreases post-operative complications. Evidence of a ‘U’ shaped curvilinear relationship is presented for surgeon familiarity and case scheduling errors. This suggests that surgeon familiarity decreases case scheduling errors to a certain point, and then begins to have an adverse effect by increasing case scheduling errors as teams become too familiar with the surgeon (incorrect assumptions or over-anticipating elements of the case). These empirically validated findings provide valuable insight into surgical team dynamics and the critical connections with operational performance and clinical outcomes. Theoretical contributions and managerial implications are discussed, and opportunities for future research efforts are offered.

DEDICATION

This manuscript is dedicated to my family, particularly my understanding and patient wife, Kaitlin, who has put up with these past few years of coursework and research, and to our children, who are truly the joy of our lives. I also dedicate this work to my late grandmother, Chrystal Erickson, who always believed in me, encouraged my academic pursuits, and loved me “a bushel and a peck.”

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INTRODUCTION

Achieving long-term success in any industry requires a collection of multidisciplinary skillsets and talents striving towards unified goals. This certainly holds true across today’s healthcare landscape, especially amidst the ever-increasing pressures and digital evolutions (disruptors) accelerated by the coronavirus (COVID-19) pandemic. Many organizations turned to lessons learned from previous disasters and crisis management events, but the uniqueness of the COVID-19 pandemic completely destabilized normal practice operations and forced organizations to develop new workflows and redesign care team approaches for core functions (Zorn et al., 2021).

While physician expertise certainly serves as a key driver for an institution’s reputation and patient referrals, the importance of teamwork and collaborative contributions are immeasurable, and evident throughout the history of medical advancements. From the surgical guidance text of Guy de Chauliac’s seminal work in 1363, *Chirurgia Magna*, to the introduction of vessel ligatures by A. Paré in 1590 for the development of the amputation technique (Hernigou, 2013), the surgical operating room environment showcases how invaluable the team is for progressing patient care. In 1910, one of the founding brothers of Mayo Clinic, Dr. William J. Mayo, stated, “The best interest of the patient is the only interest to be considered, and in order that the sick may have the benefit of advancing knowledge, a union of forces is necessary” (Mayo, 1910). Progression of modern healthcare is directly dependent on the care team’s ability to continuously learn, challenge the status quo, and strive for a higher level of performance, all while maintaining a patient-centric mindset.

As the healthcare industry continues through its complex journey of relentless change (reimbursements, regulations, digitization, pandemics, etc.), two priorities consistently touted throughout many medical centers are the emphasis on operating room (OR) performance and clinical outcomes. As referenced in Zhu et al. (2019), there is a growing level of research interest in OR performance and efficiency, with approximately fifty percent of scholarly articles on this topic being published in or after 2010. ORs are some of the most valuable resources within any healthcare organization. In addition to the brick and mortar, the embedded clinical equipment and sterile supplies are expensive, and continuously upgrading. Surgical personnel are highly compensated, which means that delays or unplanned variation in surgical case durations can quickly equate to high overtime expenses. OR staff recruitment and retention have become even more difficult with the COVID-19 pandemic igniting the “Great Resignation” and unprecedented levels of burnout and staffing shortages across the healthcare workforce. Furthermore, introducing costly temporary workers (i.e., travelers, contracted labor, or locum tenens) into the surgical environment generates new levels of uncertainty, vulnerability, and cultural risk.

Despite these significant expenses and daunting challenges, surgical care is consistently responsible for dominant proportions of total billable charges and net operating income for most medical centers (Resnick et al., 2005). Opportunities for process improvement exist across the entire spectrum of surgical care. Eliminating waste and inefficiencies from daily surgical workflows, accompanied by heightened emphasis on transparent, evidence-based reporting analytics (efficiency metrics, staffing levels, crew resource management, surgical service expenses, etc.), can provide clear directions for proactive management of surgical operations. The rapid adoption of electronic health record (EHR) systems and intraoperative documentation modules have created robust databases and registries, but many surgical practices struggle to capitalize on the full potential of this information for a multitude of reasons (Bydon & Meyer, 2021). Historical studies yield mixed results (with a wide range in statistical significance) pertaining to the interrelationships between surgical team dynamics and OR performance (O'Leary, 2011; Laskin et al., 2013; Kurman et al., 2014; Verhoeven, D., 2019; Dexter et al., 2020). Scholarly articles notoriously report findings from limited data samples, mostly consisting of one specific type of surgery (e.g., total knee replacement) to ensure validity and accurate comparisons within the results. These varying degrees of evidence are mainly attributed to surgical care complexities needed for high-quality outcomes, large multidisciplinary teams, and over-simplified experimental variables (Kozslowski & Bell, 2013).

Several studies have evaluated the current literature on OR performance and workflow efficiency in attempts to offer conceptual frameworks and highlight common catalysts that drive operational challenges, such as collective OR staff scheduling, case scheduling accuracy, and surgical acuity (Cardoen et al., 2010; May et al., 2011; Kim et al., 2014; Zhu et al., 2019). Other studies have delivered precise findings on surgical team dynamics, specifically focusing on familiarity, task continuity, professional experience, and OR interruptions (Wakeman & Langham, 2018; Stone et al., 2017; Xu et al., 2013). Even with these scholarly contributions, fragmentation and voids still exist in terms of concurrently evaluating all three elements of team dynamics, operational performance, and clinical outcomes. Recognizing the cultural nuances and situational factors impacting daily workflows within the OR environment, this study delivers new perspectives on surgical team dynamics impacting operational performance and clinical outcomes by focusing on two critical elements: case continuity and surgeon familiarity. In what follows, this dissertation is structured with six key chapters covering a comprehensive literature review, the research models guiding hypothesis development, research designs with methodologies, analyses with regression results, robustness checks, and closing discussions (centering on theoretical contributions, managerial implications, study limitations, and future research opportunities).

Guided by the common format of *why*, *what*, and *how*, the first chapter delivers a literature review that organizes historical studies into three primary sections, while simultaneously highlighting relevant implications to today's surgical OR environment and identifying gaps in current literature. The first section focuses on *why*—surgical practices and financial performance—by delivering an overview on the value of surgical practices, influence on satisfaction (for patients and staff), and financial implications. The second section centers on *what*—operational performance and clinical outcomes—by surveying relevant factors negatively (positively) impacting surgical quality and commonly cited issues associated with inefficient ORs. The third section covers *how*—OR performance measures and the importance of surgical team dynamics—by evaluating vital elements that drive OR performance and efficiencies through a historical lens.

Following the literature review, the second chapter encompasses two research models and hypothesis development. Building on historical studies and healthcare industry experience, the research models outline the projected relationships between case continuity, surgeon familiarity, case scheduling errors (proxy for operational performance), and post-operative complications (proxy for clinical outcomes). The research models offer four hypotheses that are tested through two separate empirical analyses in chapter three, which explains the research designs and respective methodologies. Multiple sources of data pertaining to 9,049 neurologic surgical cases, spanning a three-year timeframe at two integrated multidisciplinary academic medical centers (owned by the same overarching enterprise organization), were collected and applied to quantitative methods. Results are derived and analyzed in chapter four, followed by robustness checks in chapter five. The dissertation concludes in chapter six with narratives on the theoretical contributions, managerial implications, study limitations, and future research opportunities.

In summary, this dissertation offers a holistic presentation of the widely researched topic (and associated elements) of how surgical team dynamics influence operational performance and clinical outcomes within the OR environment. This paper endorses credibility and solidifies a foundational framework for guiding the accuracy of future research studies. By highlighting the impacts of team-driven factors on operational performance and clinical outcomes, this study’s findings will reaffirm relevant implications for today’s surgical practices and present a strong argument for incorporating new perspectives of team dynamics into scholarly studies going forward.

LITERATURE REVIEW

Performance, efficiency, and chemistry are often interchangeable words when someone is evaluating the current-state for a collective team's performance. The term "performance" is frequently cited as the ability to execute and accomplish desired objectives, while the term "efficient" is commonly defined as the capability to produce desired results without wasting materials, time, or energy (Merriam-Webster, n.d.). The focus on operational performance and workflow efficiency carries heightened importance in unstable, complex environments that require harmonious integration and collaboration across multiple stakeholders. Even more important than OR efficiency is an organization's never-ending pursuit of quality care. Excellent clinical outcomes are a top priority (and professional oath) throughout surgical practices within every health care organization. The following section reviews the importance of surgical care and groups the current literature into three primary themes: 1.) surgical practices and financial performance, 2.) operational performance and clinical outcomes, and 3.) surgical team dynamics and OR measurements.

Surgical Practices and Financial Performance

While the majority of health care organizations are not-for-profit, an institution's net operating income and operating margin are vital to long-term success and sustainability. Even Sister Generose Gervais (Sister of Saint Francis), a longtime leader of Mayo Clinic, was often quoted as saying, "No money, no mission." (Mayo Heritage

Society, 2020). OR performance and efficiency are pivotal to a hospital system's success, especially within the current backdrop of rising demand, increasing costs, diminishing reimbursements, and challenging constraints on timely access. The U.S. health care expenditure increased by $0.2 trillion from fiscal year 2014 to 2015, with no indicators of this paralyzing trajectory slowing. The ORs are a primary driver for more than 65% of all hospital-based admissions, and most surgical practices traditionally account for more than 40% of a hospital's total revenue (Reddy Gunna et al., 2017). Excluding physician salaries (surgeons and anesthesiologists), the average cost to staff a standard non-subspecialized OR is approximately $3.35 per minute (Dexter & Epstein, 2009), but most literature examined for this review cited an average OR cost per minute ranging from $9.00 to $20.00 (Bacchetta et al., 2005; Nundy et al., 2008; Allen et al., 2016).

An inefficient OR environment can make or break the financial performance of a health care organization. Surgical practices are a leading catalyst for patient referrals and the core foundation that steers a hospital's strategy for upstream outpatient clinical care and downstream inpatient care and rehabilitation services. Even amidst an era of digital transformation and global connectivity, acute surgical interventions are one aspect of health care that is not delivered virtually. Recent reports indicate that the global telehealth sector (also referred to as telemedicine, digital care, and virtual medicine) within the health care industry was worth approximately $38.3 billion in 2018, and that value is projected to exceed $130 billion by 2025 (Rivas, 2019). As virtual care continues to grow in acceptance (from patients, providers, and payers/insurance companies), the time lag durations of clinic-to-surgery are reducing. This coincides with growth rates in documented telehealth patient visits, which increased by 261 percent between 2015 and

2017 (Rivas, 2019). Investments in home-hospital platforms and digital care initiatives will enable health care systems to repurpose existing facilities and reallocate real estate holdings for further development of procedural and surgical services.

Staffing models and workload assignments are another critical component of a successful surgical practice. Failing to accurately quantify and resource the true staffing needs and workload demands of a surgical practice can quickly result in low employee morale and dismal satisfaction scores. To make matters worse, there are numerous clinical studies within the health sciences literature linking staff satisfaction to patient satisfaction. Trends and principles of patient satisfaction connect directly to the marketing and management literature through themes of customer-company identification (Ahearne et al., 2005), in which the perceived characteristics and attributes of the company directly correlated to the dependent variables of customer utilization and extra-role behaviors. Achieving proper balance plays a major role in staff satisfaction, particularly in high-stress environments, such as surgical ORs with complex subspecialty cases. One dissatisfier frequently cited by nursing staff across hospital systems is the unpredictability of daily schedules and the negative impacts on work-life balance (Stimpfel et al., 2012). This issue is amplified within the academic medical center settings, as there is a continuous struggle and balancing-act between learning and productivity. Given this tension and its influence on satisfaction, understanding when and how to optimize both dynamics interchangeably in the context of team membership is extremely valuable.

Most surgical practices rely on retrospective analytics and static dashboards leveraging statistical averages as a core calculation for key metrics on patient arrival time, surgical processing times, and more (Reddy Gunna et al., 2017). The vulnerability and natural inaccuracies of these calculations create a fundamental deficit because most surgical practice reporting metrics possess wide variations across multiple dimensions. This discrepancy is a major source of frustration between surgical personnel and hospital executives because staffing models and full-time equivalents (FTEs) are mainly allocated through these inferior dashboards/metrics. All too often, this results in staffing shortages that drive unfavorable overtime expenses and staff burnout.

Another inefficiency plaguing ORs across the U.S. health care system is the scheduling inaccuracies stemming from subspecialty complexities and voids in proactive planning for surgical cases that carry heightened risks of duration uncertainty. Neglecting to appropriately staff certain subspecialties can instantly create ripple-effects throughout the entire OR environment. Mazzei (1994) conducted an analysis that showed the neurologic surgery service-line consistently recorded longer anesthesia readiness scores, as compared to all other specialties. Allen et al. (2016) selectively examined 29,134 cases for more than four consecutive years to assess the impacts of staffing and educating surgical residents. The study's results showed 45 procedures took significantly longer with a resident engaged in the case and that the average operating time increased by 4.8 minutes, which was annualized to $492,889 per year based on an OR cost of $9.57 per minute, with approximately $208,722 attributed to expenses for OR nurses and CRNAs (Allen et al., 2016).

Measuring OR performance and efficiency is a combination of science and art. Previous literature has researched the short-term Hawthorne effects from implementing daily reporting and publicly displayed dashboards (Divatia & Ranganathan, 2015; Dexter, 2012). Surgical management and hospital executives are constantly titrating reporting frequencies and changing performance indicators. This instability is compounded by the modes of data collection, which often require manual extraction. While many organizations leverage EHRs (i.e., Cerner, Epic Systems, Medtronic, etc.), customizing OR reports can be extremely manual and often neglects key factors influencing performance. A survey-based study by Dexter et al. (2009) found that there is evidence of bias and lack of knowledge across health care organizations that fuel misperceptions of OR efficiency. In a 24-question survey to 57 hospital leaders, the results showed knowledge voids on principles in reducing over-utilized OR time to increase OR efficiency, based on their answering the relevant questions correctly at a rate no different from guessing at random (Dexter et al., 2009). Additionally, the survey results showed respondents falsely believed that a 10-minute delay at the start of the day causes subsequent cases to experience 10-minute delays ($p < 0.01$), which aligns with the respondent not knowing certain cases often take less time than what is scheduled (Dexter et al., 2009). While educating executive leaders on OR performance and efficiency could help bridge knowledge gaps, there is physician-driven support for hardwiring empirical evidence into operational systems and implementing automated reporting analytics to enhance the team environment, which is crucial for the surgeon’s focus during surgical interventions.

Operational Performance and Clinical Outcomes

Within the U.S. health care system, there is a systematic gap in thoroughly understanding the key drivers of OR team performance and efficiency. Publication bias also plays a major role in literature gaps pertaining to OR efficiency, as failed process improvement efforts are usually not attractive and do not gain acceptance into health care management journals. Cardoen et al. (2010) outlined six distinct categories that drive OR performance through scheduling efficiencies: patient characteristics, performance metrics, decision delineation, methodology and technique, case variation, and generalization of research findings. Similarly, May et al. (2011) approached OR scheduling efficiencies through six primary themes: capacity planning, process redesign, surgical offerings, estimation of case duration, schedule development, and monitoring control. Kim et al. (2014) developed three focal concepts of procedure types/mix, aggregate surgical schedule, and problem classification. Subsequently, Zhu et al. (2019) organized the OR efficiency literature into six designated fields: decision levels, scheduling strategies, patient characteristics, problem features, mathematical models, and solutions (with methods).

Many health care experts report that mathematical programming heuristics are frequently applied in complex linear and combinatorial optimization problems. However, it is difficult to integrate these requirements for all participants and propose a simple method to improve overall performance of hospital surgical suites (Zhu et al., 2019). A study by KC and Terwiesch (2009) showed that the processing speed of service workers (for patient transport and cardiothoracic surgery—intentionally examined two extreme examples) is influenced by system workloads. Results showed that a 10% increase in workload temporarily reduced length-of-stay (LOS) by two days for cardiothoracic surgery patients, whereas a 20% increase in the workload for patient transporters reduced the transport times by 30 seconds (KC et al., 2009). More importantly, and to the contrary, this study’s counterbalance metric of overwork revealed that workload acceleration is not sustainable over long periods of time. In fact, a 1% increase in overwork added 6 hours to the average hospital LOS, and a 10% increase in overwork reflected a 2% increase in the likelihood of cardiothoracic mortality (KC et al, 2009).

Quality anesthesia care is another crucial aspect for a successful surgical practice. Failure to proactively identify the anesthesia care type (requirements) can create substantial delays for room turnover time, in-room preoperative time (positioning and set-up of the patient), in-room post-surgery care, and total non-operative times (Caggiano et al., 2015). Compounded by downstream impacts to adjacent cases, these discrepancies and voids in preplanned anesthesia care can quickly equate to overtime labor expenses in the OR. Uncertainty characterizes the duration of activities related to intake processes, recovery processes, surgeries, emergency patient arrivals, and medical staff availability. Consequently, uncertainty strongly impacts the surgical case’s duration and the associated labor costs (Guerriero & Guido, 2011). A study by Laskin et al. (2013) analyzed 100 surgical cases and found that surgeons correctly estimated operating times 26% of the time, overestimated durations 42% of the time, and underestimated 32% of the time. Within the cohort of overestimated cases, 10 cases had actual durations that exceeded the planned durations by more than 20% (Laskin et al., 2013). Unfortunately, uncertainty and variability are commonly ignored in many OR planning and scheduling problems which assume deterministic surgery durations, while stochastic approaches try to incorporate it (Zhu et al., 2019).

In the literature review study performed by Zhu et al. (2019), supply chain logistics and materials management were identified as a smaller percentage within the cohort of OR delay reasons. While supply delays may result in minimal impacts based on the facility's supply chain management protocols (i.e., stocking inventory), the equipment delays primarily resulted in some of the longest delays, and more commonly in the surgical case being rescheduled. Equipment delays are not easily quantified in OR databases and the existing literature does not reflect significant publication content on this matter. This is likely attributed to several organization-based factors. For example, equipment delays are primarily a result of poor infrastructure systems and many institutions are unwilling to publicize gaps in their surgical operations.

One of the more underappreciated groups supporting the functionality and daily success of all OR environments is instrument processing operations. Instrument processing directly correlates to OR performance and efficiency through measures of clinical outcomes and patient safety. Immediate use steam sterilization (IUSS) items must be used promptly and cannot be stored for later use. IUSS is intended for emergency situations and not as regular course of action. High rates of IUSS typically signal inadequate inventory levels, scheduling conflicts, and miscommunications. Many organizations view IUSS use as an adverse event and monitor monthly rates to ensure safety goals and financial goals are achieved (Weart, 2014). Many instrument processing teams experience staffing shortages, mismanaged schedules, and poor reporting metrics. The lower attention to this unit from hospital executives is driven by misunderstanding and typically viewed as an expense, not an RVU-generator.

Knowledge voids on how to effectively maximize efficiencies in the ORs and psychological bias from leaders (surgeons, anesthesiologists, and hospital executives) are two leading principles that cause disproportionate concentration on insignificant factors, such as first case start delays. Surgical case scheduling encompasses more than the estimated time needed by the surgeon. A comprehensive surgical scheduling system should consider all stages of the patient's surgical experience. One aspect that is noticeably neglected in surgeon-specific studies, is the role that anesthesia preplanning plays in achieving efficiency. Caggiano et al. (2015) performed a retrospective study on 566 cases to evaluate the effects of anesthesia type on the non-operative times associated with each surgical case. The results found that the anesthesia type choice has a significant impact on OR efficiency. Monitored anesthesia cases had a lower non-operative duration impact compared to general anesthesia cases, but local anesthesia cases had the lowest non-operative time across all three types (Caggiano et al., 2015).

Merging patient prioritization and patient scheduling to improve access to services in an elective context can enhance overall efficiencies. Leveraging a "utility score" mechanism, which is a proxy for the relative urgency with regards to the other patients on the list, delivers a mathematical model for solving the patient scheduling problems, while simultaneously assigning the correct session to each surgeon, and the right patient to those sessions (Oliveira et al., 2020). This ultimately results in maximizing the total utility for the collective OR environment and scheduling higher utility patients first in order to minimize inefficiencies (Oliveira et al., 2020). Guerriero and Guido (2011) incorporated principles from operations management research to develop the data envelopment analysis (DEA) technique to address the main problems arising at tactical levels, such as increasing total OR block time for driving profits (measured through monetary gains and intangible benefits). Testi et al. (2007) developed a three-phase, hierarchical approach for the weekly scheduling of ORs that leverages integrated pathways for surgical activities in order to improve overall operating efficiencies, as measured by overtime expenses, volume/throughput, waiting list reductions, and overall department prioritization.

While OR efficiency is extensively researched and growing in popularly, there are still several crucial dynamics and elements that the current literature has failed to consistently investigate at adequate depths. The current literature primarily assesses surgical OR teams (referenced as surgical teamwork) focused on a single procedure within one subspecialty, and often overlooks the importance of inter-subspecialty multidisciplinary subgroups. This includes one-dimensional analyses on familiarity amongst surgeons, or individual surgeons with a single surgical resident, nurse, or technician. As studied by Maruthappu et al. (2016), surgical experience and team familiarity display important and distinct relationships with the operative time for total knee replacement surgery. Acknowledging this interplay may serve as an effective guide to OR allocation and implementation of procedure-specific quality improvement strategies. The interrelationships between surgeons and the respective anesthesia team are vital to understanding efficiencies (and inefficiencies) throughout the surgical workflow. Inadequate staffing levels and mismatched team compositions result in more workflow disruptions that increase surgical time, compromise quality, and unintentionally jeopardize patient safety (Henaux et al., 2019). One of the more pivotal partnerships within the actual OR environment is between the surgeon and anesthesiologist (the two primary physicians leading the surgical care). Driven by inconsistent definitions and personal perceptions, OR efficiency studies struggle to accurately quantify the dynamics of teamwork. There is a strong perceptual difference among anesthesiologists, nurses, surgeons, and certified registered nurse anesthetists (CRNAs) when viewing start-times and turnover times (Mazzei, 1994). Failing to understand the dynamics of individual productivity and team productivity can create negative consequences that impede learning, collaboration, and overall efficiency (O'Leary et al, 2011). O'Leary et al. (2011) tested the proposition that the variety of multiple team memberships is inversely related to individual and team productivity. The study found that multiple memberships enhance learning to a certain level, but then produces a declining impact once the membership is over-diluted.

The aspect of trust is crucial to success and patient outcomes in any OR setting. Mathieu et al. (2014) conducted a robust meta-analysis on modern organizational designs and numerous theoretical models, which signaled an obvious lack of coherence, integration, and understanding of how team composition effects relate to important team outcomes. Elements of integrative membership, temporal considerations, and key periods of performance episodes all play a contributing role on overall success (Mathieu et al., 2014). There is a threshold in which team familiarity becomes counterintuitive to team performance by unintentionally limiting episodes for diversity and sharing of best practices. Practitioners report that their colleagues were their most popular source of continuing education and new perspectives (Offermann & Spiros, 2001). Understanding the relationships between task change, diversity in team member experience, team familiarity, and subsequent team performance are important because teams may be the key learning unit within the organization, and organizational learning is an important source of competitive differentiation (Huckman & Staats, 2011).

Historical operations management research endorses two different work-design-related strategies for sustaining productivity: 1.) specialization to capture the benefits of repetition and 2.) variety to keep workers motivated and provide them opportunities for continuous learning (Staats & Gino, 2012). In a retrospective study by Staats and Gino (2012), they found that organizations need to transform specialization and variety into mutually reinforcing strategies, rather than treating them as mutually exclusive, through new models of effective work allocations. Crawford and Lepine (2013) developed a theory challenging the conventional view that increases in team processes are inherently and uniformly beneficial. They explained how structural configurations involve trade-offs that must be acknowledged in academic research and industry practice.

Recognizing that small stand-alone teams typically observe positive features from decentralization, Lanaj et al. (2013) presented key insights on how multi-team systems with high levels of interdependence add complexity levels, which ultimately result in strong negative effects of excessive risk-seeking and coordination failures that outweigh the gains from decentralized planning. The key takeaway from Lanaj et al. (2013) is that staple theories on teams should be challenged and reassessed before applied to multi-team environments, such as ORs. Applying heightened focus on operational acumen can improve team dynamics within surgical practices and prevent meritless initiatives from distracting OR supervisors.

Operating Room Measures and Surgical Team Dynamics

In a 2012 study, O'Leary et al. developed a model that describes how the total number and variety of multiple team memberships drive different mechanisms, which yield distinct effects. Unfortunately, mismanagement of clinical staffing levels, in the forms of team shortages and personnel not working to the top of their licensure (i.e., physician assistants functioning as documentation scribes for surgeons), plagues many institutions and prevents efficient workflows. Workflow disruptions are less common for OR teams with high levels of experience and a greater repetition frequency of surgeon-nurse familiarity (Henaux et al., 2019). Practitioners who regularly work within group settings reported that (on average) 39% of their practice time depends on other groups or involves teamwork, and almost half of practitioners reported that the demand for team development has increased over the past three years (Offermann & Spiros, 2001). There are signals indicating that the issues of decision-making, problem-solving, conflict management, role definition, empowerment, and resource management contain important insight for explaining the link between the science and practice of team development (Offermann & Spiros, 2001).

Accurate assessments of surgical OR efficiency must incorporate multiple perspectives from a wide variety of engaged stakeholders: surgeons, anesthesia teams, nursing, surgical staff, instrument processing teams, hospital-based teams, executives, and several others. Many surgical leaders and OR committees focus on evaluating the percentage of on-time first-case starts as a proxy for the overall performance of procedural suites and ORs, without fully understanding the magnitude of these delays and their effect on efficiency and productivity (Villarreal et al., 2015). While there is empirical evidence showing that correcting first-case on-time starts does not equate to OR efficiency, first case on-time starts is one of the more consistently measured, tracked, and studied dynamics because it is consistently quantified and poses less uncontrollable variances (i.e., there is no prior case delay impact). Historical literature on OR performance covers an ever-expanding scope with numerous definitions and metrics, such as OR readiness, patient arrival, wheels-in (patient entering OR), anesthesia induction, first incision, final suture, wheels-out (patient leaving OR), PACU responsiveness, and more. First-case starts are predominantly influenced by factors that the institution can control, such as educating patients on pre-surgery instructions, preoperative work-ups, equipment readiness, supply set-up, and personnel arrival times.

A delay in first case on-time starts can lead to decreased OR utilization, greater facility costs, and dissatisfaction among staff and patients (Allen et al., 2019). Delays and tardiness from scheduled start-times is a common source of frustration for both OR personnel and patients (Wachtel & Dexter et al., 2009). A retrospective study targeting surgical cases in 1989, aimed to evaluate the operational impacts of delayed case starts and prolonged turnover times, and found that variations in anesthesia induction time accounted for 21 to 49 minutes of variance in the case's actual duration compared to the planned duration (Mazzei, 1994).

Typically, hospitals and health care systems have the OR manager(s) owning the aggregate performance of the ORs. OR managers are tasked with strategically developing an efficient OR schedule and prioritization mechanisms that increase patient flow and surgical team synergies, in order to derive the highest yield translating to financial performance (Reddy Gunna et al., 2017). OR management is responsible for daily workflow and ensuring long-term sustainability. One growing challenge that OR management faces is the high turnover in middle management positions and working leads (Panditt, 2006). Huber and Lewis (2010) expanded on group performance theories by including mental models and cross-understanding dynamics to explain the varying degrees of influence on operational performance. The inability to assess the direct and indirect relationships between first-case tardiness, turnover times, underused ORs, and raw utilization, as well as determining the leading variable with the most negative impact, is commonly cited by surgical practices as a common impediment to achieving new OR efficiencies and greatest frustration by management (Van Veen-Berkx et al., 2015).

Sustained staffing stability is a rare commodity, because a multifaceted team has a composition and structure that is continuously changing over time. Huckman et al. (2009) observed that conventional measures of the experience of individual team members (such as years at the firm) are not consistently related to performance, but did note that the role experience of individuals in a team (such as years in a given role within the same team) is associated with better team performance. Teamwork is an essential factor in reducing workflow disruptions in the OR, and a study by Henaux et al. (2019) showed that 9.91% of the coded surgical time was linked to breakdowns in teamwork, in the form of avoidable distractions and colleague interruptions, at 29.7% and 25.2% respectively. Huckman and Staats (2011) recognized previous work highlighting teams with diverse prior experience are often brought together because of various knowledge demands. However, they found that certain degrees of diversity can be a double-edged sword regarding the team's ability (or inability) to cope with changing tasks when cognitive problem-solving demands are high.

Consistent with the "double-edged sword" of team familiarity, several studies have found clear evidence that the relationship between team familiarity and team performance resembles a 'U' shaped curvilinear relationship. Research has shown increased familiarity enhances performance to a certain threshold, but then carries a risk of adverse effect by plateauing or diminishing team performance (Xie et al., 2020; Muskat et al., 2022; Koopman et al., 2016; Wise, 2014; Luciano et al., 2018; Sieweke & Zhao, 2015; Berman et al., 2002). Luciano et al. (2018) evaluated team familiarity through the lens of shared team task-specific (STTS) experience within crew-based arrangements across 8,236 surgeries (specifically knee and spine cases) at one hospital. The results found an inverted 'U' shaped curvilinear relationship between STTS experience and OR efficiency, which is measured as the ratio of actual versus planned duration of the surgical case. Luciano et al. (2018) used the dependent variable of OR efficiency, which is a favorable outcome (hence an inverted 'U' shaped curvilinear relationship). This framework provides support for this dissertation's approach of using case scheduling errors (ratio of actual case duration to scheduled case duration) and would reflect a regular 'U' shaped curvilinear relationship because case schedule errors are an unfavorable outcome.

Similar support for a 'U' shaped curvilinear relationship is showcased in Koopman et al. (2016) with the addition of evaluating a team's psychological safety climate and climate intensity/strength. These findings demonstrated how the curvilinear relationship between team tenure (familiarity) and average team member creative performance was partially mediated by team psychological safety climate. The aspect of team psychology safety climate is applicable and relevant to the highly complex setting of an OR during neurological surgery. The environmental tone and psychological safety climate of an OR is established/determined by the attending surgeon. This role of leadership and authority is a critical dynamic within the OR. Research by Sieweke and

Zhao (2015) supports a 'U' shaped curvilinear relationship associated with the impacts of team familiarity and team leader experience on the negative (unfavorable) outcome of team coordination errors (TCE). If the nature of the dependent variable is favorable, several studies focusing on team dynamics (familiarity, shared experience, etc.) and team performance have delivered results supporting an inverted 'U' shaped curvilinear relationship. Berman et al. (2002) examined the inverted curvilinear relationship between tacit knowledge and competitive advantages within the National Basketball Association (NBA). Wise (2014) researched the inverted curvilinear relationship between group cohesion and team performance through a social network analysis with email communications. A study by Xie et al. (2020) also demonstrated how team familiarity and team performance have an inverted 'U' shaped curvilinear relationship based on data from 68,922 R&D (research and development) teams within the electrical engineering industry by focusing on the team's innovation performance. Regardless of inverted or regular 'U' shaped, prior literature offers strong evidence of a curvilinear relationship between a team's familiarity (shared experience) and its operational performance.

Process improvement initiatives and workflow redesign projects (within large teaching hospitals) also play a role in improving operational performance without compromising patient safety. In the retrospective study by Small et al. (2013), based on orthopedic surgery data from a major academic medical center in Iowa, the data demonstrated that using staff members familiar with orthopedic equipment and procedural needs resulted in decreased operative time by an average of 19 minutes per case. The breakdown of this 19-minute measurement consisted of the average anesthesia-controlled time decreasing by 4 minutes per case ($p < 0.001$), intraoperative incision duration reducing by 7 minutes (*p* = 0.004), and OR turnover time shortened by 8 minutes (Small et al., 2013). Based on a daily surgical schedule consisting of four primary arthroplasty procedures, the results signaled an approximate savings of 1.25 hours per day for each orthopedic surgeon (Small et al., 2013). Another study found that each one-minute reduction in first case tardiness for ORs with consistent turnovers and a routine schedule (expectation) of eight surgical hours, resulted in reductions for regularly scheduled labor costs (Dexter & Epstein, 2009).

Mason et al. (2015) conducted a systemic review on surgical practices leveraging lean and six sigma methodologies for enhancing operational performance. The study focused on 23 studies, with 11 assessing lean methodologies, 6 centered on six sigma, and 6 combining lean six sigma concepts. These studies predominantly targeted optimizing OR schedules, decreasing non-operative activities, reducing mortality, and limiting unnecessary costs. Majority of these studies delivered results indicating significant improvements, but there was clear evidence of biases and imprecisions (Mason et al., 2015). Dexter et al. (2020) found that mechanisms of thorough reporting on total operative time performed in each OR provide critical insight on workflow efficiencies. The study demonstrated that reductions in first case tardiness in rooms with seven hours or less of scheduled operative time did not produce beneficial reductions (statistically significant) in overtime expenses. Reducing first case tardiness in ORs with eight or more hours of schedule operative time did result in positive changes in observed overtime expenses (Dexter et al., 2020). From these findings, the recommendation was implemented to ensure a minimum of eight hours of operative time were scheduled to a respective room (excluding urgent/emergent rooms). From these reporting metrics and evidence-driven analyses, one could determine the univariate association between over-utilized time and tardy first-case starts was not casual (Dexter et al., 2020). Although operating times need to be used for scheduling purposes, they can be highly unpredictable. One best practice is having surgeons routinely analyze their predictions for confounding factors in order to reduce case scheduling errors (Laskin et al., 2013).

A study by Van Veen-Berkx et al. (2015) suggested that OR utilization can be improved by focusing on the reduction of underused OR time at the end of the day and by improving the prediction of total procedure times. Leveraging routine (and accurate) reports for altering the sequencing of operations, changing patient cancellation policies, and utilizing flexible staffing of ORs adjusted to patients, are proven means to reduce non-operative time (Van Veen-Berkx et al., 2015). Allen et al. (2019) conducted a study on case starts with new definitions targeting time of incision without grace periods, rather than the traditional patient-in-room metric. This nine-month study achieved 73.6% on-time starts for first cases, compared to the baseline of 30.4%. The annualized calculations reflected a savings of 80,587 OR minutes, which translated to approximately $771,220 (based on an OR cost per minute of $9.57) in variable labor cost savings (Allen et al., 2019).

As the healthcare industry endures the “Great Resignation” and difficult staffing shortages, it is important for surgical practices to evaluate operational efficiencies and performance metrics across all subgroups working within the ORs. Dexter and Epstein (2009) conducted a study across 14 surgical subspecialties with 85 anesthesiologists, which found that the frequency and occurrence patterns of tardy first case starts was homogeneously distributed amongst all ORs. There was no statistical significance, as anesthesiologists accounted for only 1% of the total variation and 3% was attributed to the surgical personnel. This provides insight on the types of analyses that should be conducted on a routine basis through OR settings to determine if certain opportunities for improvement are greater within specific subgroups. In a study of 4,276 total knee replacement cases across 1,163 different surgical teams (which measured the median experience level at 17.6 years for consultant surgeons and 3.7 years for trainee surgeons), the results showed that consultant experience, trainee experience, cumulative team operative experience, and team familiarity demonstrated concave and linear relationships (Maruthappu et al., 2016). This led to an expected reduction of 51 minutes in operative time for consultants with 25 years of experience, as compared to a reduction of 21 minutes for operative teams after 40 collaborations (Maruthappu et al., 2016).

Many organizations fail to measure the importance of shared experience, and often attempt to drive improvements by adding more teams. However, the simple addition of team members engaged in a surgical case can create an elevated risk of surgical site infections and miscommunication (Kodali, 2014). Carton and Cummings (2012) developed a theory of subgroups within work teams, which indicated the elements of identity, resources, and knowledge, as leading drivers for the formulation of subgroups. Gardner et al. (2012) expanded on the resource-based view of the firm by examining how teams can develop a knowledge-integration capability to dynamically integrate members’ resources (relational, experiential, and structural) into higher performance. A study by KC et al. (2013) used attribution theory in psychology to investigate how individuals learn from their own past experiences with both failure and success, and from the experiences of others. This study used more than 6,500 cases from

71 cardiothoracic surgeons and found that individuals learn more from their own successes than from their own failures, but learn more from the failures of others than from the successes of others (KC et al., 2013). Unfortunately, most of the academic literature does not contain stories on failures. Most publications are skewed to favor success stories in health care management journals, despite evidence of study limitations and generalization voids. As compared to relative experience, a surgeon's focal experience has a greater effect on surgeon performance and is a key driver of improvement for the patient's clinical outcomes (KC & Staats, 2012). Providing surgical subspecialties with a consistent OR environment (physical space), also results in increased productivity and efficiency from the team's continuity with supply storage and equipment configurations (Small et al., 2013).

Hospital management and surgical teams should direct scarce financial means on decreasing underused time because it has the strongest influence on OR utilization (Van Veen-Berkx et al., 2015). To avoid disruptions for surgeons and patients, OR management should leverage interventions with mathematical "corrections" to recalculate case start times, with creation of a modified or auxiliary OR schedule that proactively accounts for predictable causes of tardiness (Wachtel & Dexter, 2009). Furthermore, moving cases to different ORs towards the end of the day can result in reduced tardiness by a daily OR average of 4 minutes for a hospital-based surgical environment, and 10 minutes for an ambulatory surgical center (Wachtel & Dexter, 2009).

Seasoned employees often prove to be successful members of a team because they are strongly familiar with the corporation's products, service-lines, operating systems, resources, and key internal contacts (Smith, 1997). Kurmann et al. (2014) reviewed team familiarity relating to the surgeon and advance practice provider (nurse practitioner or physician assistant) and recognized correlations between wound closure times. Surgical OR studies face challenges in driving empirical evidence from large sample sizes when evaluating case participants, team interrelationships, activity durations and other factors. In the study by Henaux et al. (2019), the model's methodology contains scholarly contributions, but the study's data only consisted of 12 neurosurgery cases. Three common pitfalls that hamper the adoption of research results by industry stakeholders are inconsistent target audiences within the study (balancing between researchers and practitioners), use of suboptimal performance measures, and failure to understandably report on the hospital setting and method-related assumptions (Samudra et al., 2016).

Within the OR environment, familiarity has traditionally been defined as the number (unique count) of collaborations between a specific surgeon and specific subordinates within that subspecialty, such as a trainee surgeon, nurse, or surgical technician (Maruthappu et al., 2016). Kurmann et al. (2014) found that team familiarity improves team performance and reduces morbidity in patients undergoing abdominal surgery by leveraging a questionnaire from specialized work psychologists and intraoperative sound level measurements. The study mapped these variables to the surgical complications during two specific time intervals, with the first including current-state scheduling of senior and junior surgeon pairings (which rotated daily), to the second time interval of stable dyads. Despite the attention given to team familiarity and its contingencies, prior work has focused on *whether* team members have worked together (generalized), not on *which* team members worked together and under *what* conditions. Espinosa et al. (2007) demonstrated that task familiarity is more beneficial with more complex tasks and that team familiarity is more beneficial when team coordination is more difficult, but that both are complementary on team performance. Staats (2012) investigated the effects of hierarchical team familiarity (manager with front-line staff) and horizontal team familiarity (front-line staff with one another), which had different impacts on the team's overall performance. Hierarchical team familiarity showed a greater improvement on communication and proactive planning, whereas horizontal team familiarity improved immediate episodic performance (real-time).

RESEARCH MODELS AND HYPOTHESES

While OR operational performance and clinical outcomes are heavily researched topics, there are still several critical subtopics that require further investigation. Though recurrently criticized and challenging to quantify, the aspects of continuity and familiarity need to be focal points that are consistently embedded in future research studies pertaining to OR operations and quality. As highlighted in the literature review section, many studies aim to understand the composition of the surgical team (as a compliment to the surgeon's skillset and expertise), but only partially cover the implications. The following section presents two research models and purposes four hypotheses for testing. Each hypothesis aims to enhance the existing literature and strengthen connectivity between key elements of OR operational performance and clinical outcomes, while incorporating foundational theories embedded in the established academic fields of operations management research and information systems management research.

The two research models within this dissertation present frameworks that integrate two prominent dynamics of the comprehensive surgical team through the lens of case continuity and surgeon familiarity, with the intent to evaluate the impacts on operational performance and clinical outcomes. The proxy for operational performance is case scheduling errors, which are a major catalyst in OR efficiency (see Figures 1-3). Post-operative complications, observed within 30-days of the surgical interventions, serve as the proxy for clinical (surgical quality) outcomes (see Figures 4-6).

[*NOTE: INSERT FIGURE #1 HERE - CENTERED ALIGNMENT*]

Case scheduling errors are one of the key drivers impacting OR efficiency. Surgical leaders generate staffing schedules and daily assignments that are based on the scheduled duration of each case booked within the ORs. The scheduled case duration is determined and set by the respective surgeon. If a surgeon overestimates the case duration, it results in over allocation of OR staff and creates unproductive workforce time (minutes and/or hours) while waiting for the next case to begin. If a surgeon underestimates case duration, it generates delays for the following case(s) and risk of costly overtime expenses.

Case continuity captures the continuous engagement and staffing of the collective surgical team for the entirety of the case. As referenced earlier, minimizing handoffs and eliminating unnecessary disruptions in a surgical case can enhance OR efficiency. Lower levels of case continuity and inconsistent surgical teams supporting the case were associated with higher likelihood of prolonged operative time, which drives the variance between actual and scheduled case duration (Xiao et al., 2015).

Surgeon familiarity builds on the findings from Staats' (2012) study on hierarchical team familiarity, which examined team performance of software-development projects and the familiarity between the project's manager and the project's engineers. Staats' (2012) study measured hierarchal familiarity based on interaction counts (i.e., project manager and one specific project engineer have worked together on 29 projects over the past three years, this is recorded as 29 interactions). One opportunity with the hierarchal familiarity metric would be to incorporate the degree of participation (engagement) on each respective project, rather than assuming all projects are equal.

As a proposal of enhancement, this dissertation modifies previous hierarchal familiarity approaches by pivoting from an interaction count to adopt a metric that measures the participation (via total OR minutes) within the interaction. For example, if CRNA #1 participates in 17 of a particular surgeon's last 45 cases and CRNA #2 participates in 24 cases (of those same 45 cases), the interaction count methodology would reflect greater surgeon familiarity for CRNA #2. However, if CRNA #2 only covered another CRNA colleague for a quick 30-minute interval (i.e., lunch break or restroom break) in all of those 24 cases (out of 45 cases), it would not constitute as higher degrees of interaction with the surgeon. Thus, if we were to assume each of the 45 cases had a duration of 200 minutes, then CRNA #2 would have a lower surgeon familiarity score (calculation: 30 x 24 = 720 minutes, out of 9,000 minutes). If CRNA #1 was involved in 160 minutes for each of the 17 cases (calculation: 160 x 17 = 2,720 minutes, out of 9,000 minutes), this would yield a greater surgeon familiarity score than the surgeon familiarity score for CRNA #2. This is one of the theoretical contributions that this dissertation will offer—providing a new perspective on hierarchal familiarity through a measurement that encompasses the degree of participation (engagement) associated with the respective interactions.

Based on these core concepts of case continuity and surgeon familiarity, the following two hypotheses relating case scheduling errors are proposed:

Hypothesis 1 (*H1*): Case continuity is inversely related to case scheduling errors.

[*NOTE: INSERT FIGURE #2 HERE - CENTERED ALIGNMENT*]

Hypothesis 2 (*H2*): Surgeon familiarity has a 'U' shaped curvilinear relationship with case scheduling errors.

[*NOTE: INSERT FIGURE #3 HERE - CENTERED ALIGNMENT*]

As referenced earlier in the literature review, several studies have shown that increases in OR operational performance can assist in reducing surgical risks and complications. Specifically, the study by Henaux et al. (2019) outlined how insufficient staffing levels and incompatible team compositions generate OR disruptions that negatively impact case scheduling accuracy (similar concept of case scheduling errors), while jeopardizing quality outcomes and patient safety. Additionally, OR disruptions are less common for surgical teams possessing high levels of familiarity (Henax et al., 2019). Rambachan et al. (2013) examined surgical case durations for plastic surgery procedures and impacts to patient outcomes, which revealed that longer durations were associated with an increase in overall complications. The study's results found evidence that each incremental 30-minute interval in operative time carried a corresponding increased risk for 30-day complications, but not mortality (Rambachan et al., 2013).

Case continuity and surgeon familiarity also possess relevance in reducing the risk of unfavorable clinical outcomes and adverse impacts to patient safety. As referenced by Kodali (2014), adding incremental OR team members to participate in the surgical case can introduce heightened levels of risk for surgical site infections and miscommunication. For the purposes of this study, the second analysis leverages post-operative complications as the proxy for clinical outcomes associated with the patient's surgical intervention.

[*NOTE: INSERT FIGURE #4 HERE - CENTERED ALIGNMENT*]

Contrary to the 'U' shaped curvilinear relationship hypothesized for surgeon familiarity and case scheduling errors in H2, a healthcare organization's commitment to quality care and patient safety leads to H4 hypothesizing an inversely related linear relationship between surgeon familiarity and post-operative complications (no 'U' shaped curvilinear relationship). For many years, the Joint Commission's hospital accreditation efforts have developed requirements focused on active quality assurance and quality improvement (Barnett et al., 1978). The Joint Commission conducts retrospective reviews of medical care patterns and emphasizes the importance of defining key needs for continuing education of medical staff and proactively identifying systematic weaknesses (vulnerabilities) within an institution's protocols/procedures that could negatively impact patient safety and quality of care (Barnett et al., 1978).

In recognizing this heightened focus for patient care and the importance of accreditation, many hospitals have implemented quality assurance and quality improvement programs that are systemically supported by information technology (IT) applications (Aronow & Coltin, 1993). A study by Aronow and Coltin (1993) highlighted how IT applications have historically been utilized for improving the ability to measure the process of health care delivery, but that new capabilities in continuous monitoring and emerging programs are proactively signaling care deficits and heightened risks through evidence-based algorithms to alert physicians and care teams. Today, most hospitals and surgical practices have dedicated quality teams that oversee and govern the institution's protocols and safeguards to prevent negative impacts (harm) to patient safety. These quality teams ensure best practices for quality assurance and quality improvement are diffused across all patient care settings (ORs, hospitals, outpatient clinics, emergency departments, etc.). Regardless of a care team's familiarity and prior experience, the organization's quality standards and systematic protocols are hardwired to reduce (eliminate) errors and proactively monitor clinical outcomes, such as post-operative complications.

Post-operative complications typically result in increased disruptions and costs for hospital systems, and directly contribute to patient morbidity and mortality. A study by Geller et al. (2018) focused on post-operative costs within a 90-day window for a sample of 741 surgical patients and found that complications accounted for 28% of the aggregate 90-day direct hospital costs for all patients. The complications incurring the largest incremental cost per event were ones requiring surgery (200%, $p < 0.001$) (Geller et al., 2019). This dissertation's second analysis focuses on clinical outcomes, and aims to understand the impacts of case continuity and surgeon familiarity on post-operative complications—thus the following two hypotheses are stated:

Hypothesis 3 (*H3*): Case continuity is inversely related to post-operative complications.

[*NOTE: INSERT FIGURE #5 HERE - CENTERED ALIGNMENT*]

Hypothesis 4 (*H4*): Surgeon familiarity is inversely related to post-operative complications.

[*NOTE: INSERT FIGURE #6 HERE - CENTERED ALIGNMENT*]

RESEARCH DESIGN AND METHODOLOGY

The healthcare organization examined for this dissertation is a prominent academic medical center. It is one of the largest integrated, not-for-profit group practices in the world and provides care to more than 1.3 million patients per year, reaching across all 50 states and nearly 130 countries. With domestic campuses in Arizona, Florida, Iowa, Minnesota, and Wisconsin, as well as international affiliations, the collective enterprise employs more than 71,000 allied health staff and over 7,000 physicians and scientists. The organization utilizes one integrated electronic health record (EHR) across its domestic sites for clinical documentation and revenue cycle operations. Most of its subsidiaries have been determined to qualify as tax-exempt organizations under Section 501(c)(3) of the Internal Revenue Code (IRC) and as a public charity under Section 509(a)(2) of the IRC.

Data Collection and Sample Selection

Based on similarities across facilities, volumes, staffing models, and practice maturity, this study specifically focuses on the neurologic surgery practices at the organization’s Arizona and Florida campuses. This study’s operational performance OR data was reviewed and approved by the organization’s Institutional Review Board (IRB #: 21-010068) on October 14, 2021, under expedited review procedures and was determined to be exempt from the requirement for IRB approval (45 CFR 46.104d, category 4). Continued IRB review of this study is not required as it is currently written.

As protected health information is not being requested from subjects, HIPAA authorization is not required in accordance with 45 CFR 160.103. The title of the IRB is “Operational metrics and perioperative outcomes (variance between scheduled and actual case durations) of surgical patients at Arizona and Florida campuses relating to surgical team staffing and scheduling dynamics.” The data obtained within IRB #21-010068 serves as the source of intraoperative OR operational data for the study’s independent variables, control variables, and the dependent variable of case scheduling errors (ratio between the case’s actual duration and scheduled duration, as measured by “wheels-in” time to “wheels-out” time). Two separate data extractions were required for creating the aggregate operational performance data set: 1.) individual personnel entry time stamps for each case, and 2.) comprehensive details of each case, many of which are used for control variables within this study (case’s start status, combination case, performed on a weekend, incision/cut-time, suture/close-time, scheduled durations, and more).

First, all neurologic surgery (NES) case volumes at the Florida and Arizona campuses occurring within the timeframe of January 1, 2019, through December 31, 2021, were extracted from the archival EHR data feeds (under IRB #21-010068). This equated to a total of 10,609 NES cases and 110,377 individual personnel entries across all surgical roles participating in the case. The individual personnel entries consist of specific time stamp fields that captured each person’s engagement metrics (i.e., each individual time stamp of entering and exiting the OR throughout the case’s duration between actual wheels-in to actual wheels-out). It is important to note that this metric is manually recorded within the EHR intraoperative documentation module by the case’s designated nurse circulator. Of the 110,377 individual personnel entries captured in the data extraction, 552 entries were missing the individual’s name. While the person’s role (i.e., nurse, CRNA, fellow, etc.) was still recorded, these 552 entries (spread across 262 NES cases) were removed because retrospective mapping for the surgeon familiarity metrics were unobtainable without accurate names to connect historical participation throughout the respective surgeon’s prior cases. This resulted in a subtotal of 109,825 individual personnel entries across 10,347 NES cases.

A second IRB data set (IRB #: 15-006838; “minimal risk” status with most recent update/addendum approved on August 30, 2021), titled “Neurosurgery Outcomes: Improving the Quality and Standards of Patient Care” is the source of this dissertation’s clinical outcome dependent variable: post-operative complications. Keeping with the same data extraction timeframe (January 1, 2019, through December 31, 2021), this surgical quality and clinical outcomes database returned 12,459 NES cases from the same archival EHR data feeds (for the Arizona and Florida campuses). Of the 12,459 NES cases compiled, 881 NES cases had a recorded post-operative complication for the patient within 30-days. The primary difference in case counts (difference of 2,112 NES cases) between these two data sets (the operational performance data set and the clinical outcomes data set) was driven by two key factors: 1.) the clinical outcomes data set included neurologic interventional radiology (NIR) cases, whereas the operational performance data set excluded these NIR cases (due to definitions and key criteria of what constitutes as a neurologic surgical case), and 2.) the 552 missing entries removed from the operational performance data set (which, as noted earlier, reduced the NES count from 10,609 cases down to 10,347 cases). Of the 10,347 NES cases within the operational performance data set, there were 91 cases that did not match (cross-reference directly) with the clinical outcomes data set. This further reduced the data set subtotal down to 10,256 NES cases, which contained 727 occurrences where the patient experienced a 30-day post-operative complication.

As mentioned in the hypothesis development section, the surgeon familiarity metric is derived from the OR minutes each person performed with that current case's respective surgeon. This study quantified the surgeon familiarity metrics based on a retrospective 12-week window leading up to the case's operative date because the organization's surgical supervisors develop OR staffing schedules in 12-week intervals (also referred to as block-schedule builds). Within the current literature, studies centering on themes of team familiarity showcase a wide range of retrospective timelines (weekly, monthly, quarterly, annual, or greater) based on the subject of interest. In using a 12-week timeline for this study's surgeon familiarity metrics, the cases performed within the first 12 weeks of the sample were utilized to develop the surgeon familiarity scores for cases performed between March 24 to June 15 of 2019. After surgeon familiarity calculations were completed, these specific cases (December 30, 2018, through March 23, 2019) were then dropped from the study's final sample because these cases did not have adequate data to create accurate surgeon familiarity metrics (as this would have required data from cases performed between October 7, 2018, through December 29, 2018). This resulted in a reduction of 824 NES cases, for new subtotal of 9,432 NES cases.

Additionally, the organization's NES surgical quality reporting team overseeing the database for IRB #: 15-006838, had not completed the month-end December 2021 analyses at the time of this dissertation's final data extraction. As a result, the NES cases occurring between December 1, 2021, through December 31, 2021, were dropped from the sample. This was a reduction of 278 NES cases, creating a new subtotal of 9,154 NES cases that were performed between March 24, 2019, through November 30, 2021.

Further analysis and data scrubbing were required before the study's sample could be finalized. After gathering input from several NES leaders at this organization, it was determined that every NES case requires a minimum of four people covering distinct critical roles: 1.) surgeon, 2.) anesthesia personnel (anesthesiologist and/or CRNA), 3.) surgical assisting (typically fulfilled by fellow, resident, physician assistant, nurse practitioner, nurse, or surgical technician), and 4.) room circulator (typically fulfilled by nurse or surgical technician). Thus, NES cases in the data set with three or less unique persons were removed, as this indicated the case had additional missing personnel entries. This resulted in a reduction of 105 cases for a new finalized sample total of 9,049 NES cases with 94,123 individual entries, and 642 post-operative complications. Table 1 illustrates the sample determination steps leading to the final data sample that was used for the regression analyses within this dissertation.

[*NOTE: INSERT TABLE #1 HERE - CENTERED ALIGNMENT*]

Research Variables and Descriptive Statistics

The study consists of two separate empirical analyses, both of which were conducted through IBM's SPSS© software system: 1.) a multiple linear regression with ordinary least squares estimation to assess case scheduling errors, and 2.) a binary logistic regression for 30-day post-operative complications. In addition to the two dependent variables (separately analyzed), the regression analyses incorporate both independent variables (case continuity and surgeon familiarity) and fourteen control variables, which are consistent across both analyses. Table 2 provides the complete list of all variables and respective definitions. Figure 7 illustrates the definitions and timing thresholds of a surgical case's three distinct phases: "PRE" phase (duration between "wheels-in" time stamp to "cut" time stamp), "INTRA" phase (duration between "cut" time stamp to "close" time stamp), and "END" phase (duration between "cut" time stamp to "wheels-out" time stamp). Table 3 outlines the descriptive statistics for each variable within the study. In order to test all four hypotheses and better interpret the results, all continuous variables are standardized by scaling the measurements on a 0 to 1 range (summarized within Table 3 for the descriptive statistics).

[*NOTE: INSERT TABLE #2 HERE - CENTERED ALIGNMENT*]

[*NOTE: INSERT FIGURE #7 HERE - CENTERED ALIGNMENT*]

[*NOTE: INSERT TABLE #3 HERE - CENTERED ALIGNMENT*]

After exploring and evaluating the independent and control variables, the final sample had a recorded count of 1,222 unique individuals (see Table 4) and 222 different types (determined by the case posting description/title) of NES procedures. Table 5 reflects the sample's counts of NES procedures with 100 or more cases. Figure 8 reflects the distribution of the actual case durations for the 9,049 NES cases within the final sample. The following sections provide comprehensive details on the three variable types within the study: dependent variables, independent variables, and control variables.

[*NOTE: INSERT TABLE #4 HERE - CENTERED ALIGNMENT*]

[*NOTE: INSERT TABLE #5 HERE - CENTERED ALIGNMENT*]

[*NOTE: INSERT FIGURE #8 HERE - CENTERED ALIGNMENT*]

Dependent Variable I: Operational Performance – Case Scheduling Errors

The first regression analysis within this study focuses on how the surgical team dynamics of case continuity and surgeon familiarity impact case scheduling errors (proxy for operational performance). The dependent variable of case scheduling errors is calculated as the ratio between the case's actual duration (actual "wheels-in" time stamp to actual "wheels-out" time stamp) and the case's scheduled duration (planned "wheels-in" time stamp to planned "wheels-out" time stamp). This ratio measurement is a continuous variable and recorded as a percentage.

A case's scheduled duration is finalized by the surgeon, but the initially proposed case duration can be set by several members of the surgeon's support team, such as a nurse practitioner, physician assistant, clinic nurse, surgical scheduler (recommending based on the case type and previous durations), fellow, and/or resident. With the adoption of EHR technology, many surgical modules will analyze a surgeon's historical case log and propose a recommended scheduled duration for the case. Many surgeons leverage this EHR recommendation function (and proceed with the recommended duration), others will review the recommended duration and then modify based on patient-specific clinical factors, and some will not utilize the EHR recommendation. Regardless of the mechanism for establishing the case's scheduled duration, the final approval comes from the surgeon. The case's actual duration is determined by the accuracy of the room (OR) circulator's recordkeeping throughout the case's key phases. Failure to accurately record time stamps can impact the case's actual duration, thus impacting the case scheduling errors metric. The later sections of this dissertation briefly highlight opportunities to introduce radio frequency identification (RFID) capabilities into the OR setting for improvements in analytical reporting. Figure 9 reflects the distribution of case scheduling errors for the 9,049 NES cases.

[*NOTE: INSERT FIGURE #9 HERE - CENTERED ALIGNMENT*]

Dependent Variable II: Clinical Outcomes – Post-Operative Complications

Clinical outcomes and surgical quality are of critical importance within the OR environment. For this study's second regression analysis, the dependent variable is 30-day post-operative complications (proxy for clinical outcomes), which is recorded in the final sample as a binary (dummy) variable (i.e., recorded as 1 if the patient had a post-operative complication within 30-days of the NES surgical procedure). The metric of 30-day post-operative complications is a standard surgical quality measurement that is endorsed by the American College of Surgeons (ACS) and its National Surgical Quality Improvement Program (NSQIP), as it follows patients through a 30-day post-operative timeframe window to record all complications and deaths (Belmont et al., 2011). ACS NSQIP is successfully leveraged across multiple prognostic studies pertaining to many surgical subspecialties and continues to surface in recent literature (Cohen et al., 2009). As mentioned earlier, post-operative complications carry significant financial costs for hospitals. A study by Dimick et al. (2004) found that median hospital (inpatient) costs were $4,487 for patients not experiencing a 30-day post-operative complication, whereas patients with a minor and a major 30-day post-operative complication observed costs of $14,094 and $28,356, respectively.

Within the constructs of this dissertation, the final sample contained 642 NES cases where the patient experienced a 30-day post-operative complication. The three most common post-operative complications were blood transfusion (185 cases; 28.8%), seizure (97 cases; 15.1%), and urinary tract infection (66 cases; 10.2%). Patients who experienced more than one post-operative complication were only counted once within this study's final sample and the patient's first recorded post-operative complication description was the one captured within the data set. Table 6 reflects the counts and descriptions of the 642 post-operative complications (out of 9,049 cases).

[*NOTE: INSERT TABLE #6 HERE - CENTERED ALIGNMENT*]

Independent Variables – Case Continuity and Surgeon Familiarity

Surgical team dynamics are this study's independent variables of interest, which are represented by two proxies: case continuity and surgeon familiarity. Both independent variables follow consistent case measurement definitions: actual duration, scheduled duration, “PRE” phase duration, “INTRA” phase duration, and “END” phase duration (as previously outlined in Figure 7).

For testing H1 and H3, case continuity is recorded as a composite score consisting of compiled weighted percentages from three distinct measurements gathered throughout the surgical case’s “PRE” phase, “INTRA” phase, and “END” phase. This is calculated through three separate steps. Firstly, the roster of all surgical team members participating in the case’s “PRE” phase are captured. Then the “INTRA” phase’s total OR minutes are examined to analyze what percentage of these “INTRA” OR minutes are attributed to team members who were involved in the case’s “PRE” phase. Secondly, the members participating in the “INTRA” phase are captured. Then the “END” phase’s total OR minutes are examined to determine what percentage was attributed to team members involved in the case’s “INTRA” phase. Lastly, the “END” phase’s OR minutes are reviewed again, but this time for determining what percentage of these “END” phase OR minutes are attributed to team members who were involved in the case’s “PRE” phase. These three percentages are then utilized to create a weighted composite percentage score ranging from 0 to 1, with 0 representing poor (worst) case continuity and 1 representing strong (best) case continuity. The details of this calculation process are illustrated in Figure 10 and the distribution of case continuity scores from the final sample are reflected in Figure 11.

The focused measurements of OR performance across a case’s “PRE” phase, “INTRA” phase, and “END” phase are common throughout surgical practices, but the terminology can vary based on the institution. For example, a study by Myers et al. (2022) classified the “PRE” phase and “END” phase of a surgical case as fixed operating room times and found that fixed OR time makes up a significant portion of a specific type of urologic procedure (holmium laser enucleation of prostate). Similarly, research by Geldmaker et al. (2022) provided supporting evidence that a significant percentage of total OR time for robot-assisted urologic procedures is linked to fixed OR time and should be incorporated into OR efficiency analyses. This study also found that the number of anesthesia providers per case and time of day for the case did not negatively impact fixed OR times in urologic robotic surgeries (Geldmaker et al., 2022).

The example highlighted in Figure 10 demonstrates how incorporating the degree of participation provides heightened levels of accuracy in calculating case continuity. Measuring each person's participation by his/her actual OR minutes recorded for the surgical case, offers a stronger representation of the person's involvement, rather than a simplified count of the event/interaction occurring (i.e., binary answer of participating or not participating). In analyzing the first element of the case continuity score, Figure 10 illustrates the team members who participated in the "PRE" phase (30-minute duration) of the case. Persons A, B, C, D, E, F, G, and H (total of eight individuals) were recorded as participating in the "PRE" phase, but only person A, B, C, D, E, and F participated in the case's "INTRA" phase (60-minute duration). During the "INTRA" phase, four new people joined the case (for a total of ten individuals recorded in the "INTRA" phase). This is reflected with persons I, J, K, and L showing as gray-shaded (with italics), and persons A, B, C, D, E, and F showing as black-shaded. If case continuity were to be calculated through a person count metric, the results would show that 60% of the team members participating in the "INTRA" phase also participated in the "PRE" phase—which would be a true statement.

However, if the objective is to increase accuracy by incorporating the degree of participation (engagement), then calculating the actual OR minutes each person recorded in the “INTRA” phase would deliver a stronger statistic—in this example, it would be recorded as 75% participation by utilizing each person’s actual OR minutes. Below each person icon (in Figure 10), the small numeric value represents that person’s respective OR minutes for the “INTRA” phase of the case. For example, Person ‘A’ participated in 30 minutes (50% of the “INTRA” phase duration), Person ‘B’ participated in 60 minutes (100% of the “INTRA” phase duration), Person ‘C’ participated in 5 minutes (8.3% of the “INTRA” phase duration), Person ‘D’ participated in 60 minutes (100%), Person ‘E’ participated in 60 minutes (100%), Person ‘F’ participated in 50 minutes (83.3%), Person ‘I’ participated in 35 minutes (58.3%), Person ‘J’ participated in 20 minutes (33.3%), Person ‘K’ participated in 25 minutes (41.6%), and Person ‘L’ participated in 10 minutes (16.6%). As reference earlier, this analytical process is repeated for the remaining two calculation segments and those values are incorporated into a weighted composite score, which is reflected in the gray-shaded box at the bottom of Figure 10. For this specific example, the case continuity score would be 55.0% if utilizing a person count methodology. However, using each person’s actual OR minutes would result in a case continuity score of 58.7%. Within this dissertation, each NES case (total of 9,049 cases) has a case continuity score that is built on the individual person’s actual OR minutes (not interaction counts).

[*NOTE: INSERT FIGURE #10 HERE - CENTERED ALIGNMENT*]

[*NOTE: INSERT FIGURE #11 HERE - CENTERED ALIGNMENT*]

Surgeon familiarity is calculated by taking the surgeon's total OR minutes performed over the past 12 weeks (84 calendar days; includes weekend days in this timeframe) and then calculating how many of those OR minutes recorded participation from each respective team member who is supporting the present-day case. This surgeon familiarity metric is also recorded as a weighted composite percentage score ranging from 0 to 1, with 0 representing poor (worst) surgeon familiarity and 1 representing strong (best) surgeon familiarity. Figure 12 showcases this study's comprehensive calculation process for surgeon familiarity. Following the example (in Figure 12), the surgeon's current case (shown as "Case #21" performed on April 30, 2020) had an actual duration of 120 minutes, and the data recorded Person 'E' as participating in 80 minutes (66.6% of the case), Person 'I' participating in 35 minutes (29.1% of the case), and Person 'N' participating in 25 minutes (20.8% of the case). Looking retrospectively at the previous 84 days (12-week timeframe), the surgeon performed a total of 20 cases that equated to 5,509 OR minutes. Person 'E' participated in 10 of those 20 cases, for a total of 2,193 OR minutes (39.8%). Person 'I' also participated in 10 of those 20 cases, but only for a total of 414 OR minutes (7.5%; signaling small interactions for each case). Person 'N' participated in 8 of those 20 cases, for a total of 1,654 OR minutes (30.0%). These total percentages of each person's past 84 days of OR participation are then multiplied by each person's participation percentage for the current case ("Case #21"). This generates a weighted percentage for each person (on the current case's surgical team), which are then summed to create a composite score, which is 2.356 in the example of Figure 12. The composite score (2.356) is then divided by the sum of each person's current case percentage, which is 5.791 for this example. Thus, the surgeon familiarity score for this surgeon's current case ("Case #21" on April 30, 2020) is 0.406 (highlighted in the gray-shaded box). Figure 13 illustrates the distribution of surgeon familiarity scores for this study's sample.

[*NOTE: INSERT FIGURE #12 HERE - CENTERED ALIGNMENT*]

[*NOTE: INSERT FIGURE #13 HERE - CENTERED ALIGNMENT*]

This surgeon familiarity metric is sufficient for testing H4, but a second measurement of surgeon familiarity is required for accurately testing the 'U' shaped curvilinear relationship posited in H2. A second metric is generated by squaring the surgeon familiarity metric (reflected as "Surgeon Familiarity^2" in Table 9). This allows for analyzing the significance of the 'U' shaped curvilinear relationship in the results for Model 1 (multiple linear regression).

Control Variables

There are several control variables that are leveraged (consistently) for the two analyses within this study. The control variables include: surgeon's last case of the day (when the surgeon is performing more than one case on that respective day), long case duration (case duration of 180 minutes or more), performed during a COVID-19 pandemic surge timeframe (specific to each Arizona and Florida location), case started late (five or more minutes after the scheduled “wheels-in” time), number of NES cases occurring in parallel while the current case was being performed, case was performed (started) on a weekend date, patient’s age, patient’s gender, patient’s race, number implants used for the surgical treatment/intervention, combination case (more than one attending surgeon operating), number of anesthesiologists participating (3 or more anesthesiologists), case was started in the morning (case started between 6:00 AM to 11:59 AM), and patient ASA physical classification score. As mentioned earlier, the detailed descriptions of these control variables are presented in Table 2. For the physical status classification scores from the American Society of Anesthesiologist (ASA), Table 7 provides the background, descriptions, and sample’s case counts. The following sections provide comprehensive details explaining the statistical and situational relevance of the regression results and Table 8 reflects the correlations for the study’s variables.

[*NOTE: INSERT TABLE #7 HERE - CENTERED ALIGNMENT*]

[*NOTE: INSERT TABLE #8 HERE - CENTERED ALIGNMENT*]

ANALYSIS AND RESULTS

Table 9 displays the results for both the multiple linear (Model 1 – case scheduling errors) and logistic (Model 2 – post-operative complications) regression models. It is important to note that the negative coefficients (reflected in Table 9) for the independent and control variables, represent a favorable relationship with the dependent variables (case scheduling errors and post-operative complications). For example, the negative coefficient for the control variable of combo case ($p < 0.01$) means that if the current case is a combo case (two attending surgeons involved in the case), then there is a decrease in case scheduling errors. This would be an anticipated outcome from an operational context (translating this into a managerial perspective), as combo cases traditionally require heightened levels of planning and coordination because two attending surgeons are performing key maneuvers within the case. Each attending surgeon usually has planning oversight and authority over specific points during the case. These added complexities typically result in OR supervisors conducting extra reviews when planning the case's scheduled duration, thus resulting in less case scheduling errors. On the contrary, a positive coefficient represents an unfavorable relationship with the dependent variables. For example, the positive coefficient for the control variable of parallel cases ($p < 0.01$) means that increasing the number of parallel NES cases occurring at the same time of the current case (across the collective OR environment during that timeframe on that particular day) increases case scheduling errors.

For H1 and H2, a multiple linear regression with ordinary least squares estimation was used to test if the team dynamics of case continuity and surgeon familiarity have an impact on case scheduling errors. The overall regression for Model 1 was statistically significant (*R Square* = 0.075, *Adjusted R Square* = 0.073, p <0.001), suggesting that 7.5% of the variance in case scheduling errors is explained by these two independent variables (case continuity and surgeon familiarity). H1 is supported, as the regression results show that increased case continuity decreases case scheduling errors ($\beta = -0.059$, $p < 0.001$). To test H2 and the hypothesized 'U' shaped curvilinear relationship, the squared term of the surgeon familiarity variable was incorporated. Recognizing this need for two surgeon familiarity measurements to test for the 'U' shaped curvilinear relationship, the variables of surgeon familiarity and "surgeon familiarity squared" demonstrated support for H2 (reflected in Table 9). The findings show that increased surgeon familiarity decreases case scheduling errors to a certain threshold, as reflected with the surgeon familiarity variable ($\beta = -0.015$, $p < 0.05$). However, after crossing that threshold, surgeon familiarity then begins to have an adverse effect by increasing case scheduling errors, as displayed through the output and greater significance with the "surgeon familiarity squared" variable ($\beta = 0.060$, $p < 0.001$).

In addition to the findings centering on case continuity and surgeon familiarity, the results (presented in Table 9) highlight other significant relationships between several control variables and case scheduling errors. The following control variables had an impact of decreasing case scheduling errors: 1.) patient age, 2.) patient gender (being reported as female), 3.) surgeon's last case of the day (when the day consisted of more than one surgical case), 4.) combo case (more than one attending surgeon in the case), and 5.) case had a longer duration (greater than 180 minutes). The following control variables had an impact of increasing case scheduling errors: 1.) ASA physical status classification score, 2.) surgeon used more than 10 implants in the case, 3.) case was performed during a COVID surge timeframe (see Table 2 for specific COVID surge timeframes by campus), 4.) case started late (started more than 5 minutes past the scheduled start time), 5.) number of parallel NES cases occurring at the same timeframe of the current case, 6.) more than two anesthesiologists participated in the case, and 7.) case was started in the morning (between 6:00 AM to 11:59 AM). Additional commentary on the managerial implications of these control variable findings is shared in the final section.

[*NOTE: INSERT TABLE #9 HERE - CENTERED ALIGNMENT*]

For H3 and H4, a binary logistic regression was used to analyze the effect of the same two predictor variables, case continuity and surgeon familiarity, on the probability of the patient experiencing a post-operative complication within 30-days of the surgery. Model 2 (see Table 9) was statistically significant (*Chi-Square* = 229.801, *df* = 16, *n* = 9,049, $p < 0.001$), suggesting that it could distinguish between those with and without the predictor variables or that the fit of the model improved with those predictor variables added. The model explained between 2.5% (*Cox & Snell R Square*) and 6.3% (*Nagelkerke R Square*) of the variance within the dependent variable of post-operative complications, and correctly classified 92.9% of cases. As shown in Table 9, case continuity and surgeon familiarity significantly contributed to the model. H3 is supported, as the results found that, holding other predictor variables constant, the odds of post-operative complications decreased by 57% (95% *CI* [.34, .96]) for each unit increase in case continuity. Similarly, H4 is supported, as the results also found that, holding other predictor variables constant, the odds of post-operative complications decreased by 36% (95% *CI* [.13, 1.02]) for each additional unit of surgeon familiarity.

In addition to the independent variable findings, the results of the binary logistic regression present valuable insight on other relationships between several control variables and post-operative complications. The following control variables had an unfavorable impact of increasing the odds of a patient experiencing a post-operative complication within 30-days of the surgery: 1.) ASA physical status classification score, 2.) surgeon used more than 10 implants in the case, and 3.) case was performed on a weekend date (started on a Saturday or Sunday). These findings are to be expected because they represent critical clinical factors. The control variable of case started in the morning (between 6:00 AM to 11:59 AM) had a favorable impact of decreasing the odds of a patient experiencing a post-operative complications within 30-days of the surgery. Additional commentary on the managerial implications of these control variable findings is shared in the final section.

ROBUSTNESS CHECKS

This section describes two robustness checks that were conducted to address concerns that might potentially affect the empirical validity of this study's results.

Alternate Measures of Case Continuity and Surgeon Familiarity

This dissertation aims/intends to contribute to established theories by going beyond the count-based methodology to capture case (task) continuity and surgeon (team) familiarity, even though past studies have traditionally employed count-based metrics. To validate these theoretical contributions, this study deployed count-based metrics (focused counts of occurrences/episodes), instead of operationalizing case (task) continuity and surgeon (team) familiarity by measuring the personnel's degree of participation (engagement) within the current research models.

Specifically, the regressions for Model 1 (case scheduling errors) and Model 2 (post-operative complications) were repeated with count-based metrics for case continuity and surgeon familiarity, *ceteris paribus*. The regression results with count-based metrics were consistent with the regression results from the degree of participation metrics/models (using the personnel's actual OR minutes to quantify participation), as shown in Table 10. Both models were still statistically significant. For case scheduling errors, H1 was supported (case continuity, $\beta = -0.052$, $p < 0.001$), as was H2 (surgeon familiarity, $\beta = -0.026$, $p < 0.001$; surgeon familiarity squared, $\beta = 0.048$, $p < 0.001$). For post-operative complications, H3 was supported as the odds of post-operative complications decreased by 61% (95% CI [.39, .97]) for each unit increase in case continuity. H4 was also supported, as the odds of post-operative complications decreased by 25% (95% CI [.10, 0.58]) for each additional unit of surgeon familiarity.

Inflection Point for 'U' Shaped Curvilinear Relationship

While intriguing, it could be a concern that the 'U' shaped curvilinear relationship may be caused by a few extreme observations (cases) within the sample. To appropriately evaluate the validity of the 'U' shaped curvilinear relationship for H2, additional calculations were conducted to assess the curve's inflection point. There are 91 cases with a case scheduling error ratio within the first percentile of the total sample (9,049 cases), which represents the least (smallest) case scheduling errors (i.e., the case's actual duration matched or was closest to the case's scheduled duration). For these 91 cases, the average surgeon familiarity score is 0.381, with an average percentile of 0.458. The case with the lowest case scheduling error ratio has a surgeon familiarity score of 0.379, which is within the sample's forty-eighth percentile for all surgeon familiarity scores.

Similarly, there are 91 cases with a case scheduling error ratio within the ninety-ninth percentile of the total sample, which represent the greatest (largest) case scheduling errors (i.e., the case has the largest difference/variance between the actual duration and scheduled duration). These 91 cases are then sorted by surgeon familiarity score from largest to smallest, to create an upper cohort of 45 cases (consisting of the larger surgeon familiarity scores within the ninety-nineth percentile) and a lower cohort of 46 cases (consisting of the smaller surgeon familiarity scores within the ninety-nineth percentile). The upper cohort has an average surgeon familiarity score of 0.429, with an average percentile of 0.676. The lower cohort has an average surgeon familiarity score of 0.312, with an average percentile of 0.194. These calculations provide further support for H2 and validation of the ‘U’ shaped curvilinear relationship between case scheduling errors and surgeon familiarity.

DISCUSSION

As the healthcare industry continues its journey through new and old challenges, the focus on sustaining and improving surgical practices remains constant. Surgical practices are recognized for possessing strong influence over patient referral patterns, public reputation/prominence, and financial performance. Healthcare executives and surgical leaders should strive for evidence-based insights on the importance of how team dynamics can impact an OR environment's operational performance and clinical outcomes. With no indications of deteriorating interest, surgical practices will continue to be a primary focus in the research literature across medical and operational fields.

Previous literature offers mixed and incomplete results on themes of team familiarity and OR efficiency, frequently citing handoffs, late starts, and task disruptions as catalysts for negative performance. Studies routinely use historical interaction counts to measure team familiarity, which neglects the degree of participation (prior engagement) with the surgeon. Similarly, counts of handoffs or individuals entering (exiting) an OR do not offer an accurate assessment of team performance. Ample opportunity remains to further investigate the numerous complexities and evolving elements occurring in an operating room, which leads to this study's main research question: Do surgical team dynamics impact OR operational performance and clinical outcomes?

The study aims to advance the research fields of operations management and information systems management by delivering empirically validated results that center on the elements of case continuity and surgeon familiarity (proxies for surgical team dynamics) and the relationships with case scheduling errors (proxy for operational performance) and post-operative complications (proxy for clinical outcomes). Guided by historical findings, this study presents four hypotheses and argues that enhancing surgical team dynamics will yield favorable improvements for operational performance and clinical outcomes. Utilizing data from 9,049 neurologic surgery cases performed at two separate campuses (belonging to the same organization) over a three-year timeframe (March 2019 to November 2021), this study examines highly complex settings and critical control variables to better understand case continuity, surgeon familiarity, case scheduling errors, and post-operative complications.

Overall, the results of the linear and logistic regression analyses provide support for all four hypotheses. The results showcase how increased case continuity decreases case scheduling errors (H1) and post-operative complications (H3). Similarly, surgeon familiarity decreases post-operative complications (H4). Evidence of a ‘U’ shaped curvilinear relationship is presented for surgeon familiarity and case scheduling errors (H2). This suggests that surgeon familiarity decreases case scheduling errors to a certain point, and then begins to have an adverse effect by increasing case scheduling errors as teams become too familiar with the surgeon. Managerial-based explanations for this phenomenon point to over-familiar surgical teams demonstrating over-confidence that can lead to incorrect assumptions or inaccurately anticipating certain aspects of the case.

The findings within this study provide valuable insight into surgical team dynamics and the critical connections with operational performance and clinical outcomes, which have varying theoretical and managerial implications. Acknowledging lower coefficients within both regression models, this study intends to deliver directional insight on case continuity and surgeon familiarity, and the influences on case scheduling errors and post-operative complications. However, these coefficients are relevant to hospital executives, physician leaders, and nursing leaders, as they highlight opportunities to introduce action plans (controls) for new OR team improvements by incorporating metrics of case continuity and surgeon familiarity into OR staffing schedules and daily workflows.

It is important to recognize and underscore that these analyses do not incorporate findings from medical research pertaining to the nuances of patient-specific health factors. The only proxy for patient-specific health factors included in this study is the ASA score associated with each NES case. For example, a patient weighing 500 pounds with complex cardiac issues, but receiving a spinal fusion procedure, is going to have much greater variation, complexities, and vulnerability than the otherwise healthy 32-year-old patient who is getting the same spinal fusion procedure. While obesity is included in the criteria for the ASA physical status classification score, there are other patient-specific medical variations (and health factors) that are underrepresented in this study’s models. However, due to the fact that patient-specific health factors are assumed constant throughout the data set, it is appropriate to interpret the results as having a broader viewpoint on the impacts of surgical team dynamics.

Theoretical Contributions

There are four main theoretical contributions presented through the results of this study: 1.) expanding on the impacts/implications of hierarchal familiarity, 2.) offering a new holistic measurement approach on task continuity (via proxy of case continuity), 3.) supporting evidence on team performance in highly complex environments, and 4.) reinforcing existing literature on the ‘U’ shaped curvilinear relationship between team familiarity and operational performance (via proxy of case scheduling errors).

As highlighted in the study by Staats (2012), team familiarity is an important underlying element of team performance. Hierarchical familiarity provides valuable insight on *which* team members have worked together, whereas most of the existing literature on team familiarity centers on *whether* team members have worked together. Staats’ (2012) research findings demonstrate that hierarchical familiarity had a greater impact on a project’s (team’s) efficiency. Increases in hierarchical familiarity may lead to enhanced communication and information sharing that improves team performance. This dissertation applies Staats’ (2012) framework into the operational performance metric of surgeon familiarity. This study’s regression results reflecting surgeon familiarity impacts on case scheduling errors (operational performance) and post-operative complications (clinical outcomes) provide additional support that future research studies focusing on team familiarity should incorporate elements of hierarchical (surgeon) familiarity.

Multiple studies have delivered evidence of a ‘U’ shaped curvilinear relationship (inverted or regular) between team familiarity and team (operational) performance (Berman et al., 2002; Wise, 2014; Sieweke & Zhao, 2015; Koopman et al., 2016; Luciano et al., 2018; Xie et al., 2020; Muskat et al., 2022). The multiple linear regression results from this study’s analysis on surgeon (team) familiarity and case scheduling errors (proxy for operational performance) were statistically significant and provide further evidence of a ‘U’ shaped curvilinear relationship (surgeon familiarity, $\beta = -0.015$, $p < 0.05$; surgeon familiarity-squared, $\beta = 0.060$, $p < 0.001$). These contributions should be included in future literature reviews pertaining to team familiarity and team performance.

While team familiarity and hierarchical familiarity are frequently calculated through encounter/episode counts of prior work experience, this dissertation study's offers new insight into opportunities for strengthening familiarity metrics by incorporating the degree (level) of participation (engagement) associated with each encounter. While many operations management studies do not have access to data that accurately, consistently captures the degree of participation, researchers should strive to pursue these measurements to strengthen the empirical evidence with the analyses.

Prior literature on task continuity and minimizing disruptions within the OR setting have delivered mixed results (as previously stated in the literature review section). These mixed results are often a byproduct of many interconnected variables that interact simultaneously during a surgical case. This dissertation builds on the task continuity frameworks stemming from several studies (Kodali, 2014; Henaux et al., 2019; O'Leary et al., 2012) and advances the scientific measurement of case continuity by including the degree of participation of each team member involved in the case. While encounter/episode counts provide valuable insight into the implications of task continuity on team performance, researchers should expand these model metrics to encompass the degree (level) of participation throughout the task. The findings of this dissertation offer contributions to crew resource management (CRM) and task familiarity. The team continuity measurements in this study highlight how the collective team moves through various phases together (or separated)—through the "PRE" phase to the "INTRA" phase to the "END" phase (as showcased in Figure 10).

Professional healthcare careers possess varying degrees of pressure, complexity, and stress. Surgical practices provide service-line coverage across all settings—surgical, hospital (inpatient), clinic (outpatient), emergency departments, and digital (virtual) care. Neurologic surgery is one of the more highly complex OR settings across surgical subspecialties. Not only does the actual complexity of the environment impact the team's task, but the team members' (situational) awareness of the complex environment also has an influence (Salas et al., 1995). This dissertation's research findings offer additional support and insight into team performance within a highly complex environment.

Managerial Implications

While applicability may vary based on the surgical practice settings and organizational characteristics, this study presents four key themes for managerial implications: 1.) incorporating elements of team dynamics into staffing model analytics to improve team performance (particularly into staffing development plans, assignment schedules, and case scheduling), 2.) understanding the impacts of case continuity, 3.) proactively monitoring surgeon familiarity across surgical teams to identify impacts on case scheduling errors and post-operative complications, and 4.) acknowledging the need to examine other patient-specific and environmental factors (study's control variables) within the OR setting.

The regression results provide compelling evidence/support that healthcare executives and practice leaders should include elements of team dynamics (case continuity and surgeon familiarity) when formulating OR improvement tactics. These team dynamics can impact operational performance and clinical outcomes. Embedding metrics of surgical team dynamics into operational analytics can yield important gains in staffing assignment schedules and larger staffing model redesign efforts. OR leaders (managers and supervisors) can apply this study's metrics by implementing systematic reviews of case continuity scores and surgeon familiarity scores to better understand the implications on operational performance and clinical outcomes. These evidence-based metrics can guide staffing schedules to ensure an appropriate balance between efforts of cross-coverage training for OR teams and establishing team familiarity. Enhanced reporting analytics should be transparent and utilized for engaging key stakeholders in process improvement activities to better support the complex OR environment for staff and patients. Further analysis is required to calibrate this study's findings to any specific surgical practice.

Case continuity had an inversely related (favorable) impact on case scheduling errors and post-operative complications. Acknowledging its importance, OR supervisors should generalize this study's findings and measure case continuity on a consistent basis when targeting initiatives to improve surgical performance. For example, towards the end of the OR workday, some surgical cases will run longer than the OR's prime-time hours of operation. In this study, the organization's prime-time hours of operation are 7:30 AM to 5:00 PM on every weekday (with Mondays starting 8:30 AM to allow for educational sessions and various staff meetings). As the end-of-day approaches in the OR setting, many practices with have a "release list" that is overseen by the OR supervisor(s). This list indicates the sequencing of which staff are to be released from the workday shift as surgical cases conclude. The cases that are still operating beyond prime-time hours will typically experience a greater level of handoffs and staffing exchanges in an attempt to release certain staff members who might need to flex hours or have requested an on-time release from the workday shift for personal reasons. Based on the case continuity results, these frequent staffing exchanges and end-of-day handoffs should be minimized to improve operational performance and clinical outcomes. This does not mean that timely shift changes should be ignore by OR leaders. Instead, a proactive staffing model plan needs to be implemented in the days leading up to the actual OR day to ensure that these staffing factors are accounted for.

Similar to the implications of case continuity, prospective analyses on surgeon familiarity should be incorporated into managerial responsibilities within the OR settings. Surgeon familiarity scores should be recorded and studied across the practice's surgical volume. This study's findings on surgeon familiarity indicate that healthcare executives and practice leaders should acknowledge the value of familiar (consistent) teams and staffing levels. The COVID-19 pandemic generated a surge of temporary workers entering various clinical settings, including the ORs. These travelers, contracted labor, and locum tenens (all temporary workers), do not possess the levels of surgeon familiarity that are reflected across the organization's established staff members. This is further evidence of how vital staff retention and organizational loyalty are for the OR setting. While the COVID-19 pandemic created unprecedented levels of staffing pressure on organizations (staff illness, quarantine protocols, contact tracing high exposure risks, etc.), temporary workers were a necessary short-term tactic employed by many surgical practices. However, opportunities exist for organizations to utilize analytics on team (surgeon) familiarity to better assess which staffing assignments are best suited for temporary workers, such as introducing a new temporary worker into a well-established surgical team that already possesses high surgeon familiarity. Two critical managerial questions remain: 1.) Is there a surgeon familiarity score/threshold where the case should be a “no-go” decision? 2.) What are the appropriate thresholds of surgeon familiarity that OR managers should aim for when designing assignment schedules?

As highlighted in the multiple linear regression analysis, the ‘U’ shaped curvilinear relationship between surgeon familiarity and case scheduling errors should be accounted for by OR supervisors when generating staffing assignment schedules. Teams with too much familiarity carry a risk of decreasing operational performance. However, recognizing that surgeon familiarity decreases (favorably reduces the risk of) post-operative complications, surgical practice leaders are presented with the scenario of balancing varying degrees of surgeon familiarity across many teams for optimal output. Many leaders will assess this as a “quality vs. operational efficiency” situation and quickly side with maximizing surgeon familiarity for better clinical outcomes. However (and while often controversial), it is important for leaders to not immediately dismiss the influence that operational performance has on the organization’s financial performance (Bacchetta et al., 2005; Nundy et al., 2008; Allen et al., 2016).

Although this dissertation’s study focused on the independent variables of case continuity and surgeon familiarity, OR leaders can extract key findings and valuable insights from the regression results pertaining to the control variables. As one would expect, the logistic regression analysis demonstrated that critical clinical factors have an unfavorable impact on post-operative complications. Specifically, the control variables of ASA physical status classification score, ten or more implants used in the case, and the case being performed (started) on a weekend date, all have statistically significant impacts ($p < 0.001$). However, the ASA score and weekend OR date did not have statistically significant impacts on operational performance (case scheduling errors). This is largely due to the fact that the OR case scheduling teams usually account for these elements based on perioperative input from the surgeon (and/or the care teams).

Several control variables had an inverse (favorable) impact on case scheduling errors: patient age ($p < 0.05$), patient gender ($p < 0.01$), surgeon's last case of the day (when performing more than one case that day; $p < 0.01$), combo case (two attending surgeon performing the case; $p < 0.01$), and longer case duration (180 minutes or more; $p < 0.10$). Oppositely, the following control variables had a unfavorable impact by increasing case scheduling errors: ASA physical status classification score ($p < 0.10$), using ten or more implants in the NES case ($p < 0.01$), case started late (5-minutes or more past the scheduled "wheels-in" time; $p < 0.01$), case performed during a COVID-19 surge timeframe ($p < 0.10$), more than two anesthesiologists participating in the case ($p < 0.01$), case was started in the morning (between 6:00 AM to 11:59 AM; $p < 0.10$), and the number of parallel NES cases starting during the case's duration ($p < 0.01$). When aiming to improve operational performance, surgical practice leaders should incorporate several of these control variables into routine analytical reporting packages.

Study Limitations

There are several study limitations that must be acknowledged in this dissertation. First, although this is a multi-site study, the final sample of NES cases was only collected from one organization. This organization already demonstrates (and publishes on) some best practices by leveraging cross-trained subspecialization staff member cohorts embedded within the anesthesia team staffing schedules (anesthesiologists & CRNAs). Second, the physicians within this organizations are employed and have a fixed salary. This means that there is zero individual financial incentive for a surgeon to perform surgery unless it is truly the best course of clinical action for the patient. Third, this study does not incorporate a large range of individual patient-specific characteristics, thus it neglects to incorporate the full spectrum of delays and disruptions that can unfavorably impact OR operational performance and workflow efficiencies (i.e., a patient's preexisting conditions or physical factors – such as performing surgery on a patient weighing 500 lbs. vs. 150 lbs.). Last, the data collection encompasses various COVID-19 pandemic surges and many research articles have demonstrated that the changes/modifications in human behavior (patients, staff, healthcare professionals, etc.) are still being assessed. While timeframes of COVID-19 surges (based on hospitalization census) are incorporated within this study's control variables (binary dummy variable), it is important to recognize that the full magnitude of the COVID-19 pandemic is difficult to clearly quantify at this point in time.

While the amount of data captured through interoperative EHR systems and IT modules within the OR setting is quite extensive, many of these operational performance metrics are manually recorded by one (or several) members of the OR team, and many measures of subjective in nature. The ASA score is an example of a subjective metric (physical status classification, which encompasses many clinical factors, such as obesity) that is determined by the anesthesiologist. He/she follows a standard criteria during the perioperative evaluation of the surgical patient to decide if the patient has an ASA score of 1, 2, 3, 4 or 5. The surgical OR (room-specific) circulator is often staffed/fulfilled by a register nurse (RN), who is capturing data, biopsies, medications, and key time stamps throughout the case's duration. This study relies heavily on the accuracy of several key measures: "wheels-in" time stamps, "cut" time stamps, "close" time stamps, "wheels-out" time stamps, and the entry/exit time stamps for every team member participating in the surgical case. Automating time stamp recording mechanisms would elevate the accuracy of operational performance studies going forward.

The limitations (and error assumptions) of manual time stamp collections are consistently spread across all cases in similar OR environments. However, opportunity exists to implement automation, such as radio frequency identification (RFID) and other sensory capabilities to further reduce human error on data entry. A study by Buyurgan et al. (2009) examined RFID applications and provided a framework for the RFID capabilities currently deployed across the healthcare industry. Advancing healthcare supply chain logistics, quality/safety efforts, and proactive monitoring are key drivers fueling organizational investments in RFID as a mechanism to improve clinical practice workflows (Buyurgan et al., 2009).

Future Research Opportunities

There are several areas that are ripe for future research activity. Opportunities exist for further evaluation on each surgical team member's professional experience (i.e., practicing as a CRNA for two years versus twenty-five years; experience specific to this organization versus other external experience). Understanding variation pertaining to all team members' years of experience and interrelationships to specific OR roles (surgeons, anesthesiologists, CRNAs, nurses, surgical technicians, etc.) would provide valuable insight for guiding targeted retention strategies within Human Resources departments.

While this study focused on surgeon familiarity, an opportunity certainly exists to explore beyond the concept of hierarchical (surgeon) familiarity. Analyzing horizontal team familiarity (anesthesiologist-to-CRNA, CRNA-to-Tech, Nurse-to-Tech, etc.) would provide operational findings on the connections/teamwork between various dyads within the OR team. Efficiencies linked to the peripheral and core dyad pairings within the surgical team could offer valuable insight on additional drivers of efficiency and OR outcomes (Verhoeven, 2019). The coordination between the surgeon and the hospital (inpatient) team is another element that directly impacts patient outcomes. It would be interesting to examine elements of the hospital's patient census, hospital floor staffing ratios, timeliness of rehabilitation sessions (hospital rounding), and more. This would highlight key influences on a patient's recovery time between surgical intervention and hospital discharge.

Another intriguing research topic highlighted by this dissertation is the relationship between the current case's operational performance and the surrounding OR environment (both within the same surgical subspecialty, as well as total OR activity inclusive of other specialties). Assessing the surrounding activity outside of the individual case, such as the number of surgical cases being covered by the same anesthesiologist (in parallel) would build on the workload theories presented by KC et al. (2009). With a heavy dependence on partnerships and collaborative teamwork, the OR setting is prime environment for future research activity.

APPENDIX - TABLES

Table 1. Sample Determination

Step Description	**Cases**	**Entries**
Neurologic surgery (NES) cases performed at the organization's Arizona and Florida campuses during the fiscal years of 2019, 2020, and 2021. This operational performance data set includes case characteristics and individual team member entry data, which was pulled from EHR archival sources under IRB #21-010068.	10,609	110,377
Less NES cases where a team member's name was missing within the individual team member entry data fields.	262	552
Less NES cases that did not cross-reference/match with the clinical outcomes data, which was pulled from EHR archival sources under IRB #15-006838 (data does not contain individual team member entry data).	91	927
Less NES cases performed between December 30, 2018 through March 23, 2019, due to these cases not having access to complete data from the prior 84 days (prior 12-weeks) for accurately calculating surgeon familiarity. However, these cases were utilized for calculating the surgeon familiarity metric for cases performed between March 24, 2019, through June 15, 2019 (but then removed from the final sample).	824	11,028
Less NES cases between December 1, 2021, through December 31, 2021, as the organization's NES surgical quality reporting team (for IRB #15-006838) did not have the post-operative complication data completed at the time of this study's data extraction.	278	3,466
Less NES cases that had less than four people recorded for covering the critical roles required for a NES case, which signals missing individual entries for the case. Every NES case requires a minimum of four people covering distinct roles: 1.) surgeon, 2.) anesthesia personnel (anesthesiologist and/or CRNA), 3.) surgical assisting (typically fulfilled by fellow, resident, PA, NP, nurse, or surgical technician), and 4.) room circulator (typically fulfilled by nurse or surgical technician).	105	281
Final Sample	9,049	94,123

Table 2. Variable Definitions

Variable	**Type***	**Definition**
Patient Age	C	Patient's age (in years) at the date of the sugery.
Patient Gender	C	Binary (dummy) variable (recorded as 0 or 1), where 1 represents the patient's gender as female (as reported by the patient in his/her EHR demographic section).
Patient Race	C	Binary (dummy) variable (recorded as 0 or 1), where 1 means the patient's race is white (as recorded by the patient in his/her EHR demographic section). A patient reports his/her race based on eight options: American Indian or Alaska Native (n=53); Asian (n=174); Black or African American (n=536); Choose Not to Disclose (n=118); Native Hawaiian or Other Pacific Islander (n=20); Other (n=192); Unknown (n=54); White (n=7907).
ASA Score	C	Score of 1, 2, 3, 4, 5, or 6 (ordinal in SPSS). The American Society of Anesthesiologists (ASA) Physical Status Classification System has been in use for over 60 years. The purpose of the system is to assess and communicate a patient's pre-anesthesia medical co-morbidities. The classification system alone does not predict the perioperative risks, but when used with other factors (such as type of surgery, frailty, level of deconditioning, etc.), it can be helpful in predicting perioperative risks. While the Physical Status classification may initially be determined at various times during the patient's preoperative assessment, the final classification assignment is made on the day of anesthesia care by the anesthesiologist after evaluating the patient; See Table 4.
Last Case	C	Binary (dummy) variable (recorded as 0 or 1), where 1 represents the case is the surgeon's last case of the day when the surgeon has performed more than one case on that respective day.
Implants	C	Number of implants (devices) that were surgically placed in the patient during the case and remain in the patient after the surgical closure.
COVID Surge	C	Binary (dummy) variable (recorded as 0 or 1), where 1 means the case was performed on a date when the respective site (Arizona or Florida) was enduring a COVID-19 surge. COVID-19 surge timeframes are defined as dates when number of hospitalized COVID-19 patients accounted for more than 15% of the hospital census. The COVID-19 surge timeframes for each respective site are: • Florida: 6/14/20 to 8/24/20; 12/15/20 to 1/30/21; 7/9/21 to 9/15/21. • Arizona: 6/11/20 to 8/18/20; 11/20/20 to 2/12/21; 9/4/21 to 9/14/21; 11/20/21 to 12/15/21
Late Start	C	Binary (dummy) variable (recorded as 0 or 1), where 1 means the case started late, as defined by the recorded wheels-in time occurring 5-minutes (or more) after the posted scheduled start-time.

**Type: Control Variable = C; Independent Variable = I; Dependent Variable = D*

Table 2 (continued). Variable Definitions

Variable	**Type***	**Definition**
Combo Case	C	Binary (dummy) variable (recorded as 0 or 1), where 1 represents a surgical combination ("combo") case that involved more than one attending surgeon operating on the patient within the case's duration. Fellows and residents involved in a case with an attending would not be classified as a combo case.
Weekend	C	Binary (dummy) variable (recorded as 0 or 1), where 1 means the case was performed (started) on a weekend day (Saturday or Sunday). If a case started at 11:30 PM on Sunday and finished at 6:15 AM on Monday morning, this case would be recorded as a weekend case.
Parallel Cases	C	Number of NES cases happening in parallel (at the same site; Arizona or Florida) during the case's duration. Recognizing that NES staff have specialized skillsets, the surgical team sometimes cross-covers or is needed at key points and critical time intervals during a case (especially when there are more NES cases being performed by different surgeons within the same timeframe).
Anesthesiologists	C	Number of unique anesthesiologists participating in the surgical case. For example, if one anesthesiologist is participating in the case and he/she is relieved twice from the case, then that particular anesthesiologist only generates a unique person count of one.
Long Duration	C	Binary (dummy) variable (recorded as 0 or 1), where 1 means the case's actual duration (wheels-in to wheels-out) was 3 hours (180 min.) or more.
Morning Cases	C	Binary (dummy) variable (recorded as 0 or 1), where 1 means the case's actual start time (actual wheels-in time) occurred between 6:00 AM and 11:59 AM.

**Type: Control Variable = C; Independent Variable = I; Dependent Variable = D*

Table 2 (continued). Variable Definitions

Variable	**Type***	**Definition**
Case Continuity	I	Recorded as the composite score of compiled weighted percentages from the case's three phases: PRE (wheels-in to cut), INTRA (cut to close), and END (cut to wheels-out). Calculated through three steps: 1.) Roster of all surgical team members participating in the PRE phase are captured and then the INTRA phase's total OR minutes are analyzed to determine what percentage of the INTRA OR minutes are attributed to members involved in the PRE phase. 2.) Members participating in the INTRA phase are captured and then the END phase's total OR minutes are examined to determined what percentage of the END OR minutes are attributed to members involved in the INTRA phase. 3.) The END phase's total OR minutes are reviewed to determine what percentage of the END phase's total OR minutes are attributed to team members who were involved in the PRE phase. These three percentages are weighted to the actual minutes within the respective phase to create a composite score ranging from 0 to 1, where 0 represents poor case continuity and 1 represents excellent case continuity; See Figures 9-10.
Surgeon Familiarity	I	Calculated by taking the surgeon's total OR minutes performed over the past 12 weeks (84 calendar days) and then determining how many OR minutes each surgical team member (supporting the current case) participated in with the respective surgeon. Each team member's historical performance (over the past 84 days with the respective surgeon) is weighted to the degree of participation in the current case and factored into the surgeon familiarity score. Metric is recorded as a value between 0 to 1, with 0 representing poor surgeon familiarity and 1 representing perfect surgeon familiarity; See Figures 11-12.
Case Scheduling Errors	D	Proxy for operational performance. Variance between the case's actual duration (wheel-ins to wheels-out) and the case's scheduled duration, which is set by the surgeon. Metric is recorded as a percentage; calculated as the case's actual duration divided by the case's scheduled duration. A value less than 1.0 indicates the case finished earlier than expected, and a value greater than 1.0 indicates the case went longer than expected; See Figure 13.
Post-Operative Complications	D	Proxy for clinical outcomes. Binary (dummy) variable (recorded as 0 or 1), where 1 represents the patient experiencing a clinical complications (see Table 5) within 30 days of the surgical procedure. Post-operative complications are recognized by neurosurgical professional societies as an accurate metric for measuring surgical quality and clinical outcomes.

**Type: Control Variable = C; Independent Variable = I; Dependent Variable = D*

Table 3. Descriptive

Variable	**Mean (SE)**	**Standard Deviation**	**Min.**	**25th Percentile**	**Median**	**Mode**	**75th Percentile**	**Max.**	**Skewness (SE)**	**Kurtosis (SE)**	**n**
Patient Age	59.842 (0.165)	15.716	15.000	51.000	63.000	63.000	72.000	98.000	-0.674 (0.026)	-0.109 (0.051)	9,049
Patient Gender	0.480 (0.005)	0.500	0.000	0.000	0.000	0.000	1.000	1.000	0.078 (0.026)	-1.994 (0.051)	9,049
Patient Race	0.873 (0.003)	0.333	0.000	1.000	1.000	1.000	1.000	1.000	-2.245 (0.026)	3.043 (0.051)	9,049
ASA Score	2.573 (0.007)	0.646	1.000	2.000	3.000	3.000	3.000	5.000	0.005 (0.026)	0.093 (0.051)	9,049
Last Case	0.303 (0.005)	0.460	0.000	0.000	0.000	0.000	1.000	1.000	0.856 (0.026)	-1.266 (0.051)	9,049
Implants	4.829 (0.052)	4.977	0.000	0.000	4.000	4.000	8.000	36.000	1.456 (0.026)	2.989 (0.051)	9,049
COVID Surge	0.165 (0.004)	0.371	0.000	0.000	0.000	0.000	0.000	1.000	1.804 (0.026)	1.256 (0.051)	9,049
Late Start	0.372 (0.005)	0.483	0.000	0.000	0.000	0.000	1.000	1.000	0.530 (0.026)	-1.718 (0.051)	9,049
Combo Case	0.054 (0.002)	0.226	0.000	0.000	0.000	0.000	0.000	1.000	3.955 (0.026)	13.646 (0.051)	9,049
Weekend	0.021 (0.001)	0.142	0.000	0.000	0.000	0.000	0.000	1.000	6.739 (0.026)	43.436 (0.051)	9,049
Parallel Cases	3.046 (0.017)	1.595	0.000	2.000	3.000	3.000	4.000	11.000	0.474 (0.026)	0.621 (0.051)	9,049
Anesthesiologists	1.248 (0.007)	0.655	0.000	1.000	1.000	1.000	2.000	5.000	0.931 (0.026)	1.823 (0.051)	9,049
Long Duration	0.593 (0.005)	0.491	0.000	0.000	1.000	1.000	1.000	1.000	-0.378 (0.026)	-1.857 (0.051)	9,049
Morning Cases	0.680 (0.005)	0.467	0.000	0.000	1.000	1.000	1.000	1.000	-0.768 (0.026)	-1.411 (0.051)	9,049
Case Continuity	0.863 (0.001)	0.120	0.257	0.804	0.885	0.885	0.952	1.000	-1.160 (0.026)	1.516 (0.051)	9,049
Surgeon Familiarity	0.271 (0.001)	0.058	0.000	0.232	0.267	0.267	0.306	0.699	0.474 (0.026)	1.423 (0.051)	9,049
Case Scheduling Errors	1.118 (0.005)	0.446	0.061	0.854	1.058	1.058	1.299	8.767	2.982 (0.026)	25.630 (0.051)	9,049
Post-Operative Complications	0.071 (0.003)	0.257	0.000	0.000	0.000	0.000	0.000	1.000	3.342 (0.026)	9.177 (0.051)	9,049

(SE) = Standard Error

Table 4. Counts of Unique Persons and Total Entries by Role

Role Description	**Unique Persons**	**Total Entries**
Registered Nurse (RN)	350	24,658
Certified Registered Nurse Anesthetist (CRNA)	215	22,773
Surgical Technician (Tech)	289	21,291
Anesthesiologist	117	11,386
Surgeon	83	9,765
Resident	47	1,802
CRNA Student	60	761
Physician Assistant (PA)	22	718
Nurse Practitioner (NP)	19	409
NP Student	2	341
Fellow	12	192
Psychology Physician	2	18
Perfusionist	4	9
Totals	**1,222**	**94,123**

Table 5. Description of NES Procedures with 100 Cases or More

NES Procedure Description (***with count exceeding 100 cases***)	**Case Count**
Craniotomy Tumor	674
Fusion Spine Anterior Cervical And Discectomy	609
Laminectomy Lumbar	592
Laminectomy Lumbar Minimally Invasive	370
Laminectomy Lumbar With Discectomy	370
Fusion Spine Transforaminal Interbody Lumbar	275
Fusion Spine With Instrumentation - Posterior Lumbar	252
Resection Hypophysectomy Endoscopy With Navigation	244
Craniotomy	223
Decompression Posterior Lumbar With Fusion And Fusion Transforaminal Interbody - Minimal Access	215
Fusion Posterior Cervical	193
Fusion Lumbar Posterior With Transforaminal Lumbar Interbody Fusion Interbody Spacer	179
Craniotomy Awake	177
Implant Stimulator Spinal Cord	149
Laparoscopic Implantation Shunt Ventricular Peritoneal	141
Craniectomy/Craniotomy Suboccipital	137
Decompression Microvascular Cranial	123
Decompression Posterior Cervical With Fusion	122
Decompression Posterior Lumbar And Instrumented Fusion	113
Implantation Shunt Ventricular Peritoneal	102
Craniotomy Biopsy Image Guided	101
Fusion Spine Posterior Lumbar	100

Table 6. Counts of Post-Operative Complications

Total Neurologic Surgery Cases	9,049
Total Cases With No Known Post-Operative Complication	8,407
Post-Operative Complications	
Blood Transfusion	185
Seizure	97
Urinary Tract Infection	66
Death within 30-Days of Surgery	57
Wound Infection	53
Deep Vein Thrombosis	38
Cerebrospinal Fluid (CSF) Leak	31
Pulmonary Embolism	31
Pneumonia	23
Hemorrhage - Intra-Operative	19
Hemorrhage - Post-Operative	19
Sepsis	8
Stroke	8
Myocardial Infarction Following Non-Cardiac Surgery	5
Acute Renal Failure	2
Total Cases With Post-Operative Complication	642

Table 7. ASA Physical Status Classifications with Sample's Case Counts

American Society of Anesthesiologists (ASA) Physical Status (PS) Classification System			
ASA PS Classification	**Case Counts**	**Definition**	**Adult Examples**
ASA I	300	A normal healthy patient.	Healthy, non-smoking, no or minimal alcohol use.
ASA II	3,726	A patient with mild systemic disease.	Mild diseases only without substantive functional limitations. Current smoker, social alcohol drinker, pregnancy, obesity (30<BMI<40), well-controlled DM/HTN, mild lung disease.
ASA III	4,586	A patient with severe systemic disease.	Substantive functional limitations. One or more moderate to severe diseases. Poorly controlled DM or HTN, COPD, morbid obesity (BMI ≥40), active hepatitis, alcohol dependence or abuse, implanted pacemaker, moderate reduction of ejection fraction, ESRD undergoing regularly scheduled dialysis, history (>3 months) of MI, CVA, TIA, or CAD/stents.
ASA IV	415	A patient severe systemic disease that is a constant threat to life.	Recent (<3 months) MI, CVA, TIA or CAD/stents, ongoing cardiac ischemia or severe valve dysfunction, severe reduction of ejection fraction, shock, sepsis, DIC, ARD or ESRD not undergoing regularly scheduled dialysis.
ASA V	22	A moribund patient who is not expected to survive without the operation.	Ruptured abdominal/thoracic aneurysm, massive trauma, intracranial bleed with mass effect, ischemic bowel in the face of significant cardiac pathology or multiple organ/system dysfunction.
ASA VI	0	A declared brain-dead patient whose organs are being removed for donor purposes.	

©American Society of Anesthesiologists (ASA) Physician Classificiation System, Committee on Economics (approved by ASA House of Delegates on October 15, 2014, and last amended on December 13, 2020)

Table 8. Correlations

	Variable	**Mean**	**SD**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	*Patient Age*	0.54	0.19	1.00																	
2	*Patient Gender*	0.48	0.50	**-0.10**	1.00																
3	*Patient Race*	0.87	0.33	**0.11**	**-0.02**	1.00															
4	*ASA Score*	0.05	0.21	**0.04**	**-0.04**	**-0.07**	1.00														
5	*Last Case*	0.30	0.46	**0.03**	-0.01	0.01	0.00	1.00													
6	*Implants*	0.15	0.36	**0.04**	0.01	0.00	**-0.03**	**-0.05**	1.00												
7	*COVID Surge*	0.17	0.37	-0.02	0.00	0.00	-0.01	0.00	0.00	1.00											
8	*Late Start*	0.37	0.48	-0.01	**0.03**	-0.02	**0.06**	**0.27**	-0.02	0.00	1.00										
9	*Combo Case*	0.05	0.23	**-0.05**	**0.02**	**-0.02**	-0.01	**-0.05**	0.00	-0.01	**-0.02**	1.00									
10	*Weekend*	0.02	0.14	0.01	**-0.02**	**-0.03**	**0.13**	**-0.06**	**-0.03**	0.02	**0.06**	**-0.02**	1.00								
11	*Parallel Cases*	0.28	0.14	**-0.04**	**0.03**	**-0.02**	**-0.09**	**-0.16**	**0.18**	**-0.03**	**-0.03**	**0.11**	**-0.27**	1.00							
12	*Anesthesiologists*	0.04	0.21	**-0.02**	0.01	0.01	0.02	**0.10**	**0.07**	0.00	**0.12**	0.01	**-0.02**	0.01	1.00						
13	*Long Duration*	0.59	0.49	0.00	-0.01	**0.02**	**-0.02**	0.00	**0.04**	**0.37**	-0.01	**-0.03**	0.00	**0.09**	-0.02	1.00					
14	*Morning Cases*	0.68	0.47	0.00	0.01	0.01	**-0.12**	**-0.50**	**0.10**	0.02	**-0.39**	**0.05**	-0.01	**0.26**	**-0.15**	**0.03**	1.00				
15	*Case Continuity*	0.82	0.16	0.00	-0.01	0.02	0.01	**-0.17**	**-0.21**	**0.02**	**-0.14**	**-0.03**	**0.11**	**-0.15**	**-0.24**	**0.07**	**0.12**	1.00			
16	*Surgeon Familiarity*	0.39	0.08	0.00	0.00	**0.02**	**-0.03**	0.01	0.02	**-0.03**	**-0.06**	**-0.15**	-0.02	**0.05**	**-0.06**	**0.06**	**0.05**	**0.02**	1.00		
17	*Case Scheduling Errors*	0.12	0.05	**-0.02**	**-0.04**	**-0.02**	0.01	**-0.02**	**0.10**	0.01	**0.05**	**-0.07**	**-0.03**	**0.14**	**0.09**	-0.01	**0.03**	**-0.21**	0.00	1.00	
18	*Post-Operative Complications*	0.07	0.26	**0.02**	-0.01	-0.01	**0.12**	-0.01	**0.11**	0.00	0.00	0.02	**0.05**	0.01	**0.03**	-0.01	-0.02	**-0.05**	**-0.03**	**0.02**	1.00

Bold denotes significance of less than 0.05

Table 9. Regression Results

Variable	**Model 1 (DV) Case Scheduling Errors**	**Model 2 (DV) Post-Operative Complications**
Controls	Estimate (SE)	Estimate (SE)
Patient Age	-0.007** (0.003)	0.330 (0.232)
Patient Gender	-0.005*** (0.001)	-0.017 (0.084)
Patient Race	-0.002 (0.002)	-0.039 (0.122)
ASA Score	0.004* (0.002)	1.308*** (0.132)
Last Case	-0.004*** (0.001)	-0.104 (0.108)
Implants	0.005*** (0.002)	0.936*** (0.100)
COVID Surge	0.002* (0.002)	0.109 (0.121)
Late Start	0.004*** (0.001)	-0.128 (0.094)
Combo Case	-0.021*** (0.002)	0.267 (0.171)
Weekend	0.006 (0.004)	0.945*** (0.232)
Parallel Cases	0.040*** (0.004)	0.346 (0.314)
Anesthesiologists	0.011*** (0.003)	0.227 (0.177)
Long Duration	-0.002* (0.001)	-0.098 (0.093)
Morning Cases	0.003* (0.001)	-0.238** (0.122)
Predictors		
Case Continuity	-0.059*** (0.003)	-0.556** (0.266)
Surgeon Familiarity	-0.015** (0.007)	-1.013** (0.529)
Surgeon Familiarity^2	0.060*** (0.016)	
Model Statistics		
N	9,049	9,049
R-Square	0.075	
Nagelkerke R-Square		0.063
Max VIF	1.611	
Chi-Square		229.801

Note: Standardized results are shown; standard errors are in parentheses.

*** $p < 0.01$, ** $p < 0.05$, *$p<0.10$.

Table 10. Comparing Regression Results – Degree of Participation vs. Count-Based

Variable	**Model 1 (DV)** **Case Scheduling Errors**		**Model 2 (DV)** **Post-Operative Complications**	
Predictors	Degree of Participation Estimate (SE)	Count-Based Estimate (SE)	Degree of Participation Estimate (SE)	Count-Based Estimate (SE)
Case Continuity	-0.059*** (0.003)	-0.052*** (0.003)	-0.556** (0.266)	-0.480** (0.232)
Surgeon Familiarity	-0.015** (0.007)	-0.026*** (0.005)	-1.013** (0.529)	-1.403*** (0.439)
Surgeon Familiarity^2	0.060*** (0.016)	0.048*** (0.008)		
Model Statistics				
N	9,049	9,049	9,049	9,049
R-Square	0.075	0.09		
Nagelkerke R-Square			0.063	0.066
Max VIF	1.611	1.624		
Chi-Square			229.801	242.192

Note: Standardized results are shown; standard errors are in parentheses.

*** $p < 0.01$, ** $p < 0.05$, *$p<0.10$.

APPENDIX - FIGURES

Figure 1. Research Model 1 – Team Dynamics and Operational Performance

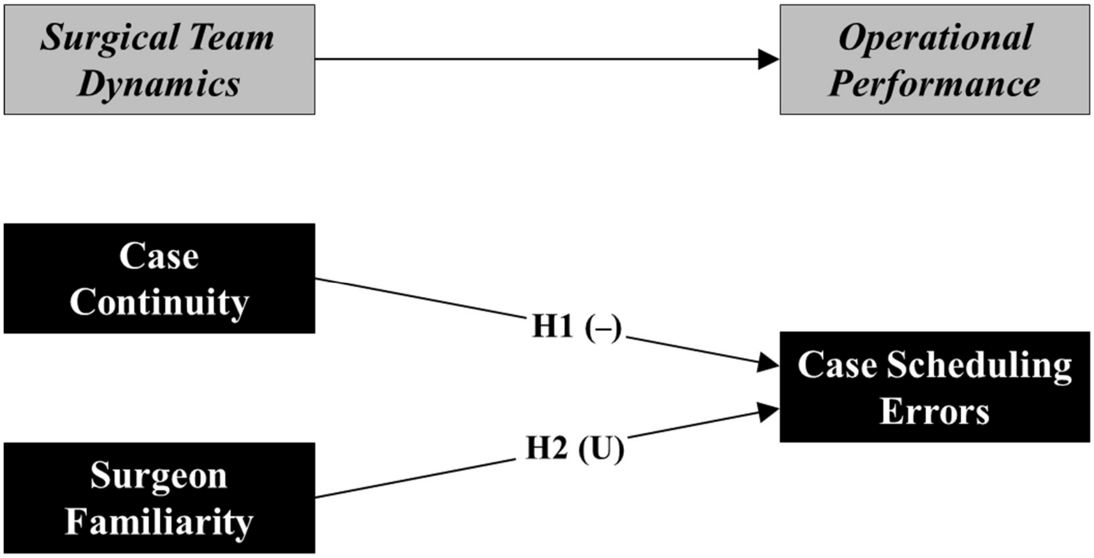


Figure 2. H1 – Case Continuity and Case Scheduling Errors

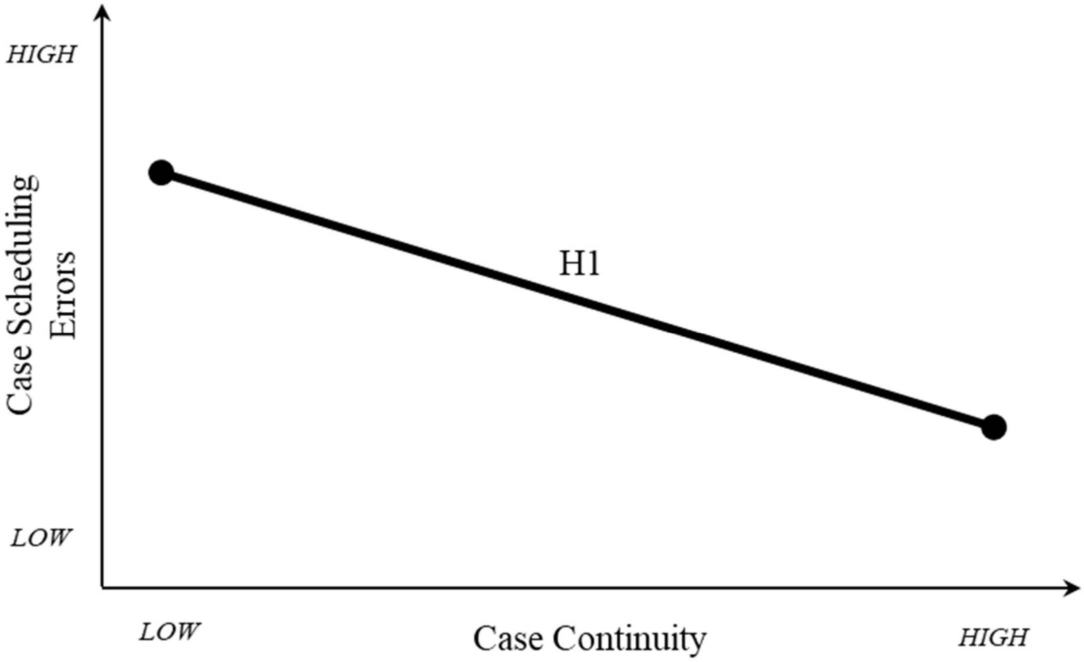


Figure 3. H2 – Surgeon Familiarity and Case Scheduling Errors

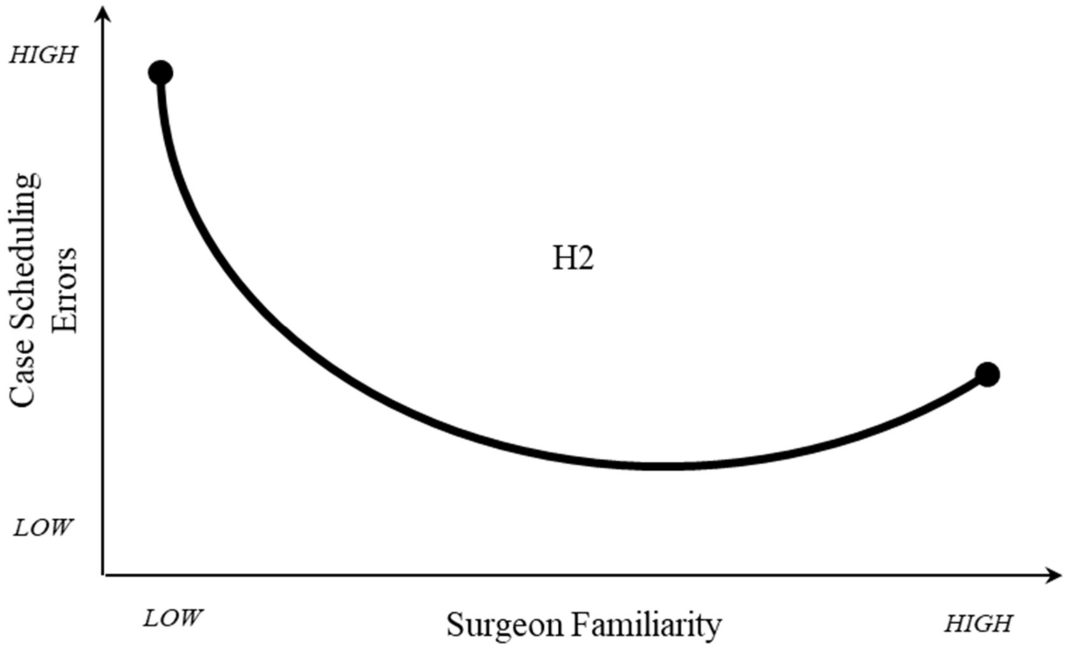


Figure 4. Research Model 2 – Team Dynamics and Clinical Outcomes

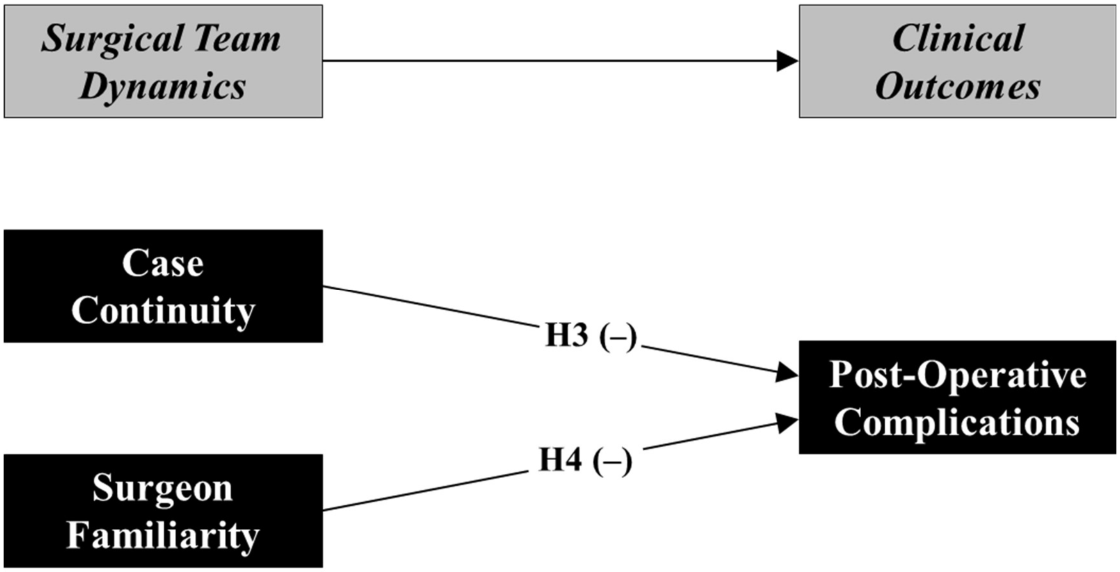


Figure 5. H3 – Case Continuity and Post-Operative Complications

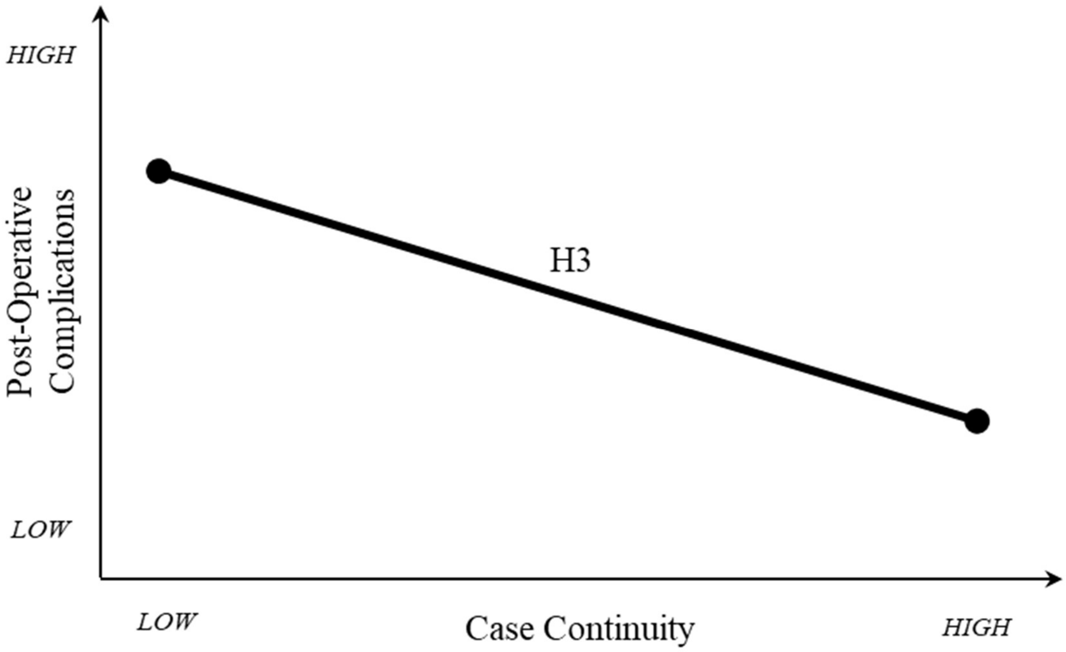


Figure 6. H4 – Surgeon Familiarity and Post-Operative Complications

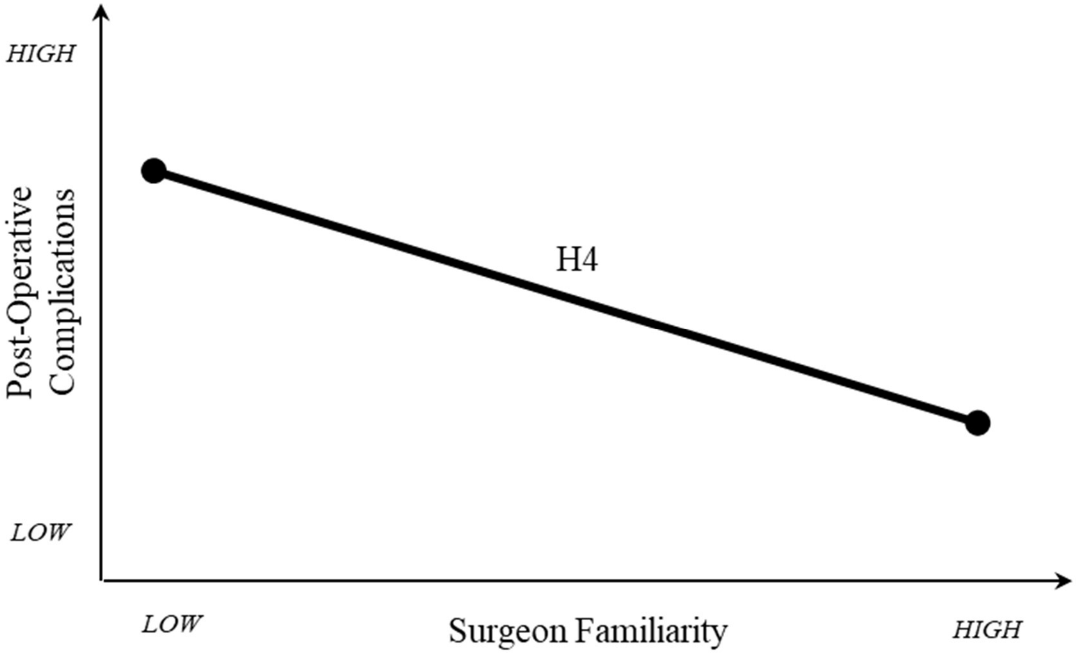


Figure 7. Defining Case Durations – Actual, Scheduled, PRE, INTRA, and END

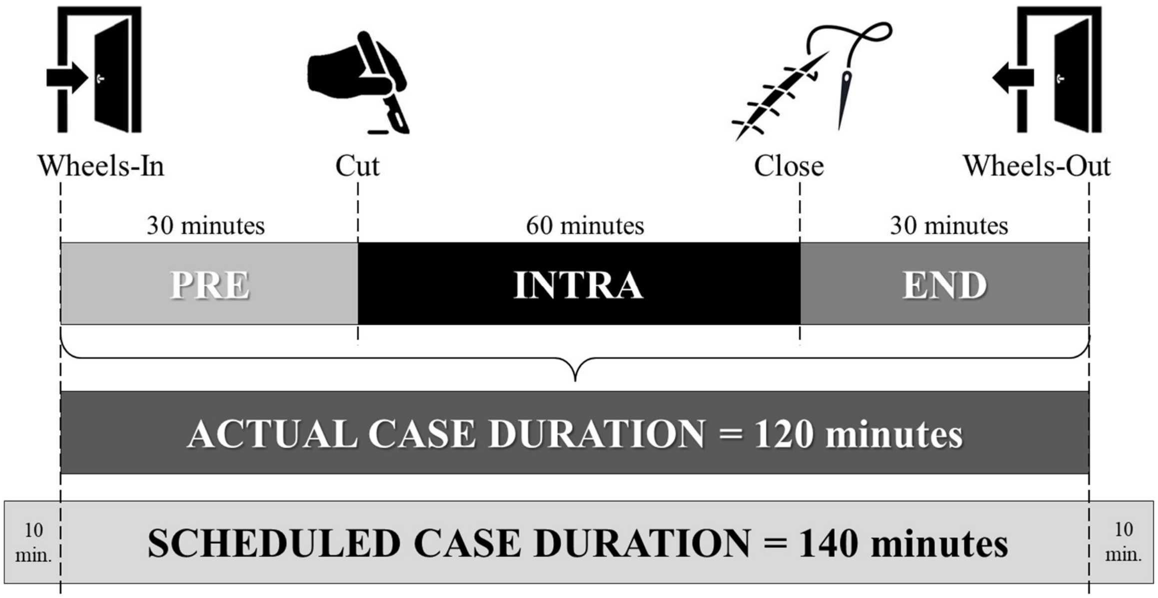


Figure 8. Distribution of Actual Case Durations by Wheel-In to Wheels-Out

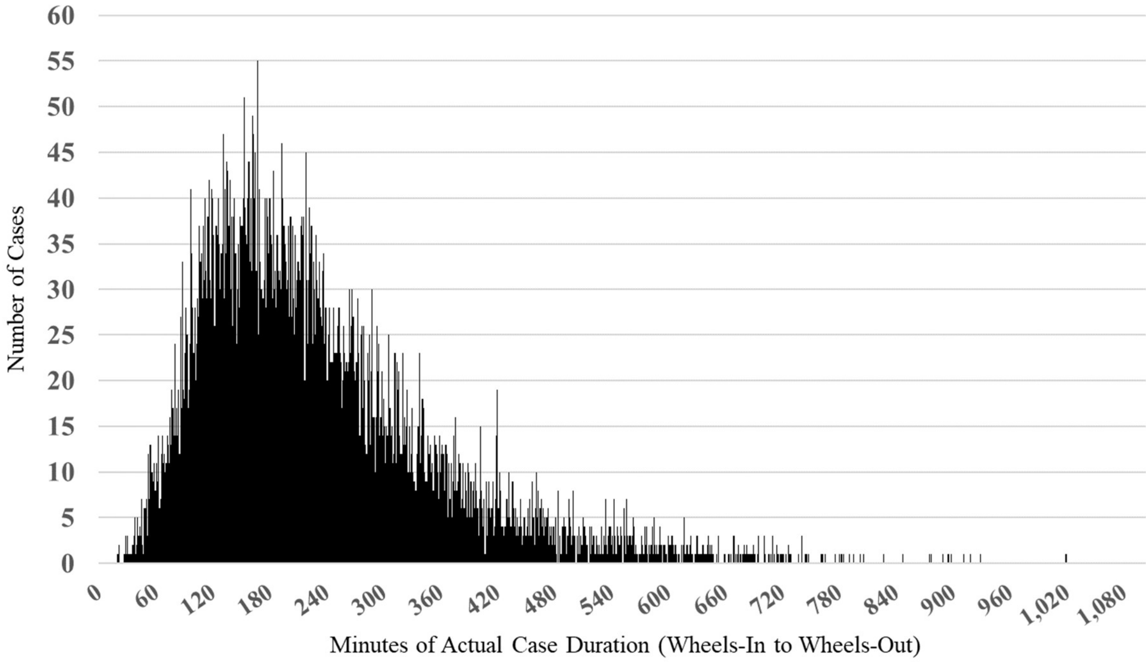


Figure 9. Distribution of Case Scheduling Errors

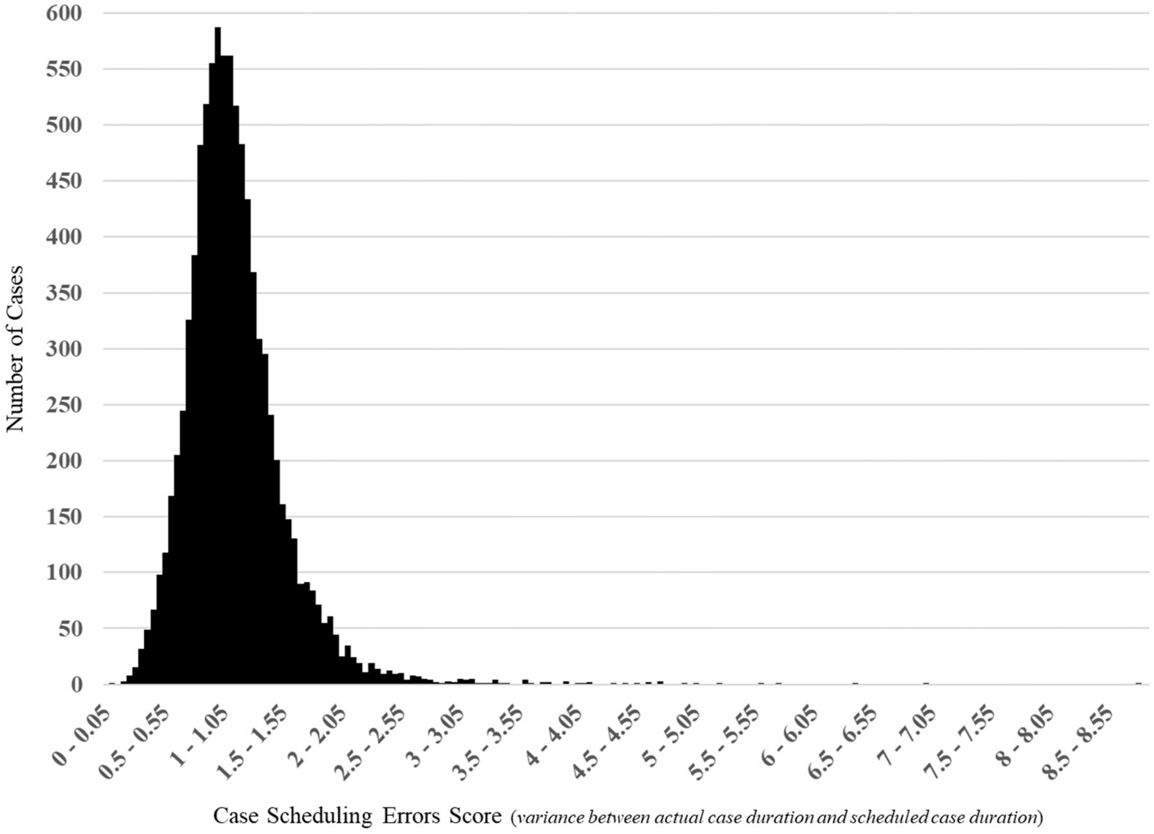
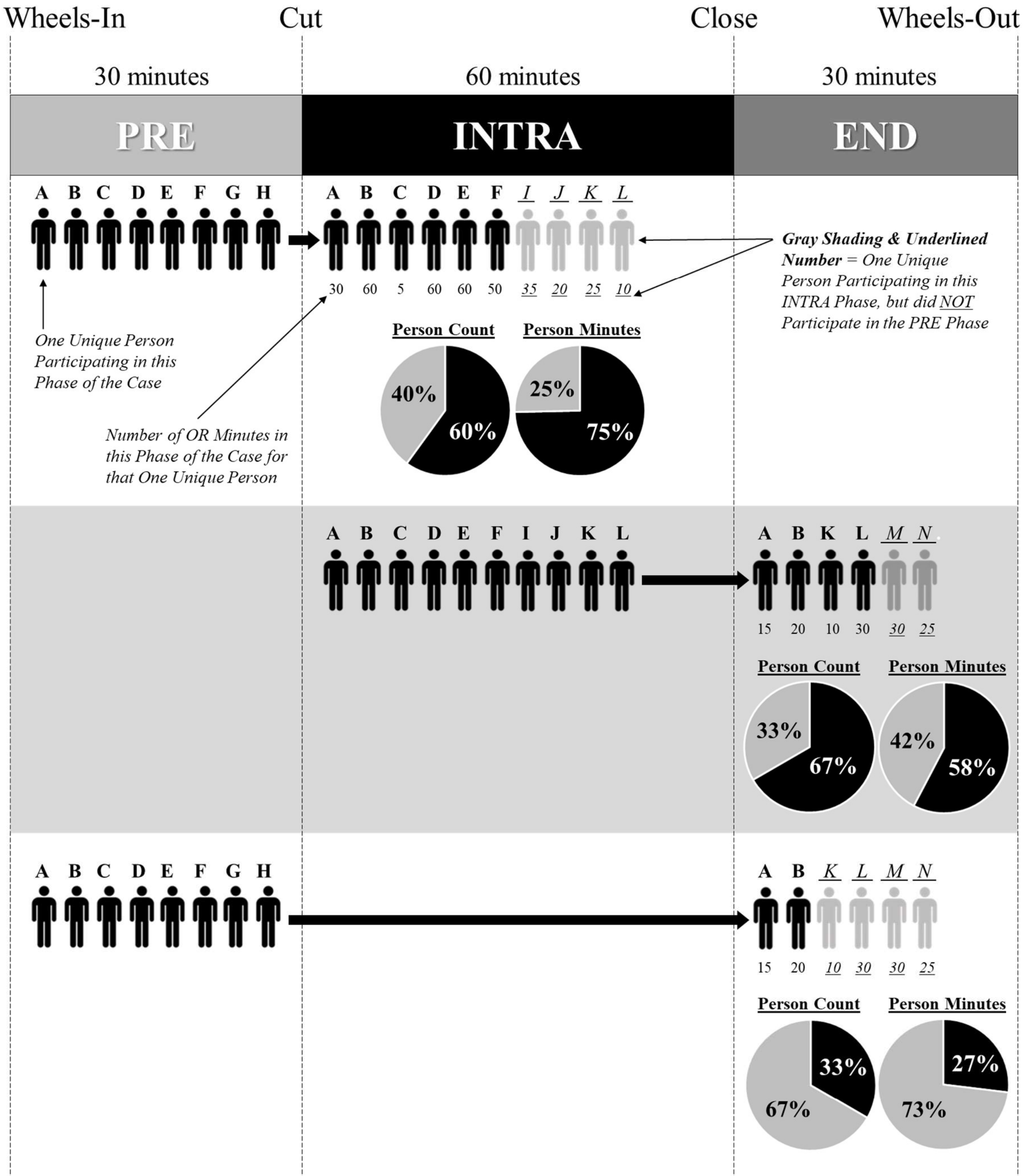


Figure 10. Case Continuity – Comparing Calculations of Counts vs. Minutes



One Unique Person Participating in this Phase of the Case

Number of OR Minutes in this Phase of the Case for that One Unique Person

Gray Shading & Underlined Number *= One Unique Person Participating in this INTRA Phase, but did NOT Participate in the PRE Phase*

Phase Percentage of Case Duration: PRE = 25% (30m of 120m); **INTRA = 50%** (60m of 120m); **END = 25%** (30m of 120m)

PRE-INTRA *INTRA-END* *PRE-END* *INTRA+END+PRE*

Case Continuity Score by Minutes: 58.7% = ((0.75 * 0.50) + (0.58 * 0.25) + (0.27 * 0.25)) / (0.50 + 0.25 + 0.25)

Case Continuity Score by Counts: 55.0% = ((0.60 * 0.50) + (0.67 * 0.25) + (0.33 * 0.25)) / (0.50 + 0.25 + 0.25)

Figure 11. Distribution of Case Continuity Scores

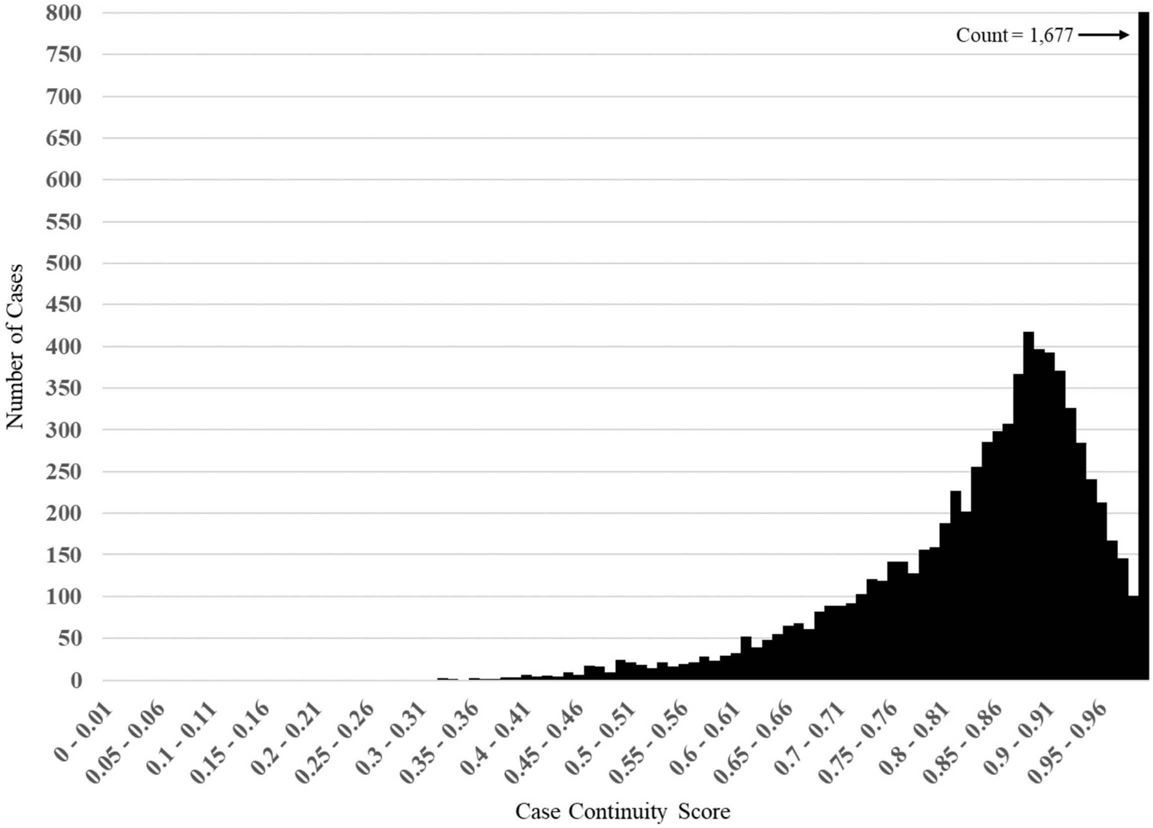
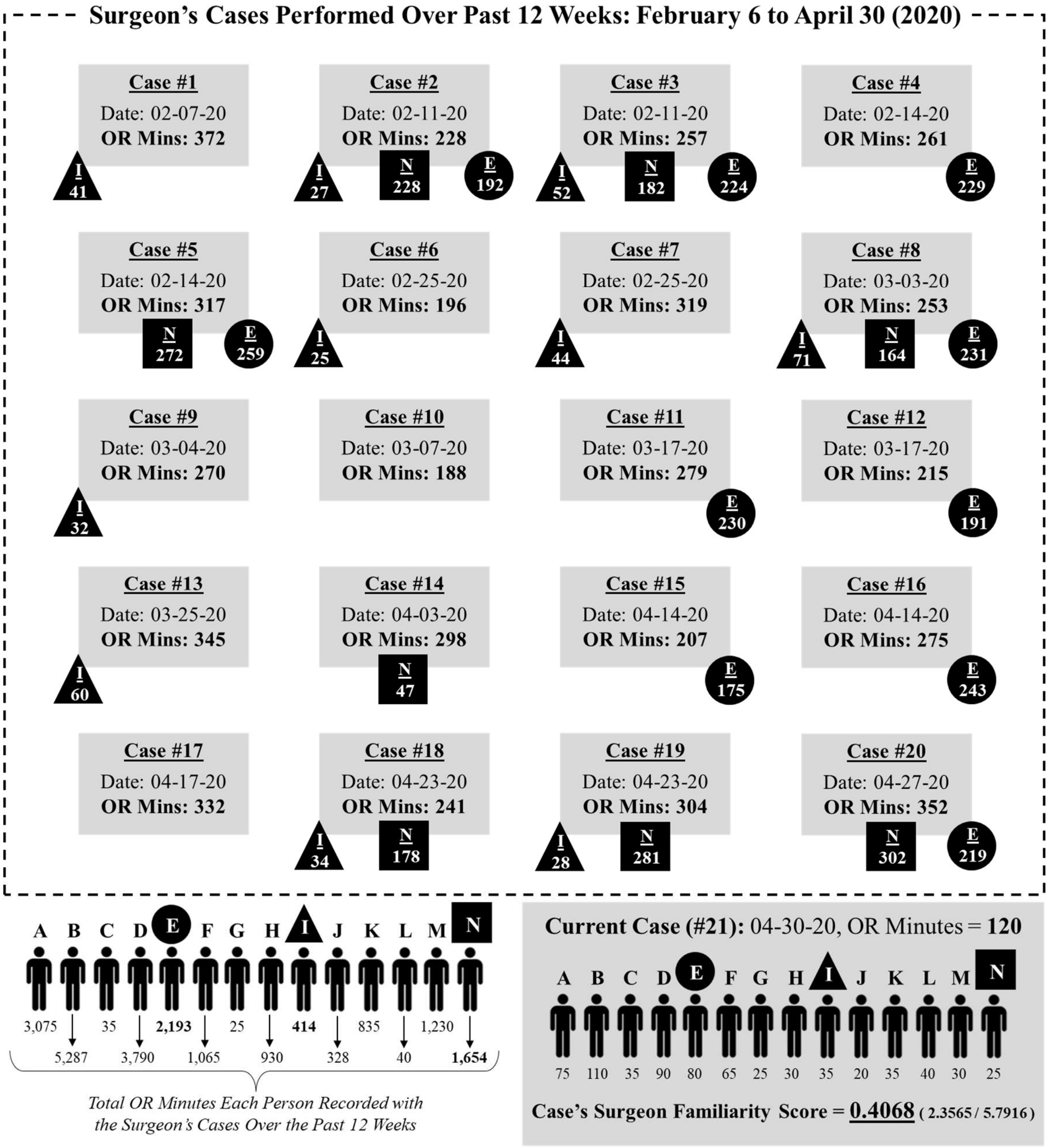
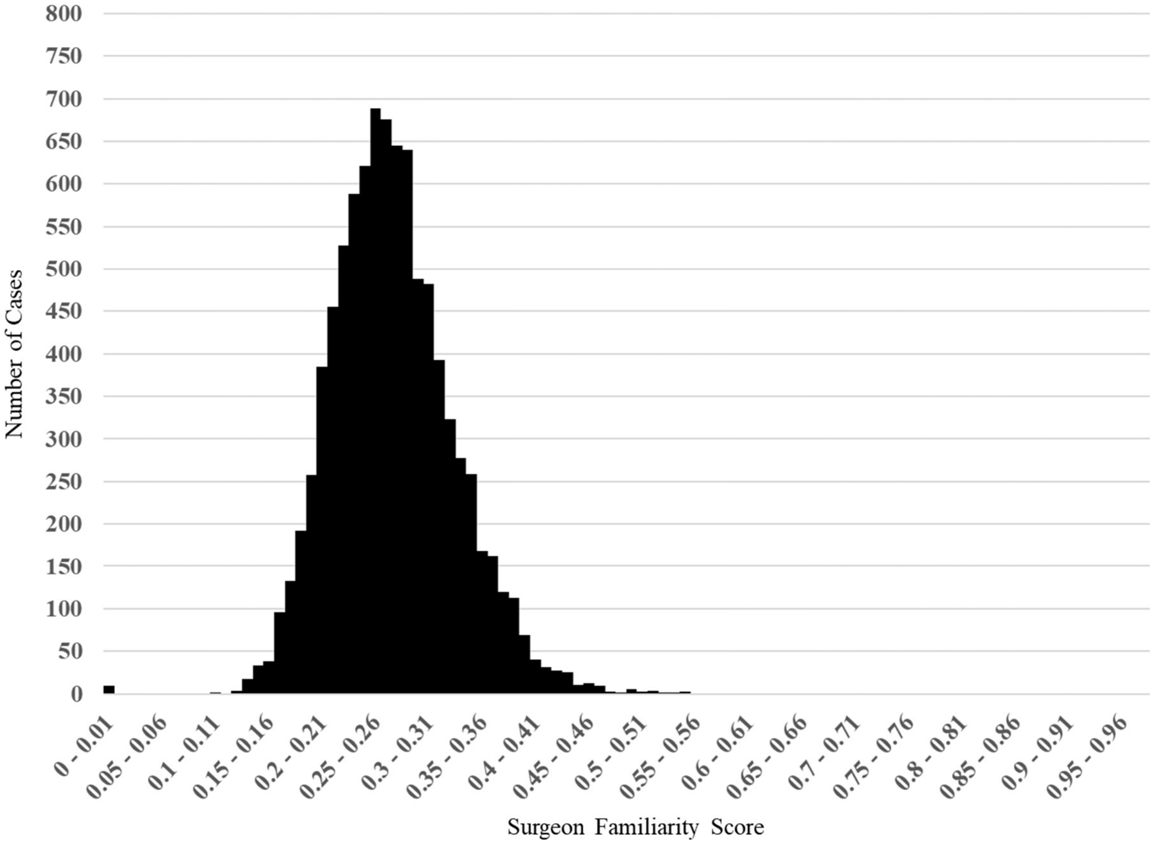


Figure 12. Surgeon Familiarity – Comparing Calculations of Counts vs. Minutes



Person (letter label)	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Person's Current Case Minutes (Mins.)	75	110	35	90	80	65	25	30	35	20	35	40	30	25
Current Case's Total Mins.	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Person's Current Case Percentage (Pct.)	62.5%	91.7%	29.2%	75.0%	66.7%	54.2%	20.8%	25.0%	29.2%	16.7%	29.2%	33.3%	25.0%	20.8%
Person's Mins. in Surgeon's Cases Past 12 Weeks	3,075	5,287	35	3,790	2,193	1,065	25	930	414	328	835	40	1,230	1,654
Total Mins. of Surgeon's Cases Past 12 Weeks	5,509	5,509	5,509	5,509	5,509	5,509	5,509	5,509	5,509	5,509	5,509	5,509	5,509	5,509
Person's Past 12 Week Percentage	55.8%	96.0%	0.6%	68.8%	39.8%	19.3%	0.5%	16.9%	7.5%	6.0%	15.2%	0.7%	22.3%	30.0%
Person's Current Case Pct. x Past 12-Week Pct.	**34.9%**	**88.0%**	**0.2%**	**51.6%**	**26.5%**	**10.5%**	**0.1%**	**4.2%**	**2.2%**	**1.0%**	**4.4%**	**0.2%**	**5.6%**	**6.3%**

Figure 13. Distribution of Surgeon Familiarity Scores



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