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Predicting Surgical Flow Disruption Recovery in Cardiothoracic Operating Rooms

Gary Palmer II
Clemson University, gpalmer@clemson.edu

PREDICTING SURGICAL FLOW DISRUPTION RECOVERY
IN CARDIOTHORACIC OPERATING ROOMS

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Gary Sherman Palmer II
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Accepted by:
A. Joy Rivera-Rodriguez, Ph.D., Committee Chair
Anand K. Gramopadhye, Ph.D.
Joel S. Greenstein, Ph.D.
Kevin M. Taaffe, Ph.D.
Scott A. Shappell, Ph.D.
James H. Abernathy III, M.D., M.P.H.

ABSTRACT

Disruptions are common occurrences in a variety of healthcare settings and early research has shown that they are likely contributors to medical errors. For this reason, healthcare researchers have focused on studying and understanding the nature of Surgical Flow Disruptions (SFDs) to increase patient safety and quality of care within the operating room (OR). Many researchers have used simplistic taxonomies to collect and categorize the types of SFD that occur within the OR. Others have gone further to study SFD recovery and have link unrecovered and recovered SFD to minor and major adverse events experienced by patients. This dissertation, focused on cardiovascular surgeries, has expanded on both of these areas of research. First, the use of the Realizing Improved Patient Care through Human-centered Operating Room Design (RIPCHORD) taxonomy was validated by observing 11 cardiovascular surgeries and collected data surrounding SFDs and their recovery. SFDs were coded into the taxonomy with a 99.994% agreement. Second, three types of SFD recovery (individual, team, or none) were predicted based upon interactions between each RIPCHORD main taxonomy category and operational phase of surgery. By predicting the proportions of individual, team, and no recovery for when and what types of SFDs occur, an organizational or second-order problem solving approach occurs and the potential for targeting interventions to minimize SFDs and SFD recovery. Removing unorganized behavior from the operating room solves the root cause behind SFDs and offers structured teamwork to promote SFD recovery.

DEDICATION

To the Palmer and Watson families, the potential of our minds and hearts are limitless.

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CHAPTER ONE

INTRODUCTION TO SURGICAL FLOW DISRUPTIONS

Healthcare professionals, such as surgeons and anesthesiologists, receive medical schooling and training for over eight years to successfully operate on patients on their own. Healthcare professionals' goal is to have the patient walk out of the hospital in better health than when they walked into the hospital. Unfortunately, no one is perfect and the healthcare system is complex, therefore mistakes are made that sometimes hurt the patient temporarily or permanently. In the past, when a patient is affected by an error, the healthcare system has turned towards blaming the individual who made the mistake. In fact in the US, in the 1970s and 1980s, anesthesiologists were at risk of becoming extinct due to the amount of malpractice suits against them (Gaba, 2000). Since then, however, healthcare in general and the operating room (OR) specifically, has slowly started to realize that there is much more to a mistake or error than just the person who committed it.

The OR is a very complex system with many people (surgeons, anesthesiologists, perfusionists, nurses), tools and technologies (scalpel, patient monitor), tasks (cutting, communicating, monitoring), environmental features (patient table, lighting), and organizational aspects (unspoken hierarchy, rules, policies) interacting with each other (Carayon, et al., 2006; Christian, et al., 2006). All of these system complexities affect healthcare professionals' performance which then influences patient safety and patient outcomes. The correlation between performance and patient safety has been studied in other complex healthcare settings such as the intensive care unit and the emergency room (Bracco D, 2001; Carthey, de Leval, & Reason, 2001; Christian, et al., 2006; Guerlain et al., 2004; Mann et al., 1994; Schaefer HG H. R., 1994; Schaefer HG H. R., 1994). One way to effectively study these interactions to understand how they influence performance and thus patient safety is with human factors engineering. Human factors engineering is the study of human-system interaction and how behavioral and non-behavioral processes affect the user (Meister, 1999; Wickens & Hollands, 2000). Human factors engineering methods have been used in healthcare in a variety of settings to redesign the system in order to enhance performance and increase patient safety (Carthey, de Leval, & Reason, 2001; Christian, et al., 2006; Reason, 1995; Vincent, Moorthy, Sarker, Chang, & Darzi, 2004; Yule, Flin, Paterson-Brown, & Maran, 2006). One area of focus in healthcare that has recently seen an increase in applying human factors engineering techniques is the OR, specifically studying surgical flow disruptions.

Surgical Flow Disruptions

Surgical flow disruptions (SFDs) are events that disrupt the flow or natural progression of the procedure (Wiegmann, El Bardissi, Dearani, Daly, & Sundt III, 2007). SFDs also have the potential to distract HCPs' attention from their primary task. Surgical flow disruptions increase the likelihood of errors which can cause sentinel events to occur in the OR. Sentinel events are adverse outcomes such as death or near misses that occur during the procedure (Joint Commission, 2007). This is similar to Reason's concept of latent failures leading to active failures which have the potential to cause accidents (Reason, 1990). Reason shows in his "Swiss Cheese" model that if a system is designed properly, latent failures are often met by system defenses built to mitigate accidents from occurring. However, if a system is not designed properly or if it is so complex that it is near impossible to account for all issues, the scattered holes in the Swiss cheese can align making it "easier" for the latent failure to travel through the system and result in an accident. Like latent failures, SFDs do not always lead to sentinel events, but they can increase the potential for a sentinel event to occur. Many times it is the individuals, the health care professionals, working in the OR that are the system defenses. They recover from SFDs blocking their effects on the patient.

Carthey et al. (2001) give an example where a surgeon is interrupted by the OR manager. As the surgeon prepares the patient for bypass the OR manager interrupts the surgeon and discusses the organization of cases for the following day. This is a negative communication SFD, especially since the surgeon was annoyed by the SFD. Then, the OR manager interrupts the surgeon again, and during this interruption, the anesthesiologist asks the surgeon if it is acceptable to start the heparin protocol. The surgeon does not hear the anesthesiologist. The second interruption is important but the surgeon is focused on the OR manager instead of the heparin protocol. The heparin is needed before the patient is put on the heart-lung bypass machine, yet because of that disturbance, the surgeon forgets about the heparin protocol and wants to proceed to the heart-lung bypass machine. Fortunately, the anesthesiologist recovers and blocks the potential effects of the SFDs by reminding the surgeon of the heparin protocol. Even though nothing bad happened to the patient, this example shows that if the anesthesiologist had not acted as a system defense, the multiple SFDs could have led to a sentinel event potentially killing the patient. Therefore, it is important to study SFDs, understand their characteristics, and understand how healthcare professionals are acting as system defenses by recovering from SFDs.

SFD Recovery

A work system is said to be *brittle* when the individuals in that system lack the ability to detect problems and adjust to make the necessary changes for the system to work properly (Hollnagel, Woods, & Leveson, 2006; Smith, McCoy, & Layton, 1997). Healthcare professionals minimize brittleness by using diagnostic reasoning (Smith, McCoy, & Layton, 1997) and clinical knowledge (Taylor, 1997), and by creating viable workarounds to manage poorly designed tools and technology and other system problems (Miller, Fortier, & Garrison, 2011; Phillips & Berner, 2004). When a system contains individuals who can recover, adapt and generate solutions, this system is said to be resilient (Hollnagel, Woods, & Leveson, 2006). Recovery has played an important role in intensive care (Faye, Rivera-Rodriguez, Karsh, Hundt, Baker, & Carayon, 2010), emergency departments (Henneman, Blank, Gawlinski, & Henneman, 2006), and cardiac surgery (de Leval, Carthey, Wright, Farewell, & Reason, 2000).

For the purposes of this research, recovery of a SFD occurs when the consequence or potential consequence of a SFD is mitigated by the actions of a healthcare professional. This is similar to previous definitions used in the literature (de Leval, Carthey, Wright, Farewell, & Reason, 2000; Wong, Vander Salm, Ali, Agnihotri, Bohmer, & Torchiana, 2006). However, this study goes beyond this definition to distinguish between individual recovery of SFDs and team recovery. If one healthcare professional is responsible for mitigating a SFD's potential consequence, it is called individual SFD recovery, however, if two or more healthcare professionals act to mitigate a SFD's potential consequence, then it is called team SDF recovery. Past literature has examined SFD recovery (de Leval, Carthey, Wright, Farewell, & Reason, 2000; Wong, Ali, Torchiana, Agnihotri, Bohmer, & Vander Salm, 2009; Wong, Torchiana, Vander Salm, Agnihotri, Bohmer, & Ali, 2007; Wong, Vander Salm, Ali, Agnihotri, Bohmer, & Torchiana, 2006), however, no one has studied the difference between individual and team SFD recovery. This is an identified gap in the research, one this dissertation intends to fill.

Research Aims

This dissertation aims to generate a systematic process of identifying SFDs and predicting SFD recovery cardiothoracic ORs. This will be done by:

- Using the Realizing Improved Patient Care through Human-centered Operating Room Design (RIPCHORD) taxonomy presented in Chapter 3 as guide for data collection and analysis and validating its success with a 90% coding rate.
- Predicting the likelihood of individual and team SFD recovery based on the high-level RIPCHORD taxonomy categories and phase of operation (pre-operative, anesthesia, pre-bypass, surgery, and post-bypass).

More details justifying these research aims and deliverables will be provided in Chapter 2, which reviews the SFD literature. Then, Chapter 3 highlights a preliminary study of SFDs in cardiac ORS, which helped develop the RIPCHORD taxonomy. Chapter 4 reviews the methodology and statistical method used to identify the SFDs and SFD recovery observed in a cardiac OR. Chapter 5 provides the descriptive statistics of SFDs and SFD recovery observed and the likelihood of SFD recovery by HCPs in each interaction between the RIPCHORD main categories and operational phases. Lastly, Chapter 6 explains the broad impacts, limitations, and future research for this dissertation.

CHAPTER TWO

LITERATURE REVIEW

The purpose of this chapter is to review the literature on surgical flow disruptions. This chapter will describe the similarities and differences between the studies reviewed. A matrix, located in Appendix A, was developed to highlight the comparisons discussed in this chapter. The columns were strategically selected to allow the reader to better understand the current literature and to emphasize the research gaps that this dissertation has identified and fills. The matrix depicts the following categories: author(s) and year of study, method of recording SFDs, types of SFDs recorded, observation tool, number of observers and their occupation, whether SFD recovery was observed, how SFD recovery was recorded, and the type of SFD recovery analysis.

Inclusion and Exclusion Criteria

The inclusion criteria for this review were: 1) the article's domain must be in healthcare and the OR; 2) the main focus of the article must be SFDs; 3) the article must be from a peer-reviewed journal; and 4) the article must be available in the English language. These articles were searched under the Google Scholar and PubMed search engines. The keywords used to search included: surgical flow disruption(s), cardiac, and operating room. By using the search engines, keywords, and the inclusion criteria, 20 papers related to the topic of this dissertation were included in this review.

Type of Surgery

There were two main types of surgeries that were covered in the reviewed literature, general surgery and cardiac surgery. General surgeries are routine procedures that provide treatment for injuries that do not need specialized repair. For example, a minimally invasive surgery (Al-Hakim, 2011) and laparoscopic cholecystectomy (Sutton, et al., 2010) are two types of general surgeries. Nine out of twenty papers conducted their studies within general surgery (Al-Hakim, 2011; Fabri & Zayas-Castro, 2008; Healey, Undre, & Vincent, 2004; Healey, Primus, & Koutantji, 2007; Healey, Sevdalis, & Vincent, 2006; Lingard, et al., 2004; Sevdalis, Forrest, Undre, Darzi, & Vincent, 2008; Sutton, et al., 2010; Undre, Healey, Darzi, & Vincent, 2006). Some of those studies reported more details about the type of general surgery than others. For example, Undre et al. (2006) reported the number of open and laparoscopic surgeries with a list of specific procedures, while Healey et al. (2004) reported nothing more than their study was conducted in general surgeries.

Although general surgeries may have a few procedures that are complex, they are generally less complex than cardiac surgeries and less time consuming. For these reasons (complexity and time), cardiac surgeries have been targeted as a good venue to study SFDs. Cardiac surgeries are specialized surgeries that focus on repairing injuries of the heart. Eleven out of twenty papers completed their study in cardiac surgeries. Of those papers, three studied pediatric cardiac surgery (Catchpole K. , 2009; Catchpole, Giddings, Wilkinson, Hirst, Dale, & de Leval, 2007; Catchpole, et al., 2006), and nine studied adult cardiac surgery (de Leval, Carthey, Wright, Farewell, & Reason, 2000; ElBardissi, Wiegmann, Henrickson, Wadhera, & Sundt III, 2008; Lingard, et al., 2004; Parker, Laviana, Wadhera, Wiegmann, & Sundt III, 2010; Wiegmann, El Bardissi, Dearani, Daly, & Sundt III, 2007; Wong, Ali, Torchiana, Agnihotri, Bohmer, & Vander Salm, 2009; Wong, Torchiana, Vander Salm, Agnihotri, Bohmer, & Ali, 2007; Wong, Vander Salm, Ali, Agnihotri, Bohmer, & Torchiana, 2006). While none of the pediatric cardiac surgery studies provided more detail on their surgical procedures, two of the nine papers looking at adult cardiac surgeries noted the number of specific cardiac procedures observed, for example, they reported observing coronary arterial bypass grafting (CABG), valve repair/replacement, CABG and valve repair, and aorta root replacement (ElBardissi, Wiegmann, Henrickson, Wadhera, & Sundt III, 2008; Wiegmann, El Bardissi, Dearani, Daly, & Sundt III, 2007). This dissertation will examine SFDs in cardiac procedures because it offers the potential for numerous SFDs in a complex environment.

SFD Terminology

Prior to discussing more about each study, it is first necessary to define what a surgical flow disruption is and how it has been described in the literature. A surgical flow disruption is an event that disrupts the flow or natural progression of the procedure (Wiegmann, El Bardissi, Dearani, Daly, & Sundt III, 2007). There are many different terms that have been used throughout the literature to describe the act of disrupting the flow of surgery. Table 2.1 shows the terms that the reviewed literature uses and their corresponding definitions.

Table 2.1. Terms Used Interchangeably with SFDs

Author(s)	Term Used	Definition
Al-Hakim, 2011; Healey et al., 2006; Healey et al., 2007; Sevdalis et al., 2008	Disruptions and Interruptions	Any event disturbing the natural progression of the surgical flow.
Catchpole, 2009; Catchpole et al., 2006; Lingard et al., 2004;	Failures	A planned sequence of activities failed to achieve its intended outcome
Catchpole et al., 2007;	Problems	Failure types were systematically associated with threats and error
de Leval et al., 2000	Events	Failures that disrupted the surgical flow of the procedure with or without serious consequences
ElBardissi et al., 2008; Fabri & Zayas-Castro, 2008	Errors	Events in which a planned sequence of activities failed to initially achieve its intended outcome
Healey et al., 2004; Undre et al., 2006	Task Completion	A successful transition from one stage to another
Parker et al., 2010; Wiegmann et al., 2006; Wiegmann et al., 2007;	Surgical Flow Disruptions	Deviations from the natural progression of an operation
Sutton et al., 2010	Gaze Disruptions	A break in the primary surgeon's gaze during the performance of the procedure
Wong et al., 2006; Wong et al., 2007; Wong et al., 2009;	Precursor Events	Events that have the potential to lead to adverse outcomes and may constitute medical errors

Methods Used to Identify SFDs

A total of four unique methods were used by the studies in this literature review to identify SFDs. One study used self-reporting (Fabri & Zayas-Castro, 2008), four studies used case report reviewing (de Leval, Carthey, Wright, Farewell, & Reason, 2000; Wong, Ali, Torchiana, Agnihotri, Bohmer, & Vander Salm, 2009; Wong, Torchiana, Vander Salm, Agnihotri, Bohmer, & Ali, 2007; Wong, Vander Salm, Ali, Agnihotri, Bohmer, & Torchiana, 2006), one study used videotaped observations (Sutton, et al., 2010), and 14 studies used direct observations (Al-Hakim, 2011; Catchpole K. , 2009; Catchpole, Giddings, Wilkinson, Hirst, Dale, & de Leval, 2007; Catchpole, et al., 2006; ElBardissi, Wiegmann, Henrickson, Wadhera, & Sundt III, 2008; Healey, Primus, & Koutantji, 2007; Healey, Sevdalis, & Vincent, 2006; Healey, Undre, & Vincent, 2004; Lingard, et al., 2004; Parker, Laviana, Wadhera, Wiegmann, & Sundt III, 2010; Sevdalis, Forrest, Undre, Darzi, & Vincent, 2008; Undre, Healey, Darzi, & Vincent, 2007; Wiegmann, El Bardissi, Dearani, Daly, & Sundt III, 2007).

Self–reporting systems allow the surgical team to report their own SFDs, then a team of adjudicators reviews the SFDs recorded. In this study, the cases were recorded by medical professionals, who had the experience and knowledge base to identify the causes of SFDs and other problems in the OR (Fabri & Zayas-Castro, 2008). One advantage of case report reviewing is that it takes less time and resources than other methods (described below) allowing for many more cases to be reviewed. Some disadvantages are that this method is retrospective and the level of detail per case is dependent on the reporting system which may be itself poorly designed. This can lead to inaccurate data being collected due to end-user confusion with the system.

Videotaping observations allows research teams to extract data from a visual and auditory source without being present in the OR. By using multiple cameras, videotaping a complex system such as a cardiac procedure helps the researchers collect data more accurately (Yule, Flin, Paterson-Brown, & Maran, 2006). Three cameras, with the visual and audio feed synchronized, were able to collect data on gaze disruptions committed by the surgeons (Sutton, et al., 2010). Although videotaping has its advantages, it can require buy-in from top management to use or install recording devices and this can become expensive and often exudes the “big brother” effect on participants.

Direct (in vivo) observations are observations that occur during a natural setting of a procedure (Robson, 2011). Direct observations can be structured in different ways. One method is using a framework that details steps needed to accomplish a successful observation such as the Observational Teamwork Assessment for Surgery (OTAS) (Healey, Undre, & Vincent, 2004) and the Non-Technical Skills (NOTECHS) framework (Catchpole, Giddings, Wilkinson, Hirst, Dale, & de Leval, 2007). Checklists, such as the Operating Room Checklist (ORCL) (Helmreich, Schaefer, & Sexton, 1995) are also used for direct observation. One negative aspect of direct observations is the Hawthorne effect (Chiesa, M., & Hobbs, S., 2008; French, 1953). An additional presence in the OR may alter the way healthcare professionals behave influencing the occurrence of SFDs, however, the Hawthorne effect will diminish with continued exposure to the medical team. Additionally, in academic settings like the one this dissertation studies, HCPs are often used to having many observers (e.g. medical students) in the OR. Other things to consider as part of structuring direct observations are related to: the number and type of observer(s), the observer's level of experience, and occupation, as the data may be influenced by these decisions. This will be discussed in more detail in the next section. A positive aspect of direct observations is observing SFDs in real–time, which allows the researcher to gain a better understanding of the context and helps during the data analysis phase. Direct observations are also easy to participate in and implement. For these reasons, this dissertation used direct observations.

Number of Observers and Occupation

Seven out of the 14 studies that conducted direct observations used one observer. Three of those studies used a human factors professional as the observer (Catchpole, 2009; Catchpole, et al., 2006; Catchpole, Giddings, Wilkinson, Hirst, Dale, & de Leval, 2007), and four of them trained a medical professional to observe SFDs (ElBardissi, Wiegmann, Henrickson, Wadhera,

& Sundt III, 2008; Healey, Primus, & Koutantji, 2007; Wiegmann, ElBardissi, Dearani, Daly, & Sundt III, 2007; Wiegmann, ElBardissi, Dearani, & Sundt, 2006). Using a solo observer for an entire study limits the perspective of recorded SFDs. The knowledge base of the observer can influence the SFDs recorded. A medical observer is more knowledgeable about surgery, but a human factors engineer observer is more knowledgeable about the surrounding system. Thus, observers with medical expertise need more training and exposure to identify SFDs, as they occur due to system interactions. Also, the number of observers in the OR can influence the amount of SFDs recorded. If the goal is to record as many SFDs as possible, one observer will not accomplish this. Multiple observers are needed since they can capture overlapping observations, but not too many observers so that the OR becomes cluttered.

The other seven studies that performed direct observations to identify SFDs used two or more observers in the OR. There were two studies that used multiple industrial engineers/psychologists (Al-Hakim, 2011; Sevdalis, Forrest, Undre, Darzi, & Vincent, 2008). Three studies used a combination of medical and human factors observers to provide a comprehensive understanding of the OR in both fields of human factors and medicine (Healey, Undre, & Vincent, 2004; Parker, Laviana, Wadhera, Wiegmann, & Sundt III, 2010; Undre, Healey, Darzi, & Vincent, 2006). Lastly, two studies used multiple observers, but did not report the observers' profession (Healey, Sevdalis, & Vincent, 2006; Lingard, et al., 2004). This dissertation used two human factors experts as the RIPCHORD taxonomy identifies SFDs from a systems perspective. It is known from our preliminary study (in Chapter 3) that two observers will supply complete coverage of the OR and be able to collect all SFDs.

Observational Tools

In this review, six out of 14 of the studies that used direct observations used an observation tool to classify and rate SFDs. Within those six papers, the four observational tools used were the Observational Teamwork Assessment for Surgery (OTAS) (Healey, Undre, & Vincent, 2004; Undre, Sevdalis, Koutantji, & Vincent, 2006), Non-Technical Skills (NOTECHS) scoring system (Catchpole K. , 2009; Catchpole, Giddings, Wilkinson, Hirst, Dale, & de Leval, 2007), Disruptions in Surgery Index (DiSI) (Sevdalis, Forrest, Undre, Darzi, & Vincent, 2008), and Surgical Flow Disruption Tool (SFDT) (Parker, Laviana, Wadhera, Wiegmann, & Sundt III, 2010). The Observational Teamwork Assessment for Surgery (OTAS) was originally modified from aviation and developed as a comprehensive measure to ascertain the way surgical teams function in the total system instead of simply considering the individual performances and mishaps (Healey, Undre, & Vincent, 2004). OTAS is comprised of two features: the task checklist, and five observable and seven-point scale rated behaviors. Both observers enter the OR with a handheld computer and pen and paper to record SFDs onto a task checklist and behavior event form. Evaluating a combination of tasks and behaviors shows the overall picture of the OR. The behaviors observed can be connected to the tasks completed and if a task is not completed, then a behavior observed can explain the reason for that omission, which is classified as a SFD.

Similar to OTAS, the Non-Technical Skills (NOTECHS) scoring system identifies SFDs related to teamwork in the OR. NOTECHS was modified from aviation (Flin et al., 2003) to be applied in the operating room (Catchpole, 2009; Catchpole et al., 2007). The goal of Flin et al.'s (2003) study was to collect SFDs based upon Reason's framework, the person approach and the system approach (Reason, 2000). This study used two observers. The SFDs were rated from 1 (Below Standard) to 4 (Exceed Standard) and were also compared to medical errors that were defined as minor, operating, or major problems. The SFDs were classified into 27 individual categories.

The Disruptions in Surgery Index (DiSI) tool provides seven categories to collect SFDs and measure them according to a questionnaire performed by the medical team after the procedure (Sevdalis, Forrest, Undre, Darzi, & Vincent, 2008). Instead of the observers rating the SFDs, the medical team assesses the seven disruption types on three predetermined measures: how often SFDs are seen, how much each SFD contributes to a potential error, and how much the SFD hinders the procedure from reaching its goals.

Surgical Flow Disruption Tool (SFDT) provides a framework to identify SFDs in cardiac surgery, but also includes an inter-rater reliability feature that accounts for the bias between observers (Parker, Laviana, Wadhera, Wiegmann, & Sundt III, 2010). Two observers initially collected SFDs for a month based upon the frameworks of Wiegmann et al. (2007) and ElBardissi et al. (2008), and then with a calibrated SFDT, collected SFDs from 10 surgeries. The entire process and framework for the SFDT is tailored for collecting SFDs and being able to transfer the calibration process to other ORs.

One positive aspect of using observation tools is the systematic approach and structure provided for a consistent study. Steps are predetermined and standardized for use in specific situations such as finding SFDs in a cardiac OR. If the surrounding parameters are met, then the observation tools will help the observers to find SFDs in an orderly manner. However, if the observers are not trained on the observation tool correctly, then the wrongful implementation of the tool produces distorted data. This dissertation uses the RIPCHORD taxonomy as a guide for data collection. Additionally, both observers, who are Human Factors Engineers, underwent rigorous training on taxonomy.

SFD Recovery

Out of the 20 papers examined in this review, four studies have analyzed SFD recovery, which they called compensation. The first paper compared SFD recovery to minor and major SFDs in two ways: frequency and logistic regression (de Leval, Carthey, Wright, Farewell, & Reason, 2000). Unrecovered SFDs were the focal point of the analysis because both minor and major unrecovered SFDs showed correlations to deaths or near misses. Individual unrecovered minor SFDs did not affect adverse outcomes but a link of multiple unrecovered minor SFDs showed a correlation to adverse outcomes. Multiple unrecovered major SFDs have a multiplicative effect, but individual unrecovered major SFDs have a correlation to adverse outcomes. Unrecovered SFDs were also averaged and compared to deaths/near misses and no adverse outcomes (Wong, Torchiana, Vander Salm, Agnihotri, Bohmer, & Ali, 2007). This study showed the impact of unrecovered SFDs was higher when compared to deaths/near misses. Therefore, based on these two papers, innovative ideas and initiatives are needed to prevent adverse outcomes due to unrecovered SFDs.

The purpose of the next two papers was to add temporal phase characteristics and timing to the analysis of SFD recovery. In addition to the recording of SFDs for temporal phases, the SFDs were timed and frequency was recorded for multiple characteristics of SFDs such as first response appropriate, faced before, rehearsed, equipment/skills available, and discussed (Wong, Vander Salm, Ali, Agnihotri, Bohmer, & Torchiana, 2006). The timed and characterized SFDs were compared to major and minor SFDs, and unrecovered and recovered SFDs. Unlike the previous two papers, minor and major SFDs were equally likely to be uncompensated. This is unusual since all SFDs have different reasons for being uncompensated. Lastly, the frequency of SFDs recovered was recorded over time (Wong, Ali, Torchiana, Agnihotri, Bohmer, & Vander

Salm, 2009). This study showed the trend of SFD recovery throughout the course of the procedure.

Although there has been some research studying SFD recovery, no one has looked at the process itself. In this dissertation, SFD recovery was coded based on who performed the recovery (individual, team, no one), which are the dependent variables. The phases of the surgery (pre-operative, anesthesia, pre-bypass, surgery, and post-bypass) and main categories in the RIPCHORD taxonomy are the independent variables that are compared to SFD recovery Once we know how, what, and when SFDs are recovered, organizations can develop target interventions to minimize specific SFDs.

Conclusion

In summary, to fill the research gaps that exist, this dissertation did the following:

- Observed cardiac procedures because they are the most complex and offer more opportunities to report SFDs
- Two human factors experts observed SFDs to provide coverage of the OR and expertise in human factors engineering
- The RIPCHORD taxonomy was used to supplement as the observational tool and structure for the observers in the OR
- SFD recovery was observed in the OR and analyzed for team, individual and no recovery to identify which types of SFDs based on the RIPCHORD main taxonomy categories need to be minimized and during which part of the operation

CHAPTER THREE

SURGICAL FLOW DISRUPTION
PRELIMINARY STUDY

This chapter is a published journal article in the Journal of Anesthesiology. The following authors contributed to this paper: Gary Palmer II, James Abernathy III, Greg Swinton, David Allison, Joel Greenstein, Scott Shappell, and Scott Reeves.

RIPCHORD: A Human Factors Methodology for Observing Flow Disruptions in the Cardiothoracic Operating Room

An initial effort to capture surgical flow disruptions was attempted to develop a taxonomy and potential standard of a methodology to find these disruptions. Research has shown that this is possible in a number of scenarios. Some researchers generated flow disruption tools such as OTAS (Healey, Undre, & Vincent, 2004) and SFDT (Henrickson-Parker, Laviana, Wadhera, Wiegmann, & Sundt III, 2010). Others focused on comparing medical errors to surgical flow disruptions and looking into their connections. This study focuses solely on the human factors aspects of surgical flow disruptions and their correlation to operation phase, team members in the OR, and different types of disruptions. Developing a trend among these traits is important since a completely new taxonomy can reveal new information. New data establishes its own identity and influences the changes made in the methodology (Chapter Four) to provide an improved study and more accurate data.

The Medical University of South Carolina Cardiothoracic Department

Located in Charleston, South Carolina, the Medical University of South Carolina (MUSC) is a medical institution that provides education in several fields, including medicine, dentistry, and pharmacology. The hospital itself is a large complex that is a teaching hospital and serves the southern coastline with 700 hospital beds. The cardiothoracic department houses newly renovated surgical suites and schedules aortic valve replacement, mitral valve replacement, and coronary artery bypass graft procedures daily. All operating rooms are not constructed the same. The organization and inventory of equipment is different across multiple operating rooms as well.

Detailed Description of Cardiothoracic (CT) OR Environment

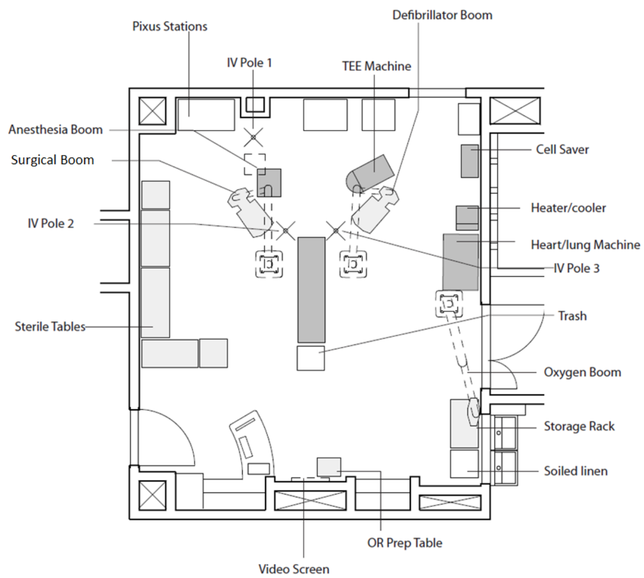

Figure 3.1. Equipment Layout in the MUSC CT OR.

A list and positioning of equipment in a cardiothoracic OR at MUSC is shown in Figure 3.1 with the operating bed in the center. The sterile tables, located to the left of the operating bed, are where the surgical instruments are placed. The top left region of the layout is also known as the sterile field during the operative phase. Nurses primarily use this area and the bottom of the layout to obtain anything needed by the team. The anesthesiologists are found at the top of the operating bed between the transthoracic echocardiography (TEE) instrument and IV Poles 1 and 2. Their area is small in comparison to the amount of students and doctors that frequently work in this area. Use of the supply cabinet and medication distributors to the patient also constricts the movement of these individuals. The perfusion area is on the right of the operating bed and the heater/cooler and heart/lung machine are pulled closer to the bed. In addition to the sterile tables in close proximity to the operating bed, the surgeon's space is also relatively small. New equipment to the surgical suites includes the anesthesia, surgical, and defibrillator booms that hover over and around the operating bed.

Cardiothoracic OR Team Members

Figure 3.2. Denomination of Personnel Areas

An explanation of Figure 3.2 sheds light upon the multiple doctors and staff that exist in the operating room. There are four professions that collaborate and work together to perform cardiothoracic surgeries. First, the surgeons (Region B) are the leaders of the OR since they interact the most with the patient. Surgeons use techniques to dissect the inside of a patient to replace valves and organs. The other three groups in the operating room use the middle of the room, or surgical table, as the hub where all information flows inward and outward. Since the MUSC hospital is a teaching hospital, surgical residents and students accompany the head surgeon during operations. Next, the anesthesiologists (Region A) are located at the head of the patient table. Depending on certain stages of the surgery, they inject medicines to manage how the patient reacts to the activity being performed by the surgeon. Unlike the surgeons, anesthesiologists have technicians that bring them information on occasion, but still have residents that are being educated.

Perfusionists (Region D) do not interact with the surgeons and anesthesiologists until the middle of the surgery where bypass begins. Their job is to be the patient's functioning heart and circulation while the surgeons repair organs in the chest area. Similar to the surgeons and anesthesiologists, perfusionists have students that they train and also medical students that observe as a part of their rotation. In smaller ORs, one perfusionist is necessary but two perfusionists are often stationed in this particular OR. The last profession in the OR is the nurse team (Region C) that supports each of the other three team members during the surgery. There are two types of nurses that preside over the surgery. Scrub nurses stand beside the surgeon and hand tools for them to complete the operation and a circulating nurse walks around the OR and helps everyone, including the scrub nurse.

Surgical Stages in the Cardiothoracic OR

Throughout the entire surgery, each team member in the OR has a specific role during different periods. There are three main stages of cardiothoracic surgery that will be observed. They are the pre-operative, operative, and post-operative stages. Snapshots of these phases are provided by Figure 3.3 with a description of the team members involved.

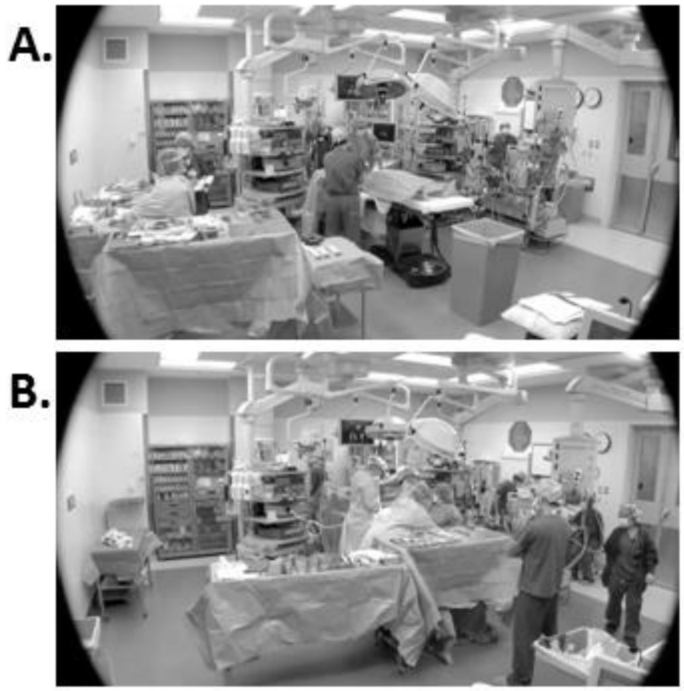

Figure 3.3. Snapshots (Panels) of Pre-op and Operative Stages

Panel A shows the pre-operative stage of surgery. In this period, anesthesia and nursing is preparing the patient. Anesthesia is prepping the patient to receive medicine during surgery and the nurses are keeping track of supplies and prepping the body of the patient below the neck. Panel B depicts the operative stage of surgery and is designated as the incision phase. The surgeons are the primary team members that are focused on in this phase. The perfusionists set up their equipment during the first phase to be ready for the operative phase. Nurses secure the sterile field and the anesthesiologists are on standby. The post-operative stage (not shown) is the last stage of cardiac surgery. The surgeons and perfusionists finish their respective jobs in the operative phase. However, the nurses and anesthesiologists are now out of the supporting role and back on the forefront. The anesthesiologists secure the patient's vitals and escort the patient to the recovery ward. The nurses stay behind to evaluate the inventory and clean up the OR for the next surgery.

This research studies all of the interactions made by the team members during the stages of surgery mapped above. Some instances of flow disruptions will be between certain team members or individual occurrences. The team members, environment, and methods used regulate the outcome of results. Consequently, the variety of what can occur is immense and the specific factors that go into how the cardiac OR is observed is pertinent. The literature, which examines earlier research in this specific topic, offers categories that are important to generating a systematic approach for observing surgical flow disruptions in the OR.

Preliminary Study at MUSC

Human factors have made impacts in multiple arenas such as aviation and railways, yet its introduction into healthcare and the operating room are recent. Initially in the realm of patient safety, the doctors and staff themselves are blamed for their lapse in technical skill and the sole reason for surgical error in healthcare. The advancement of operating suites and complexity of working environment also adds to the challenge of reducing near misses and deaths in the OR. In the 1950s, anesthesiologists began to investigate the incidence of adverse events (Lunn, 1986; Derrington & Smith, 1987; Warden, Borton, & Horan, 1994; Gaba D., 2000). Anesthesiologists later applied human factors engineering and systems approach techniques to better patient safety (Drui, Behm, & Martin, 1973; Gaba D., 2000). The importance of patient safety and its origination have increased and are currently understood by all medical personnel, yet the methods to monitor and decipher patient safety are still in their genesis.

While patient safety was growing in the medical field, methods of understanding patient safety were being generated and steering away from the premise of surgical performance. Several behavior markers were identified and showed that the technical skill of a surgeon is not the reason behind adverse events (Carthey, de Leval, & Reason, 2001; ElBardissi & Sundt, 2012). New research shows that the external and surrounding factors were causing the decrease in performance. The view of patient factors and surgical skill as the primary source neglects several factors that are key to accomplishing safe and high-quality performance in other high-risk environments (Vincent, Moorthy, Sarker, & Chang, 2004). These factors were human and ergonomic factors, such as leadership (Helmreich & Schaefer, 1994), organizational culture (Westrum, 1997), and decision-making (Flin, Salas, Strub, & Martin, 1997; Vincent, Moorthy, Sarker, & Chang, 2004). Therefore, to properly exhibit these human factors, observations are essential to providing accurate data.

Observations in the operating room provide a real-time occurrence of events. The recording of adverse events in the operating room is in-depth and easily recollected. Adverse events are all unique and have the ability to be misinterpreted from a participant's perspective. Observations in operating rooms have been performed by medical teams (Healey, Sevdalis, & Vincent, 2006; Wiegmann, ElBardissi, Dearani, Daly, & Sundt III, 2007), then afterwards with a mixture of medical and human factors experts (Undre, Healey, Darzi, & Vincent, 2006; Henrickson Parker, Laviana, Wadhera, Wiegmann, & Sundt III, 2010) or human factors experts alone (Al-Hakim, 2011; de Leval, Francois, Bull, Brawn, & Spiegelhalter, 1994; de Leval, Carthey, Wright, Farewell, & Reason, 2000). Allowing multiple human factors experts to position themselves inside an operating room adds quality to the observation and less bias of what occurs during the procedure. In addition, using observational methods are useful for researching a complex environment such as operating rooms (Hazelhurst, Mcmullen, & Gorman, 2004; Nemeth, Cook, O' Connor, & Klock, 2004; Roth, et al., 2004; Healey, Undre, Sevdalis, Koutantji, & Vincent, 2006).

Observations provide a real-time occurrence of adverse events that have the potential to cause danger to the patient's safety in a complex environment. The ability to evaluate the human factors of each team member is important to the accuracy of classifying and tallying surgical flow disruptions. Recently, studies have been completed showing how human factors impact the threats of patient safety in ORs (Wiegmann, et al., 2007; Leape, 2000; Gawande et al., 1999). The goal of this preliminary study is to generate a common taxonomy that includes all known human and physical elements. These components are captured to produce valid and reliable comparisons so that a common nomenclature is used throughout all cardiothoracic ORs.

Development of Taxonomy

A total of 1158 observations were made by the two observers. Since each observer had an overlap in recording responsibilities, 1080 observations remained after duplicate observations were screened. All of the flow disruptions were recorded on evaluation sheets seen in Appendix B. Each flow disruption was screened and classified into initial groupings to create potential flow disruption classes. Once all of the flow disruptions found groupings, six clusters were created with 33 subcategories (i.e., communication, usability, physical layout, environmental hazards, interruptions, and equipment failures). Specific data within each disruption, such as team member and description of the event, helped with the dissemination of subcategories within each cluster. A complete catalog of the final observational taxonomy is shown in Table 3.1.

Table 3.1. Description of Clusters and Subcategories for Observational Taxonomy

Communication (verbal and non-verbal)

Environmental Noise – The increasing sound level in the OR may cause flow disruptions of communication, or decrease concentration of the current task.

Lack of response–The failure of an individual to answer communication requiring a reply or confirmation.

Poor Communication – Communication between two or more individuals that does not achieve its desired goal and is not captured by other categories within this area of interest.

Simultaneous Communication – Two or more individuals are communicating at the same time resulting in miscommunication or repeating of information.

Confusion – A demonstrated lack of understanding associated with communication directed at the individual or otherwise intended for his use.

Non-essential Communication – There are periods of time within any undertaking where attention must be focused on the task at hand and all non-essential communication (e.g., sports-talk, jokes, personal inquiries) must be eliminated.

Usability

Computer – This category includes problems associated with operating software, programs, and utilities; however, usability issues associated with pointing devices, monitors, and other hardware are also included here.

Equipment – Usability and design issues associated with equipment other than computers and software related devices like iPads and smartphones.

Connectors – Textures, colors, and other design-controlled attributes that inhibit optimal use.

Barriers – There are numerous barriers erected for maintaining sterile fields. Problems associated with erecting those barriers or donning protective equipment (e.g., gloves, gowns, etc.).

Packaging – Issues associated with unwrapping, untying, or opening packaging containing supplies and instruments.

Data Entry (non-computer) – This category includes usability issues associated with hard-copy data entry devices (e.g., forms, checklists, etc.).

Layout

Positioning – Disruptions due to the location of any staff member that prevents efficient movement in the surgical suite.

- **Connectors**– The entanglement or misplacement of wires and tubes, which can hinder movement, and continuation of a task.
- **Equipment** – Machines and tools may restrict or prevent the movement and actions of the staff.
- **Furniture** – Chairs, operating room bed, and desk can cause OR staff to deviate from their original movement.
- **Permanent Structures** – Doorways are frequently used in the OR during surgical procedures that prevent continuous movement and possible injury.

Inadequate Use of Space –Surface and floor space is used inappropriately through clutter, untidiness, congestion, and blockage.

Impeded Visibility – The staff may have objects that obstruct their ability to see at important junctions during the procedure.

Environmental Hazards

Slips – OR staff have the potential of slipping on liquids and materials on the floor while not being cognizant of surroundings.

Sharps – Incidents that involve the interaction of OR staff with contaminated needles.

Crushing – Objects that are forced and wedged between unintentional spaces.

Interruptions

Phone Calls – Incoming or outgoing calls occur that draw attention away from the surgical procedure.

Pages – During surgery, pagers are given to the circulating nurse and interrupt the surgeons and anesthesiologists when each page comes in.

Non-essential Personnel – MUSC staff that are not essential to the Cardiothoracic procedure are labeled as a distraction.

Spilling/Dropping Items – When materials are dropped or spilled on the floor, the staff member is potentially diverted away from his current task.

Teaching Moments – The hospital at MUSC is used as a teaching tool for its medical students, which means the staff may pause and teach students during the procedure.

Outside Distractions –Disruptions external to the operating room that interfere with normal activities (e.g., noises in the passageway, fire alarms, etc.).

Shift Changes – During a shift change among nurses, they communicate about where they are within the procedure and distracts all team members.

Searching Activity – Miscellaneous items become missing in the OR and are pursued when they are needed immediately.

Common Information –Information that every staff member should be knowledgeable of, yet forgets and interrupts others to retrieve the information.

Equipment Failure

Surgeons Equipment – Equipment that malfunctions during surgery used by surgeons.

Anesthesia Equipment – Equipment that malfunctions during surgery used by anesthesiologists.

Perfusion Equipment – Equipment that malfunctions during surgery used by perfusionists.

Results

Flow Disruptions: Overall

A total of six categories encompassing a wide variety of flow disruptions were observed throughout 9 surgeries. The overall frequency and percentage of each category is displayed in Figure 3.4. With 31% of the flow disruptions, the physical layout of ORs is the most prominent disruption. Subsequent disruptions such as general interruptions (24%), usability concerns (20%), and communication issues (15%) followed. The last two disruptions, environmental hazards (8%) and equipment failures (1%), were scarce throughout the study. However, these are categories that are noteworthy and the frequency of occurrences only shows the exceptional work performed by the OR team.

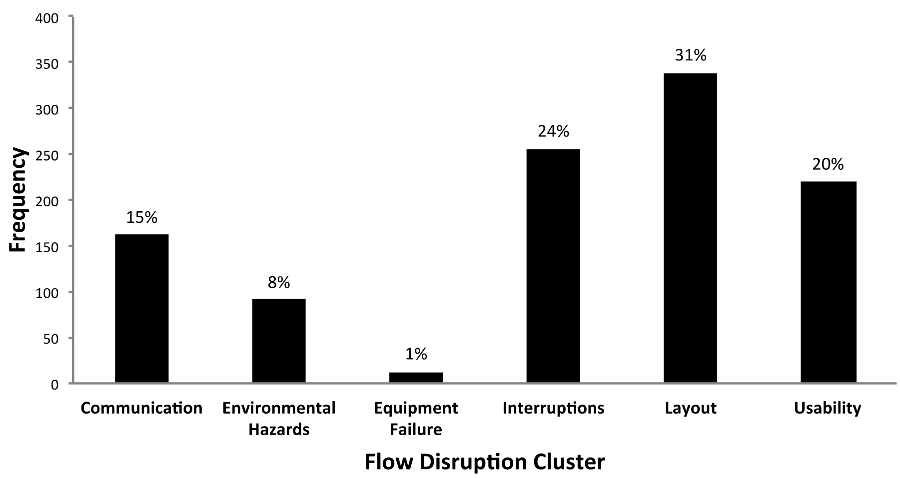

Figure 3.4. Overall Frequency Data with Percentages

Inadequate use of space (158), and the wrongful positioning of furniture (74) and equipment (72) were the more prevalent disruptions among the layout category. The group of interruptions also shows a comparable frequency with its top subcategories, such as spilling and dropping items (117) and shift changes (70).

Usability was observed in one-fifth of the total observations in this research. As the third largest category, multiple types of usability disruptions were observed. Non-computer equipment usability such as IV poles, beds, television monitors, and equipment booms were observed the most (91). Next, computer usability, such as software and data input devices, were another issue that was seen (26). The difficulty of handling tubes and wires also showed a low frequency but ranked third in this classification (19).

Communication has been a focal point in some flow disruption research, but with 15% of the total amount, several notable subcategories were defined. Poor communication between OR team members was seen the most in this category (72). Confusing communication between two team members was the second most frequent disruption (33). Lastly, a team member not responding to an inquiry made by another team member occurred 25 times.

Flow Disruptions During Specific Phases of the Operation

Evaluating flow disruptions by phase of operation can isolate a particular type or subcategory. The division of flow disruptions among operation phase is shown in Figure 3.5. A chart of flow disruption frequencies divided into operation phase and disruption category is given in Table 3.2. In the pre-operative phase, the first amount that immediately draws attention is number of layout issues (152). This total is nearly double that of the subsequent leading types, which are usability (80) and interruptions (76). The main issue seen in the layout category was the inadequate use of space (65), followed by the incorrect positioning of furniture (44) and equipment (28).

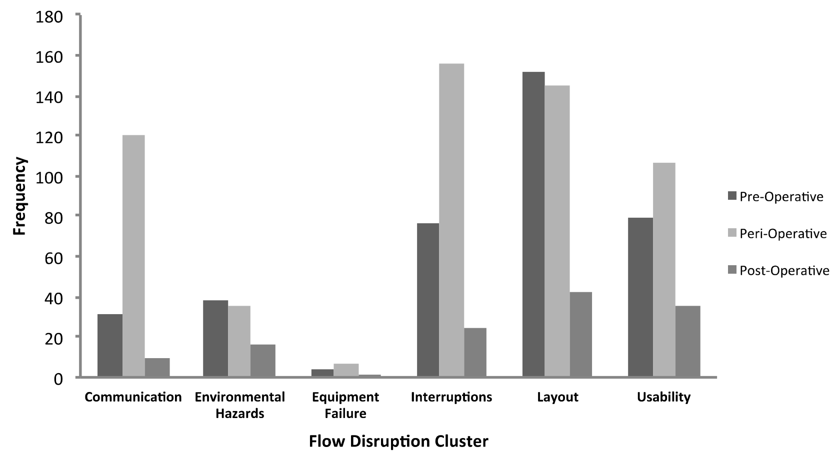

Figure 3.5. Flow Disruptions for each Operational Phase

Table 3.2. Tabular Form of Overall Frequency Data

	Communication	Environmental Hazards	Equipment Failure	Interruptions	Layout	Usability
Pre-operative	32	38	4	76	152	80
Operative	120	37	7	154	145	105
Post-operative	10	17	2	24	42	35

Interruptions (27%) were present slightly higher than layout issues (25%) in the operative phase. Throughout the six groups of disruptions, the operative phase showed that inadequate use of space (82), spilling and dropping materials (63), and searching activities (47) were the most prevalent. The operative period contrasted to the pre-operative period by observing more communication and usability issues. Communication issues nearly quadrupled and interruptions doubled from pre-operative to operative phases.

An issue from the previous figure is the actual subcategory within layout, communication, and usability that contributes the most disruptions. Frequencies and percentages of every subcategory in the study are illustrated in Table 3.3. Those percentage values are calculated vertically and within each grouping of operation phase and category. Through the inspection of this table, inadequate use of space was the most observed layout issue in both phases [Pre-operative: 65, (43%); Operative: 82, (57%)]. The positioning of equipment and furniture showed consistency across pre-operative and operative stages. Then, spilling and dropping items closely trailed these instances.

Table 3.3. Specific Layout Flow Disruptions between Pre-Op, Operative, Post-Op Phases

Flow Disruption	Pre-Operative	Operative	Post-Operative
Communication			
Poor Communication	10 (31%)	60 (50%)	2 (20%)
Lack of Response	9 (28%)	16 (13%)	0 (0%)
Confusion	7 (22%)	21 (18%)	5 (50%)
Simultaneous Communication	0 (0%)	5 (4%)	0 (0%)
Non-Essential Communication	2 (6%)	8 (7%)	2 (20%)
Environmental Noise	4 (13%)	10 (8%)	1 (10%)
Usability			
Computer	9 (11%)	16 (15%)	1 (3%)
Equipment	31 (39%)	52 (50%)	8 (23%)
Connectors	16 (20%)	24 (23%)	20 (57%)
Barriers	10 (13%)	0 (0%)	3 (9%)
Packaging	9 (11%)	8 (8%)	2 (6%)
Data Entry (non-computer)	5 (6%)	5 (4%)	1 (3%)
Layout			
Connector Positioning	5 (3%)	8 (5%)	6 (15%)
Equipment Positioning	28 (18%)	23 (16%)	14 (36%)
Furniture Positioning	44 (29%)	27 (19%)	10 (26%)
Permanent Structure Positioning	7 (5%)	0 (0%)	1 (2%)
Inadequate Use of Space	63 (43%)	82 (57%)	11 (21%)
Impeded Visibility	3 (2%)	5 (3%)	0 (0%)
Environmental Hazards			
Slipping/Falling	24 (63%)	29 (78%)	9 (53%)
Sharps	12 (32%)	3 (8%)	1 (6%)
Crushing	2 (5%)	5 (14%)	7 (41%)
Interruptions			
Phone Calls	3 (4%)	6 (4%)	1 (4%)
Pages	0 (0%)	10 (6%)	4 (17%)
Non-Essential Personnel	1 (1%)	5 (3%)	0 (0%)
Spilling/Dropping Items	41 (54%)	63 (41%)	13 (54%)
Teaching Moments	3 (4%)	9 (6%)	0 (0%)
Outside Distractions	3 (4%)	10 (6%)	2 (8%)
Shift Changes	20 (26%)	46 (30%)	4 (17%)
Searching Activities	5 (7%)	1 (1%)	0 (0%)
Common Information	0 (0%)	4 (3%)	0 (0%)
Equipment Failure			
Surgeon Equipment	2 (50%)	3 (42%)	2 (100%)
Anesthesia Equipment	1 (25%)	2 (29%)	0 (0%)
Perfusion Equipment	1 (25%)	2 (29%)	0 (0%)

Usability issues displayed a small disparity between the first two phases (Pre-op: 80; Operative: 105). Equipment usability was the most frequent disruption observed at 50%. The subsequent flow disruptions, connectors (23%) and computer use (15%), were far behind. In the communication group, however, a large difference existed between the pre-operative (32) and operative (120) phases. Specifically in this category, poor communication (60) was observed the most, followed by confusion (21) and non-responsive communication (16).

In the post-operative phase, a majority of categories recorded witnessed little to no observations. The amount of observations in this phase was due to the small amount of team members and time to clean the OR. Nonetheless, layout (42), usability (35), and interruptions (24) were the most observed in the post-operative phase. This order is identical to the pre-operative phase. Several noteworthy subcategories in the post-operative phase were the usability of connectors (20), improper layout of equipment (14), and spilling/dropping items (13).

Flow Disruption for Personnel Type

Another method of analyzing this data is separating the flow disruption categories by personnel types that were observed. The complexity of the hospital is well documented and the relationships of all four team members are included. Similar to the last section that dissected operation phase, Figure 3.6 and Table 3.4 provide pictorial and tabular forms of how each team member in cardiac surgery were observed under the flow disruption categories.

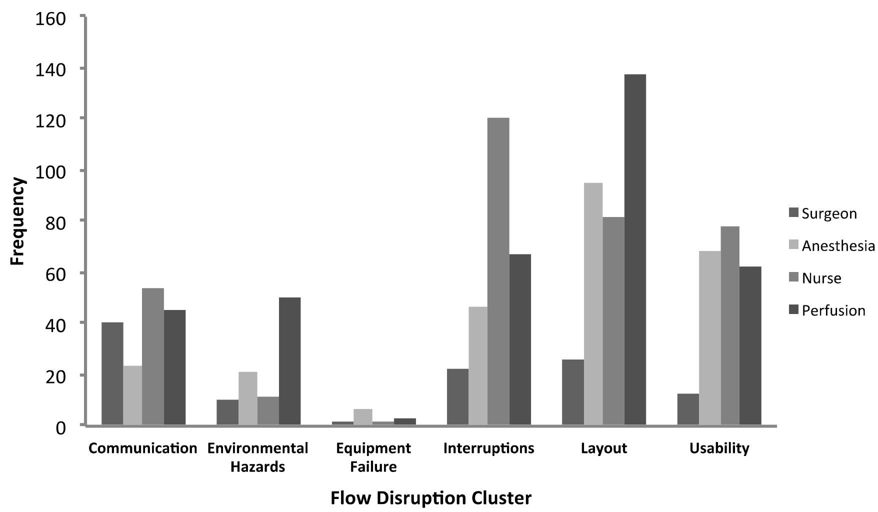

Figure 3.6. Flow Disruption Frequency Data Sorted by Personnel Type

Table 3.4. Tabular Form of Personnel Type Data

	Communication	Environmental Hazards	Equipment Failure	Interruptions	Layout	Usability
Surgeon	40	10	2	22	26	13
Anesthesia	24	21	7	47	95	69
Nurse	54	12	1	119	81	77
Perfusion	44	49	3	66	137	61

Surgeons have one of the most invasive parts of surgery and the lowest amount of flow disruptions out of the entire group. Communication was the disruption that occurred the most (40). After communication issues, layout concerns (26) and interruptions (22) follow as subsequent categories. Though communication was the highest among surgical disruptions, nurses (33%) and perfusionists (28%) had higher amounts of disruptions within this category.

For anesthesia flow disruptions, a different order of groups emerged. Layout issues (36%) were the most frequent, while usability (26%) and interruptions (18%) followed directly behind. Equipment failure is the only category where anesthesia had the most occurrences (7), but also had the second-most in two other groups: layout (95) and usability (69). The total amount of equipment failures seen by the anesthesiologists is 2% of the entire data collection.

The nurses have three flow disruption categories that account for at least one third inside that particular group: interruptions (47%), usability (35%), and communication (33%). A large disparity is also seen in the interruptions category where the amount nearly doubles the amount for perfusion. In terms of nursing disruptions only, the most frequent groups were interruptions (119), layout (81), and usability (77). Nurses were constantly observed in circulation around the OR and assisting the other team members.

Anesthesia and perfusion showed the most frequency of flow disruptions in the layout category (38%). The most prominent subcategories for perfusionists in the layout group were the inadequate use of space (53%), and wrongful positioning of equipment (21%) and furniture (18%). Within the amount of occurrences under perfusion, layout issues (137) more than double any other amount. Interruptions (66) and usability concerns (61) follow physical layout issues in frequency. In addition to leading the amount of layout issues over all other personnel types, perfusionists also had the most environmental hazards (49).

Discussion

This preliminary study had two goals to accomplish: to provide a developed taxonomy under human factors only and to show that all flow disruptions found can be analyzed within the scope of the taxonomy. Creating a taxonomy without the influence of medical error gave a chance to the observers to shape categories freely. All disruptions found during this study cannot be linked to a particular medical error, but can later be compared to surgical outcomes. Another aspect of this taxonomy is the amount of subcategories within the disruption types. Developing 33 subcategories allows the root cause of issues in the operating room to be clearer. Researchers have described their main groups of disruptions in detail and given severity of each occurrence, but rarely an exclusive cause within those groups. Al-Hakim dissected disruptions found in the OR as general areas and particular sources (Al-Hakim, 2010). Specific event types were presented with general event types (Parker et al., 2010) and contributing factors were supplemental to seven factor types in another study (Vincent, Taylor-Adams, Chapman, 2000). Therefore, this level of specificity is useful for targeting potential areas to rectify in surgical suites.

Physical layout issues are the clear leading disruption type found in surgery. Layout disruptions also have the largest subcategory observed in this study, which is the inadequate use of space (n=145, 13%). Equipment and technology have been defined in the past and noted in research studies in surgical flow disruptions. However, specific factors in physical layout, such as the use of floor or surface space, positioning of equipment, furniture or connectors, and impeding visibility, have not been recorded in this manner. In previous literature, the operating room environment was discussed differently. Bleeps, external noise, loud music, people walking in and out, temperature, and unavailable equipment describe the detailed items under environment (Sevdalis et al., 2008). Another study described environment as the instruments, equipment, staffing, and distractions in the surgical suite (Wong et al., 2007). Design, availability, and maintenance of equipment were identified as one factor in a systems approach to quality but are extremely broad in explaining a flow disruption (Vincent et al., 2000). This category could help the architectural design of a surgical suite but the actual use is for those particular issues by the OR team to be recognized through observation.

Another unusual flow disruption type is usability. Usability describes the team member's trouble with attempting to use specific objects during surgery. This category can be comparable to tools and technology (Morrow et al., 2005; Karsh and Holden, 2007) or procedural (Parker et al, 2010) disruptions in other studies. These flow disruptions were grouped together because of how the events were described. The team members did not fluidly continue their task because of issues with objects that they may or may not have had experience operating. Since these disruptions range from connectors (wires and tubes) and equipment to barriers and packaging, the variation in potential issues can attest to this group being the second highest in this study.

Similar to usability, the interruptions group is not seen often in literature. Other researchers call the interruption factors “miscellaneous items” or place them in the category of “other.” Interruptions are events that are extraneous to the other five categories and also distract the team member from their primary task. Among the variety of interruptions, this study denotes shift changing as the highest extraneous factor seen in surgery (n=70, 27%). However, communication is a highly researched disruption, but only ranks fourth in these standards. Communication disruptions are the focal point of many research studies (Carthey et al, 2003; DeFontes and Surbida, 2004; Wiegmann et al., 2007). One researcher dissected communication into four types of failures and evaluated how preoperative checklists solved communication (Lingard, et al., 2004; Lingard, et al., 2008). Regardless, there is no emphasis placed on communication because 15% of the total observations are low compared to the top three main flow disruptions.

Converse to overall surgical flow disruption frequency, two other trends were examined: phase of operation and personnel types against disruption categories. There were studies that involved the entire operation and observed all phases but did not distinguish them (Catchpole, 2009; Christian et al., 2006; Nast et al, 2005). Concentrating on one phase is beneficial for targeting specific flow disruptions or using solutions adopted from that phase on the rest of the operating procedure. One study removed flow disruptions from the postoperative phase, due to unavailability of observing in the postoperative ward (Wong et al., 2006). Nonetheless, trends were established using operative phases as a classification. Physical layout concerns produced the most disruptions in all three phases. Communication, as a whole category, was low in observations but showed a comparable amount of disruptions to interruptions and layout issues in the operative phase. During the operative phase, the surgeon plus the perfusion team enter the procedure. Also, the majority of interruptions was seen in the operative phase and doubled the amount seen in the preoperative phase.

The analysis of personnel types was another way to differentiate flow disruptions against one another. Since there are four distinct roles and areas, additional help can be provided to the team more efficiently. Perfusion was first or second in every category, with the exception of a close third in usability. Perfusion is very active and interacts with every team member as frequently as the nurses. Perfusionists were also noticeably the leaders in environmental hazards and layout issues. Nurses had the most disruptions in interruptions with a large disparity and narrowly in usability and communication. The professional with the lowest amount of disruptions total were surgeons. This finding is consistent in other studies that have concentrated on the events of surgeons in stress levels and communication (Sevdalis et al., 2008; Bognar et al., 2008). However, surgeons and anesthesiologists will not have as many surgical flow disruptions because this study is focusing on human factors related events. Though medical events committed by the physicians will not be seen, it will provide a snapshot of every personnel type's need of improvement.

Conclusion

Through the course of this preliminary study, several accomplishments were made. A taxonomy of surgical flow disruptions was created by only considering human error during the procedure. This taxonomy will serve as a nomenclature for other researchers and hospitals to use in their search for surgical flow disruptions. New trends have been developed from the taxonomy. Physical layout and usability are the primary sources of disruption, unlike previous research where communication or procedural issues are at the forefront. Once the data is sorted by operational phase and personnel type, trends among those categories were straightforward. The optimization of the taxonomy and observation procedure will increase the accuracy of detecting flow disruptions.

CHAPTER FOUR

METHODOLOGY

As a follow-up to the preliminary study, the methodology of this study validates the use of the RIPCHORD taxonomy, developed in the preliminary study, as a method to guide observations and analysis of SFDs. The literature review in Chapter 2 identified research gaps, which needed to be addressed in order to move the research forward. Chapter 4 describes the details of building and expanding on the preliminary study to fill such research gaps. This chapter begins with an overview of the study design. Then the work system that is the focal point of this research is described by providing details of the study setting and the participants within that setting. Next, recruitment procedures are reported followed by an explanation of the data collection procedures. Finally, there is an explanation of the data analyses steps that were taken to evaluate the results of the study.

Overview of Study Design

As stated in chapter one, the two aims of this study are to 1) validate the use of the taxonomy developed in the preliminary study (Chapter 3), and 2) predict the likelihood of surgical flow disruption recovery. In order to accomplish both of these aims, direct observations with two observers were conducted during eleven cardiovascular surgeries. Direct observations have been used before to collect data on surgical flow disruptions (Helmreich & Schaefer, 1994; de Leval et al., 2000; Wong et al., 2006; Undre et al., 2006; Wiegmann et al., 2007). Standing in an OR and observing surgeries provides an advantage of visually and contextually identifying SFDs. Several characteristics are directly observable in ORs, such as implicit communication, and social cues (Yule, Flin, Paterson-Brown, & Maran, 2006). The hospital's Institutional

Review Board (IRB) approved the study protocol and it was agreed to by Clemson University's IRB.

Study Setting

The hospital that was observed is a large complex teaching hospital that serves the southeast region. The hospital has 700 hospital beds and their Heart and Vascular Center treats over 14,000 patients per year. The cardiothoracic department houses newly renovated surgical suites and schedules aortic valve replacement, mitral valve replacement, and coronary artery bypass graft procedures daily. Two out of the twelve surgical suites are solely used for cardiac surgeries. The cardiac surgery operating room is the system of interest for this study and observations are focused on the cardiac surgical team. Within the cardiac operating room environment there are two sub-systems: the social sub-system and the technical sub-system. The complexity of the cardiac procedure emerges from these two sub-systems interacting with one another. Below each sub-system is described in more detail to help the reader understand the environment in which surgical flow disruptions occur.

The Social Sub-System

In the cardiothoracic operating rooms, there are four types of personnel that work together to perform the surgical procedures. First, anesthesiologists and anesthesia residents control the immobility, pain responses, and memory of the patient. Next, surgeons and surgical residents physically repair the body of the patient in conjunction with all other team members. Head nurses, circulating nurses, surgical nurses, and technicians are the support group for all others in the OR. OR nurses and technicians support the other professions by providing real-time lab results, beeper notifications, supplies from external storage areas when needed, counting all sponges used during the procedure, and keeping track of patient information. Perfusionists and perfusion students control the flow of blood that comes in and out of the patient. Lastly, because this is a teaching hospital, medical students are frequently present in the cardiac OR for observational purposes.

The Technical Sub-System

The social sub-system of the cardiac OR is surrounded by the technical aspects of the system. In Chapter 3, Figure 3.1 shows the physical layout of the cardiothoracic OR. The top left region of the layout is known as the sterile field during the operative phase. The sterile tables, located to the left of the operating bed, are where the surgical instruments are placed and pulled closer to the surgical table to separate the sterile field from the normal walking area. Nurses primarily use this area and the area shown at bottom of the layout to provide anything needed to the team. Ice, surgical wire, replacement aortas, and other materials are retrieved by accessing the storage area which is located outside the bottom left corner of the layout (this area is called the CORE). The anesthesiologists are found at the top of the operating bed between the transesophogeal echocardiography (TEE) instrument and two intravenous (IV) poles. All of the anesthesiologists' instruments are in close proximity to them and are frequently used to monitor the patient's condition such as the TEE, which is a non-invasive screening method that shows an ultrasound of the heart's four chambers. Their area is small in comparison to the amount of space the residents and doctors have to work in. This space can hold up to five people at one time. At the top of the diagram, the supply cabinet also constricts the movement of the anesthesiologists. The perfusion area is at the right of the surgical table and the heater/cooler and heart/lung machine are pulled closer to the bed during surgery. The surgical suites also include anesthesia, surgical, and defibrillator booms that hover over and around the operating bed. The nursing station is located in the bottom left corner of the layout.

Recruitment Procedures

The large complex teaching hospital in the southeast region is the procurement site for surgical flow disruptions in cardiac surgeries, so the schedules for this type of surgery needed to be known. The hospital liaison and champion of this study, Dr. Abernathy, gathered the dates and times of the operations and relayed that information to the observers. Since the characteristics of the participants in the OR were not being recorded, specific staff member information was not needed for observation. The IRB states that no names of individuals in the OR should be recorded during the observations and obtaining patient information is not a part of this study. Also, the observers did not divulge the specific nature of the study to avoid compromising the data.

Data Collection Procedures

Direct observations were conducted using a structured protocol seen in Appendix B. Two observers, human factors engineers, conducted the direct observations. The human factors observer (dissertator) who had experience collecting SFD data (see Chapter 3) trained the other human factors observer (YY, see acknowledgements). Training consisted of an iterative process of: 1) reviewing the taxonomy developed in the preliminary study, and providing examples of previous data collected and coded in each category, 2) a test where the human factors observer was given data and asked to categorize it using the taxonomy, and 3) comparing observation notes, observing two trial observations and discussing disagreements afterwards. Once both observers were confident in their ability to collect similar data, formal observations for data collection purposes began.

Eleven surgeries in total were observed. Observations were performed until saturation was met. Saturation is the limit where the latter portion of observations shows little fluctuation in the number and category of SFDs observed (Richards, 2009). The taxonomy developed in Chapter 3 was the framework used as a guide for data collection (Palmer II et al., 2013). Data was collected during the pre-operative, anesthesia, pre-bypass, surgery, and the post-bypass phases of the surgery. Observers recorded the following information: timestamp of the SFD, description of SFD, whether the SFD was recovered (team, individual, or none), and location of SFD.

Based on Wong et al., 2006, data collection commenced with the start of the pre-operative phase, which starts as soon as the nurses and perfusionists enter the OR. Observers had minimal communication with the HCPs in order to not be sources of SFDs themselves and to allow the HCPs to concentrate on their primary tasks and perform as naturally as possible. The nurses and perfusionists setup the OR and their stations before the patient enters. Next, the anesthesiologists walked in with the patient and setup their stations simultaneously (anesthesia phase). Once the patient was induced under anesthesia, the pre-bypass phase began. As the moment of incision nears, the surgeons walked into the OR and talked to the anesthesiologists about anticipated complications during the surgery. Then, the surgeons scrubbed their arms and hands, and prepared to make the first incision into the patient. Just before the incision (transition from pre-bypass to surgery stage), a timeout is taken to inform every one of the patient's vital statistics, confirm techniques being done on the patient, and discuss a plan for potential problems that may occur. No SFDs are recorded during the timeout. Then, the surgery began and the recording of SFDs resumed simultaneously. Once the incision is made on the patient, the surgery phase begins. The surgery phase lasts until the start of closing the incision, which is then the start of the post-bypass phase. During the post-bypass phase, nurses also prepare the OR for the next procedure by cleaning the OR and returning equipment and materials back to their standard positions.

Statistical Analysis

Coding SFD Data

Chapter 3 provided a taxonomy with six main categories and 33 subcategories (Palmer II et al., 2013). The taxonomy was used as the framework for coding SFDs for this dissertation's observations. To develop the taxonomy, qualitative deductive coding was applied, where each disruption was organized into clusters or similar groupings before a meaning was associated to each group (Creswell, 2009; Rossman & Rallis, 1998). For this dissertation, qualitative inductive coding was used following the steps below:

1. Read and understood all of the SFDs collected to gather a sense of what occurred throughout the observations.
2. Grouped all SFDs individually into a corresponding RIPCHORD taxonomy cluster based upon the categories' definitions.
3. Grouped all SFDs within suitable main categories and subcategories.
4. Reassessed all of the SFDs within the main categories and subcategories to determine if more groups needed to be added, or if SFDs needed to move into a more appropriate group.
5. Documented all SFDs that did not fit within the predetermined categories of the taxonomy.
6. Determined whether the SFDs that did not fit the category should be grouped to develop new categories or subcategories within the RIPCHORD taxonomy.

Research rigor was met by ensuring internal validity, objectivity, and reliability. Internal validity of a research study establishes the accuracy between the researchers and participantss (Creswell, 2009; Creswell & Miller, 2000). One way to ensure internal validity is by conducting member checking. Member checking is done by allowing participants to determine whether the coding is accurate (Creswell, 2007; Devers, 1999; Padgett, 2008). Member checking for this data set was completed by a medical expert, who was also a participant in the study (JA). Methodological rigor was also confirmed by accounting for objectivity. Objectivity is obtained when findings are examined and determined to be free from bias (Devers, 1999). This dissertation confirmed objectivity by having a human factors expert (AJR-R) skeptically review the data. Lastly, the reliability of analyzing SFDs was confirmed through holding a review of SFDs after the data was compiled, documenting all coding procedures of possible SFD occurrences, and double-checking coding of the SFDs (Devers, 1999).

Predicting SFD Recovery

The independent variables (IVs) for this study were the 6 RIPCHORD main categories and the 5 operational phases. The dependent variable was SFD recovery which has three levels: 1) team recovery, 2) individual recovery, or 3) no recovery. Before predicting the likelihood of recovery, all independent variable outliers were identified and eliminated to determine the set of interactions, between RIPCHORD categories and operational phases, which could be analyzed. There were SFDs in certain interactions between the 2 levels of IVs that rarely occurred during data collection. The independent variables related to these interactions were evaluated by frequency first. If the row or column of the independent variables contained cells with zero observations, then those variables were subject to elimination. The deviance of the regression, and its significance, without the infrequent interactions determined what independent variables to eliminate. Deviance is a goodness-of-fit statistic that tests the variance between log-likelihood functions of the data within a model (Cohen, Cohen, West, & Aiken, 2003). Also, hierarchical regression was performed to analyze the difference in significance between the model with all 11 IVs and the model without the eliminated IVs. When the hierarchical regression is run without the outliers and the deviance is still significant, then this is the first step to validating the modified model.

Multinomial Logistic Regression

Multinomial logistic regression was used to calculate the probability of SFD recovery. Multinomial logistic regression techniques is used when the dependent measure has three or more categories that are unordered, which is the most frequent type of regression used (Menard, 2002). By using the maximum likelihood method, the best fitting function can be generated to describe how the IVs will help contribute to predicting the likelihood of the dependent variables. The probabilities of the dependent variables will all add up to one is a relatively easy way to evaluate the multivariate nature of the problem (McFadden, 1997). A multinomial logit model also has a multinomial probability distribution where binomial and multiple logistic regressions have binomial distributions (Allison, 2012). The major difference between multinomial and binomial logit models is the conditional probability that is assumed when more than two dependent variables are used.

The symbols and equations below explain how the prediction probability (p) of whether SFD recovery (team, individual, or no recovery) occurs, within a certain operative phase, and taxonomy grouping.

First, the probabilities for each dependent variable are:

p_{i1} = the probability that there is no recovery
p_{i2} = the probability that there is individual recovery

p_{i3} = the probability that there is team recovery

Then, let **x** be a column vector for independent variables:

$\mathbf{X}_{\boldsymbol{i}} = [1\ x_1\ x_2]$

where x_1 refers to the main taxonomy categories and x_2 refers to the operational phases. Next, let **β** be a row vector of the IV coefficients. For a three-category dependent variable case, there are three binary logit models that include:

$$\log\frac{p_{i1}}{p_{i3}} = \beta_1 \boldsymbol{x}_i$$

$$\log\frac{p_{i2}}{p_{i3}} = \beta_2 \boldsymbol{x}_i$$

$$\log\frac{p_{i1}}{p_{i2}} = \beta_3 \boldsymbol{x}_i$$

The choice of variables within this study is derived from the parameters seen by observing cardiothoracic surgeries (taxonomy categories and operational phases). Contrary to the preliminary study, personnel type will not be evaluated in this statistical analysis. Connecting a healthcare professional to an SFD is similar to placing blame of error on an individual. Additionally, SFDs are not always caused by people (e.g., technology malfunctioning), therefore linking causation can be both difficult and inappropriate.

To find the likelihood of SFD recovery, the properties of logarithms help to solve this problem (Allison, 2012). The equation below creates a relationship between the independent variable coefficients.

$$\log\frac{p_{i1}}{p_{i2}} = \log\frac{p_{i1}}{p_{i3}} - \log\frac{p_{i2}}{p_{i3}}$$

$$\beta_3 x_i = \beta_1 x_i - \beta_2 x_i$$

$$\beta_3 x_i = (\beta_1 - \beta_2) x_i$$

When the IV cancels on both sides, the coefficients are left with the identity: $\beta_3 = \beta_1 - \beta_2$. By substituting the probabilities for IVs and coefficients, each probability can be solved for and are shown as:

$$p_{i1} = \frac{e^{\beta_1 x_i}}{1 + e^{\beta_1 x_i} + e^{\beta_2 x_i}}$$

$$p_{i2} = \frac{e^{\beta_2 x_i}}{1 + e^{\beta_1 x_i} + e^{\beta_2 x_i}}$$

$$p_{i3} = \frac{1}{1 + e^{\beta_1 x_i} + e^{\beta_2 x_i}}$$

These equations were used in the SPSS 19. There are four categories that entered into SPSS to run the Multinomial Logistic Regression program. Each column within SPSS contained an independent variable with either a ‘zNo’ for no disruption and a ‘Yes’ for indicating a disruption in the category. The last column contained the dependent variable, SFD Recovery, where No Recovery = 1, Individual Recovery = 2, and Team Recovery = 3. Once the dependent variables, IVs, and frequencies were entered into SPSS, the multinomial logistic regression was run. The logistic regression table provided the IV coefficients, odds ratios, p-values, and goodness of fit tests. Also, the proportion estimations provided a numerical estimate of each unique combination given from the data.

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CHAPTER FIVE

RESULTS

This chapter is written as a prospective paper that will be submitted to a peer-reviewed journal; however, the headings and captions mimic the section headings for this dissertation document. Although this chapter includes topics discussed in previous chapters, Chapter 5 covers the data analysis, results, and discussion sections of this dissertation.

Introduction

Surgical flow disruptions (SFDs) are events that disrupt the flow or natural progression of the medical procedure (Wiegmann, 2007) and increase the likelihood of medical errors which can cause adverse events to occur in the operating room (OR). SFDs have also been called *minor and major events* (Healey et al., 2004), *precursor events* (Wong et al., 2006), and *failures* (Catchpole et al., 2007). SFDs can be thought of as one type of latent failure. Latent failures increase the opportunity for active failures to occur, which have the potential to cause accidents. Reason (1990) shows in his Swiss Cheese model that if a system is designed properly, latent failures are often met by system defenses built to mitigate accidents from occurring. However, if a system is not designed properly or if it is so complex that it is near impossible to account for all issues, the scattered holes in the Swiss cheese can align making it easy for latent failures to travel through the proverbial holes and result in an accident causing the patient harm or killing them. As a result, the identification of SFDs in the OR, in hopes of it leading to elimination of SFDs, is pertinent to increasing patient safety.

Methods such as self-reporting systems (Fabri & Zayas-Castro, 2008), videotape observation (Sutton et al., 2010), and direct observation (Al-Hakim, 2011; Catchpole, et al., 2006; Healey, Undre, & Vincent, 2004; Lingard, et al., 2004; Wiegmann, El Bardissi, Dearani, Daly, & Sundt III, 2007) have been used to identify SFDs. Fabri and Zayas-Catro (2008) identified SFDs through a self–reporting system, which allowed the surgical team to report their own SFDs, followed by a team of adjudicators which reviewed the reports. Although this method encourages active participation from the healthcare providers (HCPs), the level of detail acquired per surgical case is dependent on how much time and energy HCPs give to the study coupled with human memory limits and the design of the reporting system, as a poorly designed system can translate to collecting poor data on SFDs. Sutton et al., (2010) utilized videotaped observations to identify SFDs. Using video allows research teams to extract data from multiple visual and auditory sources; however, this method can be expensive and complicated to implement if the OR is not already designed with cameras. Additionally, installing video for this purpose could create a big brother effect on participants influencing the data. The primary method used by many researchers to identify SFDs is direct (*in vivo*) observations, where observations occur in the natural setting of a procedure (Yule, Flin, Paterson-Brown, & Maran, 2006). Not only is this easy to implement but it also provides the researcher an understanding of the context in which SFDs occur. This knowledge can also facilitate data analysis. Observations can be performed from an inductive perspective, identifying all SFDs that are observed to occur and then subsequently grouping them into categories; or they can be conducted from a deductive perspective, using a priori templates or taxonomies as a data collection tool or guide. Most of the research conducted to identify SFD has used the latter approach.

Surgical flow disruption a priori identification through direct observation has been implemented by using tools modified from other domains. The Observational Teamwork Assessment for Surgery (OTAS), that originated from aviation, is used as a method to identify what type of tasks are completed and to measure how surgical teams behave within the context of the work environment instead of simply considering individual performances and mishaps (Healey, Undre, & Vincent, 2004). Through evaluating interdisciplinary teamwork and team training in 50 cases, OTAS found that SFDs to occur most often in the communication, coordination, and awareness categories. The Non-Technical Skills (NOTECHS) system was also developed in aviation and modified for healthcare. NOTECHS uses a framework of behavioral characteristics that included leadership, teamwork, problem solving, and situational awareness to identify disruptions (Catchpole, Giddings, Wilkinson, Hirst, Dale, & de Leval, 2007). While identifying the minor, intraoperative, and major SFDs seen in the OR, three out of the 27 types of disruptions were equipment-related. In addition, aviation-style non-technical skills training was studied to see how it influenced the different types of SFD (McCulloch, Mishra, Handa, Dale, Hirst, & Catchpole, 2009).

Beyond observation tools, other researchers have use SFD taxonomies as frameworks to guide their data collection and analyses. Two taxonomies have been developed to identify SFDs (Wiegmann, ElBardissi, Dearani, Daly, & Sundt III, 2007; Wong, Torchiana, Vander Salm, Agnihotri, Bohmer, & Ali, 2007), where each study correlated their respective classifications to surgical errors and adverse outcomes. Not only were their results limiting due to their taxonomy, but they only focused on disruptions that lead to adverse events. However, we know that based on Rivera-Rodriguez & Karsh (2010) that there are also necessary disruptions that need to be identified and understood. Necessary SFDs are events that disrupt the flow of the procedure, but are essential to the continuation of the current procedure or patients outside of the environment. One example of a necessary SFD is where an HCP stops their primary task to find information pertaining to the current procedure (Rivera-Rodriguez & Karsh, 2010). The Realizing Improved Patient Care through Human-Centered Operation Room Design (RIPCHORD) taxonomy

(Palmer II, et al., 2013) applied in this research takes a human factors engineering, systems perspective and allows for the classification of both unnecessary and necessary SFDs without the association of medical errors, which generally denotes blame.

The RIPCHORD taxonomy has six main categories and 33 subcategories; the RIPCHORD taxonomy offers a systematic method of identifying both unnecessary and necessary SFDs (Palmer II, et al., 2013; Rivera-Rodriguez & Karsh, 2010). The main categories consist of communication, environmental hazards, equipment failure, general interruptions, physical layout, and usability. This study set out to validate the RIPCHORD taxonomy's usefulness in acting as a guide for both data collection and analysis of SFDs. Examining the OR using the RIPCHORD taxonomy as a framework will show its ability to capture a broad perspective of SFDs. Previous studies using taxonomies as coding guides have established successful coding agreements when 80.2% and 95% of their data fit within the taxonomy categories. (Henrickson, Wadhera, ElBardissi, Wiegmann, & Sundt III, 2009; Wong, Torchiana, Vander Salm, Agnihotri, Bohmer, & Ali, 2007). Therefore, we took the rough average of these studies and used 90% coding agreement rate as our measurement of success in validating the usefulness of the RIPCHORD taxonomy.

SFD Recovery

Although some SFDs are necessary to enhance communication and teamwork, most SFDs increase the potential for an adverse event to occur. Therefore, the HCPs working in the OR must act as system defenses either alone or with one or more other persons to maintain the workflow and mitigate harm to the patient. SFD recovery is defined as the process in which a HCP mitigates one or more potential consequences of the SFD. In the medical literature others have used the term compensation in lieu of recovery (de Leval, Carthey, Wright, Farewell, &

Reason, 2000; Wong, Vander Salm, Ali, Agnihotri, Bohmer, & Torchiana, 2006); however we felt that the term compensation is generally associated with financial language, which could be confusing in regards to the topic of SFD. One example of an individual acting as a system defense is a surgeon who clarifies a command that a nurse did not understand. Since the nurse is responsible for many tasks in the OR, a command that is not clear or not heard can lead to an improper step performed or additional wait time that could negatively impact workflow and the patient. Once the HCP recovers from the SFD, in this case the surgeon clarifying a command, the potential for the improper step is minimized, thus blocking the potential effect the patient may otherwise have experienced. Minimal research has been conducted on the topic of SFD recovery or compensation.

Previous research on SFD recovery examined recovery to: determine a link between recovery and adverse outcomes (de Leval, Carthey, Wright, Farewell, & Reason, 2000; Wong, Torchiana, Vander Salm, Agnihotri, Bohmer, & Ali, 2007), record the frequency of SFD recovery in individual operational phases (Wong, Vander Salm, Ali, Agnihotri, Bohmer, & Torchiana, 2006), and determine the correlation between SFD recovery and OR time (Wong, Ali, Torchiana, Agnihotri, Bohmer, & Vander Salm, 2009). However, no one has examined the method in which SFDs are recovered from. This study breaks SFD recovery into three methods: individual, team, and no recovery. If one healthcare professional is responsible for mitigating a SFD potential consequence, it is called individual SFD recovery. If two or more healthcare professionals act to mitigate a SFD potential outcome, then it is called team SFD recovery. Lastly if no HCP mitigates an SFD from occurring, then it is classified as no recovery. Using these three methods and the RIPCHORD taxonomy, this study will examine how, when and what type of SFDs are recovered from, which can help determine where to focus SFD interventions.

The comparison of SFD recovery types is how SFD recovery is examined. Operational phases identify when, and the RIPCHORD main categories are what types of SFDs that are recovered. For example, if environmental hazards SFDs are not recovered during the pre-operative phase, then a solution can be developed to address this specific need.

Methodology

The two aims of this study are to: 1) validate the usefulness of the taxonomy developed in the preliminary study (Palmer II, et al., 2013) to act as a guide for both data collection and analysis, and 2) predict the likelihood of surgical flow disruption recovery methods: individual, team, none. The hospital's Institutional Review Board (IRB) approved the study protocol and it was agreed to by Clemson University's IRB.

Study Setting

The study took place in a large academic teaching hospital in the Southeast of the US. This facility has 700 hospital beds. Their cardiothoracic department houses recently renovated surgical suites. The Heart and Vascular Center treats over 14,000 patients per year, scheduling aortic valve replacement, mitral valve replacement, and coronary artery bypass graft procedures daily. Two out of the twelve surgical suites are solely used for cardiac surgeries. The system of interest for this study is bounded by the physical walls of the cardiac OR. Within the cardiac OR there are two sub-systems: the social sub-system and the technical sub-system. The social sub-system consists of the cardiac surgical team including: anesthesiologists, surgeons, nurses, and perfusionists and all that is human about them (decision making, communication, etc.). The technical sub-system consists of the tools and technology, the physical layout, the lighting, etc. (Karsh B-T., Holden, Alper, & Or, 2006). The complexity of the cardiac procedure emerges from these two sub-systems interacting with one another.

Recruitment Procedures

Our hospital liaison and study champion (JA) gathered the dates and times of the operations and relayed that information to the observers. The surgeries had to be cardiac procedures, which consisted of coronary arterial bypass grafts (CABG), aortic valve replacements, and mitral valve replacements. Each type of procedure involves all four types of HCPs and is similar medical procedures.

Data Collection Procedures

Two observers, human factors engineers, conducted direct observations. To reduce biasing the data and becoming sources of SFDs, the observers did not divulge the specific nature of the study nor did they engage in conversation with the HCPs during observations. The human factors observer (GP) who had previous experience collecting SFD data trained the other human factors observer (YY).

Training consisted of an iterative three part process. First, all of the previous data collected in the pilot study was reviewed by YY. Next, a quiz was developed by GP and given to YY to complete. The quiz was reviewed by GP and a discussion about the quiz and SFDs in general commenced. Lastly, two trial observations were done by both observers where YY asked GP about any discrepancies seen in the OR.

The observers entered the OR before the HCPs and took positions behind the anesthesiologist station and at the nurse station. Data was collected during the pre-operative, anesthesia, pre-bypass, surgery, and the post-bypass phases of the surgery. Direct observations were conducted using a structured protocol slightly modified from the preliminary study (Palmer II, et al., 2013). Observers recorded the following information: timestamp of the SFD, description of SFD, whether the SFD was recovered (team, individual, or none), and location of

SFD. Data collection commenced with the start of the pre-operative phase, which starts as soon as the nurses and perfusionists enter the OR. Observers had minimal communication with the HCPs in order to not be sources of SFDs themselves and to allow the HCPs to concentrate on their primary tasks and perform as naturally as possible. The nurses and perfusionists setup the OR and their stations before the patient enters. Next, the anesthesiologists walk in with the patient and setup their stations simultaneously (anesthesia phase). Once the patient is induced under anesthesia, the pre-bypass phase begins. As the moment of incision nears, the surgeons walk into the OR and talk to the anesthesiologists about anticipated complications during the surgery. Then, the surgeons scrub their arms and hands, and prepare to make the first incision into the patient. Just before the incision (transition from pre-bypass to surgery stage), a timeout is taken to inform every one of the patient's vital statistics, confirm techniques being done on the patient, and discuss a plan for potential problems that may occur. No SFDs are recorded during the timeout. Then, the surgery begins and the recording of SFDs resume simultaneously. Once the incision is made on the patient, the surgery phase begins and when the incision starts to close, the post-operative phase begins. During the post-operative phase, nurses also prepare the OR for the next procedure by cleaning the OR and returning equipment and materials back to their standard positions.

Data Analysis

Coding SFD Data

The RIPCHORD taxonomy was used as the framework for coding SFDs (Palmer II et al., 2013). For this dissertation, qualitative deductive coding (Creswell, 2009; Rossman & Rallis, 1998) was used by following the steps below:

7. Read and understood all of the SFDs collected to gather a sense of what occurred throughout the observations.
8. Grouped all SFDs individually into a corresponding RIPCHORD taxonomy cluster based upon the categories' definitions.
9. Grouped all SFDs within suitable main categories and subcategories.
10. Reassessed all of the SFDs within the main categories and subcategories to determine if more groups needed to be added, or if SFDs needed to move into a more appropriate group.
11. Documented all SFDs that did not fit within the predetermined categories of the taxonomy.
12. Determined whether the SFDs that did not fit the category should be grouped to develop new categories or subcategories within the RIPCHORD taxonomy.

Research rigor was met by ensuring internal validity, objectivity, and reliability. Internal validity of a research study establishes the accuracy between the researchers and participantss (Creswell, 2009; Creswell & Miller, 2000). One way to ensure internal validity is by conducting member checking. Member checking is done by allowing participants to determine whether the coding is accurate (Creswell, 2007; Devers, 1999; Padgett, 2008). Member checking for this data set was completed by a medical expert, who was also a participant in the study (JA). Methodological rigor was also confirmed by accounting for objectivity. Objectivity is obtained when findings are examined and determined to be free from bias (Devers, 1999). This dissertation confirmed objectivity by having a human factors expert (AJR-R) skeptically review the data. Lastly, the reliability of analyzing SFDs was confirmed through holding a review of

SFDs after the data was compiled, documenting all coding procedures of possible SFD occurrences, and double-checking coding of the SFDs (Devers, 1999).

Predicting SFD Recovery

The independent variables (IVs) for this study were the 6 RIPCHORD main taxonomy categories (communication, environmental hazards, equipment failres, general interruptions, physical layout, and usability) and the 5 operational phases (pre-operative, anesthesia, pre-bypass, surgery, post-bypass). The dependent variable was SFD recovery which had three levels: 1) team recovery, 2) individual recovery, or 3) no recovery. The goal of this analysis, conducted in SPSS 19.0 using multinomial logistic regression, was to predict the likelihood of how SFDs can be recovered (team, individual, or no recovery) within a certain operative phase, and taxonomy grouping.

Prior to determining the likelihood of recovery, all independent variable outliers needed to be identified and removed. When frequencies of cells are less than five for regression analysis, the analysis becomes inaccurate. There were SFDs in certain combinations of interactions that rarely occurred during data collection. The independent variables related to these interactions were evaluated first. If the row or column of the independent variables contained cells less than five, then those variables were subject to elimination (see table 5.6). Evaluating the deviance of the overall and reduced multinomial logistic regression models is the first step in determining which cells to eliminate. The deviance of the regression and its significance was calculated with and without the interactions with the infrequent or zero data points to determine which independent variables to eliminate. Deviance is a goodness-of-fit statistic that looks at the variance between log-likelihood functions. A good fit for a model equates to a small deviance. Additionally, for a model with a high number of degrees of freedom, the deviance should be as small as it possible to maintain the accuracy of the model. With all 11 independent variables, the deviance was calculated to be 59.779 (p = 0.014) (see table 5.1). However, when the Equipment Failure, Environmental Hazard, and Post-Bypass variables are eliminated from the multinomial logistic regression analysis the deviance is smaller (31.912) and still significant (p = 0.010). Since the deviance is lower but still remains significant in the modified model, the removal of the three independent variables is justified.

Table 5.1. Deviance and Significance of Deviance

	Deviance	P-value (sig p < .05)
Overall	59.779	.014
Modified	31.912	.010

In addition to the deviance statistic, hierarchical regression was used to determine the differences between the models with and without the rarely represented independent variables. Hierarchical (sequential) regression places the 11 independent variables as one set of predictors that contributes a significant prediction over another set of predictors with a lower amount of independent variables (Cohen, Cohen, West, & Aiken, 2003). First, the first block of predictors excludes the independent variables with zero data points in interacting cells. The second block of predictors was the rest of the independent variables (total number minus the first block) and represents the overall model. Therefore, the hierarchical regression compares the model without the outlying variables (modified or first block) to the entire model (overall or second block). The significance of the F value of the modified model was used to determine the difference between both sets of predictors. If the significance of the F value from the modified model is below 0.05, then the modified model is cleared to be analyzed further. Table 5.2 shows the R^2 and F values, and significance of the F value. The change in the F-value from the modified model to the overall model is 0.214. Therefore, the overall model with all 11 IVs is not significant compared to the model without the 3 IVs (environmental hazards, equipment failure, and post-bypass). Both deviance and hierarchical regression statistics show that there is an increase in goodness-of-fit when the model is reduced from 11 to 8 IVs.

Table 5.2. Hierarchical Regression Results

Change Statistics				
Model	R^2	F	df	Sig. F
Overall	.025	5.706	9	.214
Modified	.024	4.163	8	.000

Then, the remaining IVs (second block of predictors) from the hierarchical regression analysis were entered into the multinomial logistic regression program. Each column within SPSS contained an independent variable with either a 'zNo' for no disruption and a 'Yes' for indicating a disruption in the category. The last column contained the dependent variable, SFD Recovery, where No Recovery = 1, Individual Recovery = 2, and Team Recovery = 3. The reference datum is the non-metric number of 2 or individual recovery to provide more data entries as a base for the other two dependent variables. Once the dependent variables and IVs are recognized by SPSS, the logistic regression table provided the IV coefficients, p-values, goodness of fit tests, and likelihoods. Three comparisons that occurred within this analysis are: 1) no recovery versus individual recovery; 2) team recovery versus individual recovery; and 3) no recovery versus team recovery. The main effect of the IVs was analyzed first and independent from the interactions between the RIPCHORD main categories and operational phases. Data within the two IVs are compared between one dependent variable to the other (e.g., individual recovery v. team recovery). The 30 viable interactions between the IVs (i.e., the six main categories of the RIPCHORD categories and five operational phases) were also analyzed in SPSS. This analysis provided the p-values and likelihoods of each interaction of RIPCHORD main category, operational phase, and type of recovery.

Results

RIPCHORD Validation Results

We determined that classifying 90% of the SFD data collected would validate that the RIPCHORD taxonomy is useful as a guide for both data collection and analysis. Previous research has claimed success after finding between 80.2% and 95% classification agreement in their data (Henrickson, Wadhera, ElBardissi, Wiegmann, & Sundt III, 2009; Wong, Torchiana, Vander Salm, Agnihotri, Bohmer, & Ali, 2007). A combined 1439 SFDs were recorded by both observers. By evaluating each disruption, 44 duplicate disruptions were found reducing the total count to 1395 over 11 surgeries. Discounting the duplicate disruptions, there are only nine SFDs that could not be classified into the RIPCHORD taxonomy. Therefore, 99.99% of the SFDs were able to be categorized within the RIPCHORD taxonomy. The SFDs that did not fit within the taxonomy were coded as “Idle Time” disruptions, defined as a time in which the healthcare professionals had to wait for an event to occur that suspended the surgery from continuing. “Idle Time” could be considered a subcategory under the main “General Interruptions” category; however, since this was not in the original taxonomy it was not included in the analysis of this study. More research should be conducted to determine the whether this new subcategory should be added.

Figure 5.1 and Table 5.3 present descriptive statistics of the SFDs identified and then categorized into the RIPCHORD taxonomy. Physical Layout SFDs were observed the most (N = 401), followed by General Interruptions (N = 392), Communication SFDs (N = 276), and Usability SFDs (N = 244). The Environmental Hazards (N = 48) and Equipment Failure (N = 25) were the least observed SFDs. When looking across operational phases, SFDs were observed the most in the Surgery phase (N = 594), followed by the Anesthesia (N = 340), and Pre-Bypass (N

= 243) phases. SFDs were least observed to occur in the Pre-Operative (N = 111) and Post-Bypass (N = 98) phases. These results were as expected as they align with the duration of each operational phase.

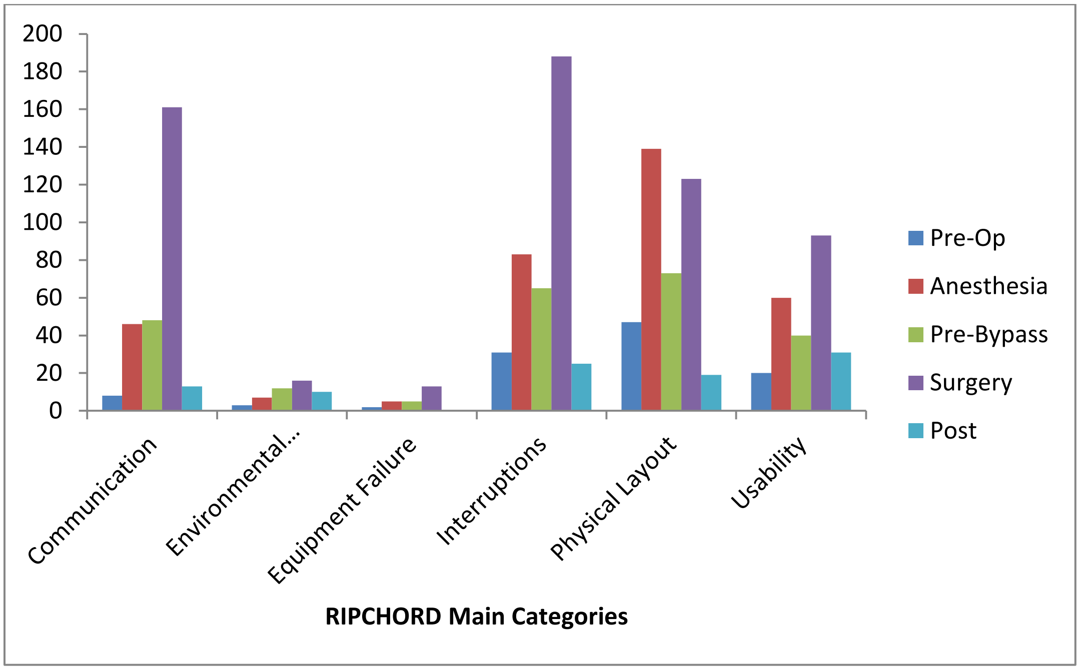


Figure 5.1. SFD Frequency for each Operational Phase

Table 5.3. SFD Frequency for each Operational Phase

	Pre-Operative	Anesthesia	Pre-Bypass	Surgery	Post-Bypass
Communication	8	46	48	161	13
Environmental Hazards	3	7	12	16	10
Equipment Failure	2	5	5	13	0
General Interruptions	31	83	65	188	25
Physical Layout	47	139	73	123	19
Usability	20	60	40	93	31

SFD Recovery Descriptive Results

Overall, SFDs were recovered the most by individuals (N=723), followed by teams (N=419) and then no recovery (N= 244), Figure 5.2 and Table 5.4 show the frequency of recovery type evaluated by operational phases. Individual recovery was observed to be the most frequent recovery type in each operational phase. Team recovery was observed to be the second-most frequent recovery type in each operational phase with the exception of the pre-operative phase, where No Recovery was the most frequent. SFD recovery (both team and individual) proportionately occurred most often in the surgery (Individual: 52%; Team: 32%), followed by anesthesia (Individual: 49%; Team: 33%), and pre-bypass (Individual: 52%; Team: 32%) phases of operation. This was expected due to the amount of time spent in each of these phases and the number of people working during each phase as opposed to the pre-operative and post-bypass phases.

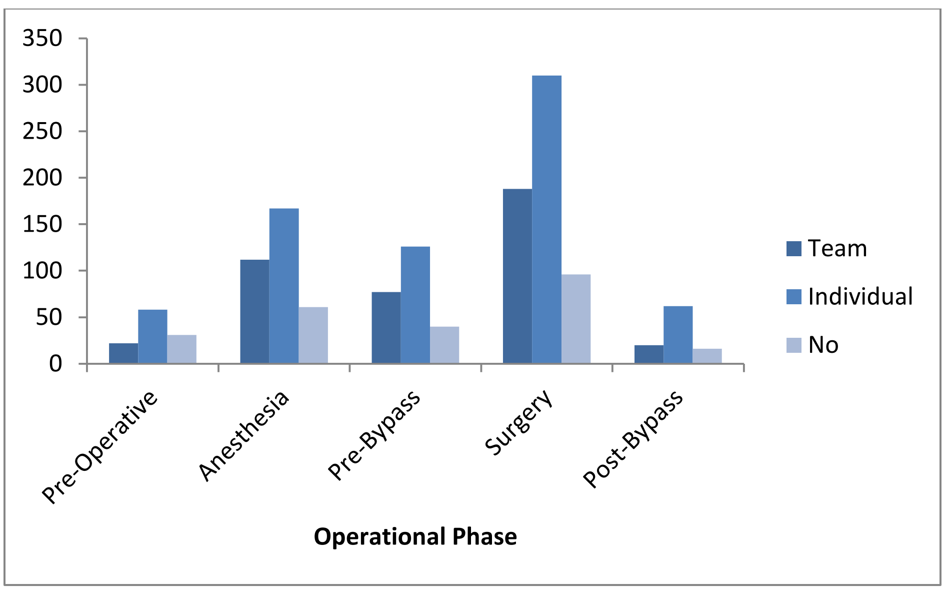


Figure 5.2. SFD Recovery Frequency for each Operational Phase

Table 5.4. SFD Recovery Frequency for each Operational Phase

	Pre-Operative	Anesthesia	Pre-Bypass	Surgery	Post-Bypass	Total
Team	22	112	77	188	20	419
Individual	58	167	126	310	62	723
No	31	61	40	96	16	244

The data presented in Figure 5.3 and Table 5.5 show the frequency of SFD recovery by RIPCHORD taxonomy categories. SFDs classified in the Physical Layout and General Interruptions categories were recovered the most by individuals (N=224; 221), followed by teams (N=107; 100) and then no recovery (N=70; 71). Then, individuals recovered the third-most SFDs categorized as Usability (N=169) and teams recovered the third-most SFDs in the Communication category.

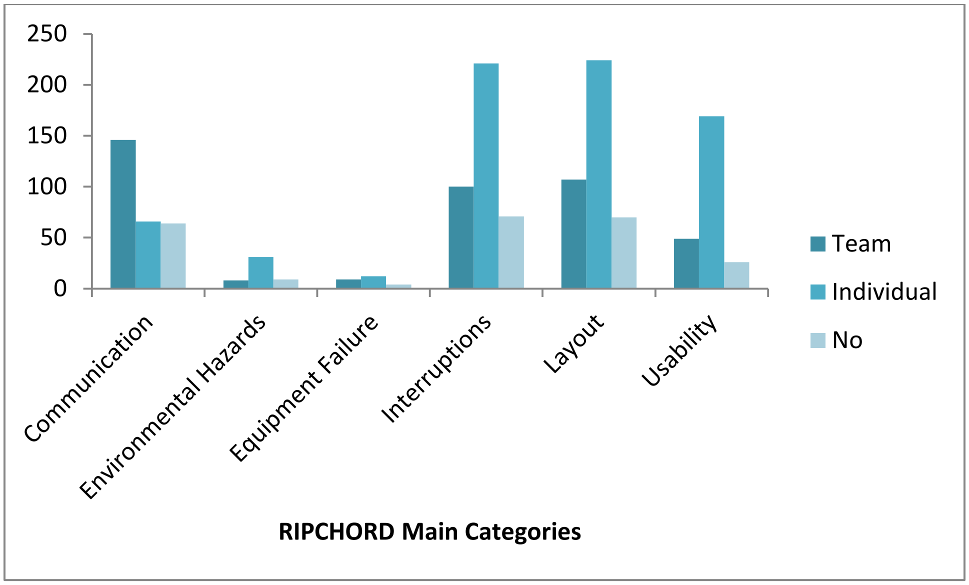


Figure 5.3. SFD Recovery Frequency for each RIPCHORD Category

Table 5.5. SFD Recovery Frequency for each RIPCHORD Category

	Communication	Environmental Hazards	Equipment Failures	General Interruptions	Physical Layout	Usability
Team	146	8	9	100	107	49
Individual	66	31	12	221	224	169
No	64	9	4	71	70	26
Total	276	48	25	392	401	244

The SFD recovery data was not evenly distributed across the 6 main RIPCHORD taxonomy categories and the 5 operational phases. There were several types of SFD that were rarely observed as they did not occur often. This also means that there were limited opportunities to observe those SFD being recovered from (or not). The SFD data were categorized into a matrix to show the interactions between the main RIPCHORD taxonomy categories and the operational phases (see Table 5.6). In doing this, we found that several cells lacked sufficient data to be included in the multinomial logistic regression. They were interaction cells under the Communication/Pre-Operative (Team), Environmental Hazards/Pre-Operative (Team and None), Environmental Hazards/Anesthesia (Team), Equipment Failure/Pre-Operative (None), and Equipment Failure/Post-Bypass (Team, Individual, and None) that had a frequency of zero.

This is not surprising as our previous study also found that SFDs observed in the Equipment Failures and Environmental Hazards categories and the Pre-Operative and Post-Bypass phases are generally uncommon (Palmer II, et al., 2013). For the first and last phase of the operation, SFDs are infrequent because the amount of time spent in those phases was the least. The frequencies contained in these interaction cells provide a guide to what IVs to eliminate.

Table 5.6. SFD Recovery Frequency for each Interaction

		Pre-Operative	Anesthesia	Pre-Bypass	Surgery	Post-Bypass
Communication	Team:	0	21	30	88	7
	Individual:	3	14	9	38	2
	No:	5	11	9	35	4
Environmental Hazards	Team:	0	0	1	4	3
	Individual:	3	5	9	8	6
	No:	0	2	2	4	1
Equipment Failure	Team:	1	2	2	4	0
	Individual:	1	2	1	8	0
	No:	0	1	2	1	0
General Interruptions	Team:	8	29	18	40	5
	Individual:	11	43	33	121	13
	No:	12	11	14	27	7
Physical Layout	Team:	11	41	21	32	2
	Individual:	27	69	40	74	14
	No:	9	29	12	17	3
Usability	Team:	2	19	5	20	3
	Individual:	13	34	34	61	27
	No:	5	7	1	12	1

Predicting SFD Recovery Results

The cells that are infrequent and rarely occur are also statistical liabilities when using regression analysis. When frequencies of cells are zero for regression analysis, the analysis becomes inaccurate. To predict when (operational phases), what (RIPCHORD taxonomy categories) and how (Team, Individual, No) SFDs are recovered, multinomial logistic regression was used to analyze the main effects of the IVs and the interactions of the 8 remaining IVs. Tables 5.7 and 5.8 show the p-values for the main effects of the IVs and their interactions, respectively. The reference variables for both tables are the Pre-Operative phase and Communication category.

Table 5.7. Regression Analysis of SFD Recovery by Main Effects

Variable	*No Recovery vs. Individual Recovery*				*Team Recovery vs. Individual Recovery*				*No Recovery vs. Team Recovery*			
	Contrast Estimate	S.E.	Odds Ratio	*p*	Contrast Estimate	S.E.	Odds Ratio	*p*	Contrast Estimate	S.E.	Odds Ratio	*p*
Intercept	0.70	0.30		0.020*	0.57	0.31		0.063	0.13	0.33		0.700
Main Effects												
Anesthesia	-0.52	0.28	0.59	0.059	0.48	0.29	1.62	0.098	-1.00	0.33	0.37	0.002*
Pre-Bypass	-0.77	0.30	0.46	0.011*	0.29	0.31	1.33	0.350	-1.05	0.35	0.35	0.003*
Surgery	-0.87	0.27	0.42	0.001*	0.12	0.28	1.12	0.679	-0.99	0.32	0.37	0.002*
General Interruptions	-1.20	0.23	0.30	<0.001*	-1.58	0.20	0.21	<0.001*	0.38	0.23	1.47	0.090
Physical Layout	-1.25	0.24	0.29	<0.001*	-1.54	0.20	0.21	<0.001*	0.29	0.23	1.34	0.205
Usability	-1.79	0.29	0.17	<0.001*	-1.95	0.23	0.14	<0.001*	0.16	0.30	1.17	0.599

Note: *Significant variables *Reference variables*: Pre-Operative phase, Communication category

Table 5.8. Regression Analysis of SFD Recovery by Interactions

Variable	*No Recovery vs. Individual Recovery*				*Team Recovery vs. Individual Recovery*				*No Recovery vs. Team Recovery*			
	Contrast Estimate	S.E.	Odds Ratio	*p*	Contrast Estimate	S.E.	Odds Ratio	*p*	Contrast Estimate	S.E.	Odds Ratio	*p*
Intercept	-0.96	0.53		0.069	-1.87	0.76		0.014*	0.92	0.84		0.273
Interactions between Main Categories and Operational Phases												
Interruptions v. Anesthesia	-0.70	0.99	0.50	0.481	-18.1	1.04	1.4E-8	<0.001*	16.4	1.30	1.3E7	<0.001*
Interruptions v. Pre-Bypass	-0.43	1.02	0.65	0.669	-19.1	1.06	5.2E-9	<0.001*	17.6	1.30	4.6 E7	<0.001*
Interruptions v. Surgery	-0.99	0.90	0.37	0.269	-19.0	0.95	4.6E-9	<0.001*	17.2	1.23	3E7	<0.001*
Layout v. Anesthesia	0.98	0.95	2.68	0.298	-17.6	0.98	2.3E-8	<0.001*	17.6	1.27	4.4E7	<0.001*
Layout v. Pre-Bypass	0.41	1.01	1.50	0.687	-18.5	1.01	9E-9	<0.001*	17.9	1.30	6.1E7	<0.001*
Layout v. Surgery	0.22	0.90	1.25	0.806	-18.4	0.90	1.1E-8	<0.001*	17.6	1.23	4.3E7	<0.001*
Usability v. Anesthesia	0.13	1.07	1.14	0.905	-16.7	0.55	5.6E-8	<0.001*	15.8	1.12	7.4E6	<0.001*
Usability v. Pre-Bypass	-2.06	1.44	0.13	0.151	-18.8	0.69	6.7E-9	<0.001*	15.8	1.50	7E6	<0.001*
Usability v. Surgery	-0.08	0.98	0.93	0.937	-17.7	0.00	2.1E-8	<0.001*	16.6	0.98	1.6E7	<0.001*

Note: *Significant variables
Reference variables: Interactions with Pre-Operative phase and/or Communication category

When comparing main effects of the operational phases, the anesthesia phase has a significant relationship between no recovery and team recovery ($p = 0.002$). During the anesthesia phase, no recovery is 0.37 times less likely to occur than team recovery. In the pre-bypass and surgery phases, two dependent relationships are significant (no v. individual recovery, $p = 0.011$ & 0.001; no v. team recovery, $p = 0.003$ & 0.002). When evaluating the likelihood of no recovery occurring less than individual recovery, SFDs have a lower odds as the procedure is extended (Pre-Bypass: OR = 0.46; Surgery: OR = 0.42). However, the likelihood of no recovery occurring less than team recovery has higher odds in the surgery phase (Pre-Bypass: OR = 0.35; Surgery: OR = 0.37).

For the main effects of the RIPCHORD main categories, General Interruptions is the most likely to have no recovery and team recovery occur than individual recovery (no v. individual recovery, OR = 0.30; team v. individual recovery, OR = 0.21). Physical Layout and Usability categories subsequently follows General Interruptions and decreases in likelihood where no recovery and team recovery are more likely to occur than individual recovery, respectively (no v. individual recovery, OR = 0.29 & 0.17; team v. individual recovery, OR = 0.21 & 0.14). All three RIPCHORD categories are insignificant when comparing no recovery to team recovery (General Interruptions: $p = 0.090$; Physical Layout: $p = 0.205$; Usability: $p = 0.599$).

When evaluating the interaction effects in Table 5.1, two points are extracted from the results given. First, the relationship between no recovery and individual recovery is not significant in any interaction. The second aspect is where the other two dependent relationships exhibit an omnibus effect. An omnibus test determines whether the model is predictive using the IVs. Even though both relationships are significant, high odds ratios and Wald's chi-squared statistics indicate that the group of interactions analyzed together does not predict the likelihood of SFD recovery. However, the model of observing SFD recovery is more suitable to the frequency data observed. The dependent variable relationships between team recovery versus individual recovery and no recovery are still significant and the proportions shown in Table 5.9 provide information of how SFDs are recovered during those interaction cells. An evident pattern in each interaction cell is that the sequence of SFDs are likely to be recovered by individuals, then by teams, and followed by no recovery. The Usability category has the three highest proportions of SFDs being individually recovered (Surgery: 0.70; Pre-Bypass: 0.67; Anesthesia: 0.62). SFDs are also proportionately most likely to be recovered by teams between the interactions of Physical Layout/Anesthesia (0.31), General Interruptions/Anesthesia (0.30), and General Interruptions/Pre-Bypass (0.28). Lastly, SFDs are proportionately more likely to not be recovered in the same interactions but different order (General Interruptions/Anesthesia: 0.19; Physical Layout/Anesthesia: 0.18; and General Interruptions/Pre-Bypass: 0.16).

Table 5.9. Proportion of SFD Recovery by Interactions

	No	Individual	Team
Interruptions v. Anesthesia	0.19	0.51	0.30
Interruptions v. Pre-Bypass	0.16	0.57	0.28
Interruptions v. Surgery	0.15	0.60	0.25
Layout v. Anesthesia	0.18	0.51	0.31
Layout v. Pre-Bypass	0.15	0.56	0.28
Layout v. Surgery	0.14	0.60	0.26
Usability v. Anesthesia	0.12	0.62	0.25
Usability v. Pre-Bypass	0.10	0.67	0.23
Usability v. Surgery	0.10	0.70	0.20

Discussion

This study had two interrelated aims. The first was to validate the usefulness of the RIPCHORD taxonomy as a guide for data collection and analysis to increase its reliability and generalizability. The second aim was to predict which SFDs are recovered (i.e., the 6 main RIPCHORD categories), when they are recovered (i.e., the 5 operational phases) and how they are recovered (i.e., Individual, Team, No). The data revealed that the RIPCHORD taxonomy is a useful guide for data collection and analysis for SFDs. Additionally, it highlighted the current state of SFD recovery, making it very apparent that HCPs play a significant role at mitigating SFD in the OR. Once the recovery of SFDs is captured, then interventions and resources can be directed in a structured approach.

Broadening Taxonomies for Identifying SFDs

This study validated the RIPCHORD taxonomy by coding the SFDs at 99.99%. This study showed that the RIPCHORD taxonomy is a transferable tool that can be used to identify and code SFDs. Fitting nearly 100% of the SFDs observed in a dynamic environment such as cardiac operations demonstrates that the RIPCHORD taxonomy could be applied in other types of operations (e.g., minimally invasive, pediatric, or orthopedic).

Operating rooms are complex environments; therefore it is necessary to use a taxonomy that is broad enough to capture all SFDs regardless of differences between systems, yet specific enough to make the data meaningful in order to develop targeted interventions. The RIPCHORD taxonomy is exactly that. Additionally, the RIPCHORD taxonomy is a neutral framework for SFD research which means that as a data collection tool and analysis guide it reduces biases and allows researchers to be inclusive of both necessary and unnecessary (or negative) SFDs. Others studying SFD have limited their perspective of SFD by using certain terminology. Terms such as, *failures* (Catchpole K. , 2009; Lingard, et al., 2004), and *minor and major events* (de Leval, Carthey, Wright, Farewell, & Reason, 2000; Wong, Vander Salm, Ali, Agnihotri, Bohmer, & Torchiana, 2006) imply negativity because of their association to medical errors or adverse outcomes. However, including necessary and unnecessary SFDs, we believe, is consistent with and indicative of taking a holistic, systems approach, where the entire OR environment is evaluated (Rivera-Rodriguez & Karsh, 2010).

Necessary SFDs occur frequently in ORs, however, there is limited research that highlights their existence (Healey, Primus, & Koutantji, 2007; Healey, Sevdalis, & Vincent, 2006). Necessary disruptions are those that disrupt the flow of surgery, but that are needed from a systems perspective (Rivera-Rodriguez & Karsh, 2010; Rivera, 2013). For example, a surgeon answering a call about a patient recovering from a previous surgery; although the call disrupts the current surgery, another patient's care is dependent on the information exchange that occurs through that disruption. Unnecessary SFDs are also disruptions that break the procedural flow of the surgery; however, they are systematically non-value added (i.e., they do not benefit the current procedure nor any process or person external to the procedure).For example, nurses a cryogenic machine into the OR and take 5 minutes to figure out how to operate it. As a Usability SFD, the value of the 5 minutes was not value added to the procedure but lost because the nurses did not have proper training on the cryogenic machine.

Eliminating all SFDs is impossible, nor is it recommended from a systems perspective (Rivera, 2013). Therefore, distinguishing between necessary and unnecessary SFDs is important because interventions look differently for each. For example a necessary disruption intervention might be one that delays the disruption to a more opportune time, or redirects the disruption to an HCP that can more easily be pulled away from their primary task; whereas unnecessary disruption interventions should set out to block the disruption entirely from occurring or needing to occur. Developing flexible interventions helps to reduce the potential for unintended consequences to occur by making sure the solutions fit with the workflow of the OR (Karsh B.-T. , Holden, Alper,

& Or, 2006). Additionally, understanding how HCPs recover from SFDs can help us understand the current method used to intervene, which can be built upon to create interventions that are compatible with the realities of such a complex system.

Positive Aspects of SFD Recovery

Through multinomial logistic regression, it was determined that SFDs were more likely to be recovered individually and not recovered than recovered by teams of two or more HCPs. Predicting what, when, and how SFD recovery occurs helps the organization understand the current state of system resilience. Resilience is known as the system's (including the people in it) ability to adapt to disturbances and disruptions in complex systems (Hollnagel, Woods, & Leveson, 2006; Patterson E. , Woods, Cook, & Render, 2007). Resilience is common in healthcare and other complex systems such as aviation and nuclear power (Patterson E. , Woods, Roth, Cook, Wears, & Render, 2006). When systems are intricate and tightly coupled, they often must rely on frontline workers to be flexible enough to adapt to the dynamic nature in order to keep them functioning properly (Cook & Woods, 1994). The OR is no different; it is an extremely resilient system which relies on HCPs to keep patients safe. Grouping individual and team recovery together, 82% of SFDs are recovered from prior to reaching the patient. As described above, SFD can be thought of as latent system failures which can easily result in active errors; however, HCPs continuously act as successful barriers blocking the potential effects of SFDs from the patient (Cook & Woods, 1994).

Negative Aspects of SFD Recovery

While recovering from SFDs is extremely important and needed for patient safety, the fact remains that while HCPs are acting as system defenses, their primary tasks are being disregarded which in and of itself is a problem. This problem is compounded when HCPs are recovering in teams as two or more people must stop their primary task to attend to the disruption. Teamwork within an OR environment is an important part of creating a safe culture; therefore we are by no means stating that working as part of a team should be discouraged. However, often times, when recovering from SFDs, HCPs are only temporarily fixing the problem in order to reestablish the flow of procedure. This means that if team SFD recovery is to be more beneficial, than detrimental, to the system, this teamwork recovery behavior should be planned and training should be provided to make sure HCPs are appropriately and safely engaging in team recovery to solve the problem. Otherwise, we are left with just a temporary fix known as first-order problem solving.

Tucker, Edmondson, and Spear (2002) defined first-order problem solving behavior as an attempt to solve the immediate problem but to not change the fundamental conditions that create it. Due to the fast-paced nature and the limited resources including time, first-order problem solving is ubiquitous in the OR. Quickly mitigating the SFDs serves as instant gratification, as workflow spontaneously continues and the procedure progresses. However, recovering from SFDs in the OR is much of the time based on instinctual reactive behavior. This behavior is generally not well thought out, which means that while HCPs are recovering from a particular SFD, their recovery behavior could be teetering on the boundary of permissible risk potentially creating larger problems (Holden, Rivera-Rodriguez, Faye, Scanlon, & Karsh, 2013; Novak, Holden, Anders, Hong, & Karsh, 2013).

Second-order problem solving is much more preferred as it targets the root cause of the SFD eliminating its reoccurrence (Edmondson, 2004). Additionally, unlike first-order problem solving, second-order problem solving does not add risk to the system. For example, if a SFD occurs due to the patient's bed continuously bumping into the cardiopulmonary bypass machine (CBM) when it enters the OR, the first-order problem solving behavior would be to simply move the CBM out of the way without thinking of how moving the CBM affects the rest of the OR layout. On the other hand, second-order problem solving behavior would be to investigate the pattern of the patient bed as it is rolled into the OR, then to study how the CBM machine is used to determine the best location for the CBM to be permanently moved to eliminate all future collisions.

Unfortunately, HCPs tend not to second-order problem solve when recovering from SFDs as they lack the time and resources to do so. To maintain high reliability and thus patient safety within the OR, second-order problem solving must be done at an organizational level (Tucker, 2004). In order to develop appropriate second-order problem solving (i.e., interventions) it is necessary to understand the current first-order problem solving behaviors (i.e., SFD recovery).

Conclusion

Surgical flow disruptions have the potential to compromise patient safety. Previous research has taken a limited perspective to identifying SFD. A taxonomy that shows the ability to encompass all types of disruptions (unnecessary and necessary) redefines how surgical flow disruptions are identified in the OR environment. The RIPCHORD taxonomy's usefulness was validated by coding nearly 100% of the observed SFDs. This proves that a broadened taxonomy captures the dynamic nature of surgery. In addition to validating the RIPCHORD taxonomy, significant interactions between RIPCHORD main categories and operational phases highlight when and where to target SFD interventions.

CHAPTER SIX

CONCLUSION

This dissertation conducted a literature review to identify research gaps related to the topic of surgical flow disruptions and the literature review showed inconsistencies in the number and occupation of observers, terminology used to define SFDs, and differences in methodologies used to study SFDs. The perspective researchers take when studying SFD recovery was also identified as another gap in the literature. SFD recovery research has been limited by only looking at adverse outcomes or potential adverse outcomes and not examining the actual process of SFD recovery. These gaps led to the development of the two research aims: 1) validating the RIPCHORD taxonomy's usefulness to a 90% agreement and 2) predicting the likelihood of SFD recovery based on the RIPCHORD taxonomy categories and phase of operation. This dissertation is the first step in understanding the nature of SFDs and their recovery from a socio-technical systems perspective which leads to the *broader impact* of facilitating researchers in developing targeted interventions that are compatible with the OR workflow and the realities of such a complex system. As SFDs are reduced or eliminated, this creates a more efficient system (Healey et al., 2004), which reduces HCPs' frivolous workload allowing them to spend more time on direct patient care. All of this increases both the quality of care and patient safety within the OR environment.

Chapter 3's preliminary study initially set out to establish a taxonomy that can provide stability for identifying SFDs. Then this dissertation successfully validated the RIPCHORD taxonomy's usefulness as a guide for data collection and analyses by coding nearly 100% of the SFDs within the taxonomy. The RIPCHORD taxonomy also has the ability to find necessary and unnecessary SFDs consistently as it is not tied to adverse outcomes or medical errors like other SFD taxonomies. For Research Aim 2, likelihoods were calculated to determine when and where to expect team, individual, and no SFD recovery. It was determined that team and individual recovery was predominantly observed in the OR. In addition to the frequency of SFD recovery, the Surgery phase is the most probable for the individual recovery of SFDs and the Anesthesia phase is the most probable for team and no recovery to occur. These results highlight where organizational resources should be focused: 1) SFDs that are not recovered are SFDs that could reach the patient causing harm, and 2) team recovery, although promoted as part of the OR culture, requires that multiple HCPs negate their primary tasks while dealing with the SFD.

Limitations

Cardiothoracic surgery is the only type of surgery observed for this dissertation. Choosing only to observe one type of surgery limits the generalizability of the study. However, within cardiac surgery there are four types of HCPs (anesthesiologists, surgeons, nurses, and perfusionists), an abundance of tools and technology used by all HCPs, and there are tasks, and complex procedures that are integrated in the OR environment with every procedure. We feel the RIPCHORD taxonomy's holistic perspective is broad enough to capture the entire cardiac environment, which is one of the most complex surgeries, thus making it transferable to other types of surgeries.

Not only was the study limited through operative procedures, but through the amount of operative procedures that could be observed. Limited resources, such as funding for travel, were a constraint to collecting more data. With more resources, data collection could have been more extensive and produced more robust data for the multinomial logistic regression. For example, not all of the independent variables (Equipment Failures, Environmental Hazards, and Post-Bypass) were evaluated to predict the likelihood of SFD recovery because these cells had zero frequencies. Future research can conduct more observations adding to this data, to help support the analysis that was performed.

The selection of cardiac surgeries was determined by convenience and familiarity which is also a limitation. A medical expert (JA) was the liaison at a teaching hospital in the southeast region and provided the two observers with the surgeries to observe for this dissertation. The medical expert surveyed the procedures that were most favorable, so the familiarity with other surgeons and anesthesiology staff influenced the decision of which surgeries to observe. These surgeries were not randomly selected, which could limit the variability of HCPs seen throughout the hospital.

In addition to the absence of interactions between RIPCHORD taxonomy categories and operational phases, lacking knowledge of severity or importance of the SFDs observed serves as a limitation to providing context to the results. Likelihood of team, individual, and no recovery were given for each interaction, based on this, recommendations of where to focus intervention were made. However, determining the severity ratings of SFDs would certainly impact those recommendations.

Future Research

In the field of healthcare, more research is needed to understand the impact of SFDs in the OR, how the RIPCHORD taxonomy impacts the classification of SFDs, and expands upon this research in SFD recovery. Since the RIPCHORD taxonomy and prediction of SFD recovery are novel concepts, there are avenues that can be explored to advance these research fields. The list of future research topics is provided below:

- Severity of SFDs has not been evaluated when using the RIPCHORD taxonomy. What is the severity of SFDs? Does the severity score differ between an HCPs perspective and a Human Factors perspective?
    - Importance of SFD recovery could also be examined in the same manner. Obtaining perceptions from both HCPs and HFE experts
- The ability to transfer the RIPCHORD taxonomy to any operating room or hospital shows how well the broad nature of the taxonomy can capture surgical flow disruptions. Therefore, observing SFDs in other hospital settings to determine the transferability of the RIPCHORD taxonomy.
    - Organizational influences and supervisory aspects of each hospital reveal what disruption types are prominent within their environment. So if the RIPCHORD taxonomy was used in different hospitals, it is expected that different categories and subcategories would be more prevalent than previous studies.
    - Different operating room settings, such as ERs, ICUs, and general procedures, will provide different results but could also add more

categories or subcategories to the taxonomy. The breadth of the RIPCHORD taxonomy should be validated in other OR environments and must happen in order to have a complete taxonomy that holistically identifies SFD.

- The development of human factors training courses in healthcare for HCPs in ORs could equip the HCPs with knowledge of how to identify SFDs and recover from SFDs in a systematic way.
    - Managers will benefit from this by running and analyzing the prediction data of SFD recovery and practicing the development of targeted interventions.
    - Managers can also implement interventions with the frontline HCPs that were derived from predicting SFD recovery.

APPENDICES

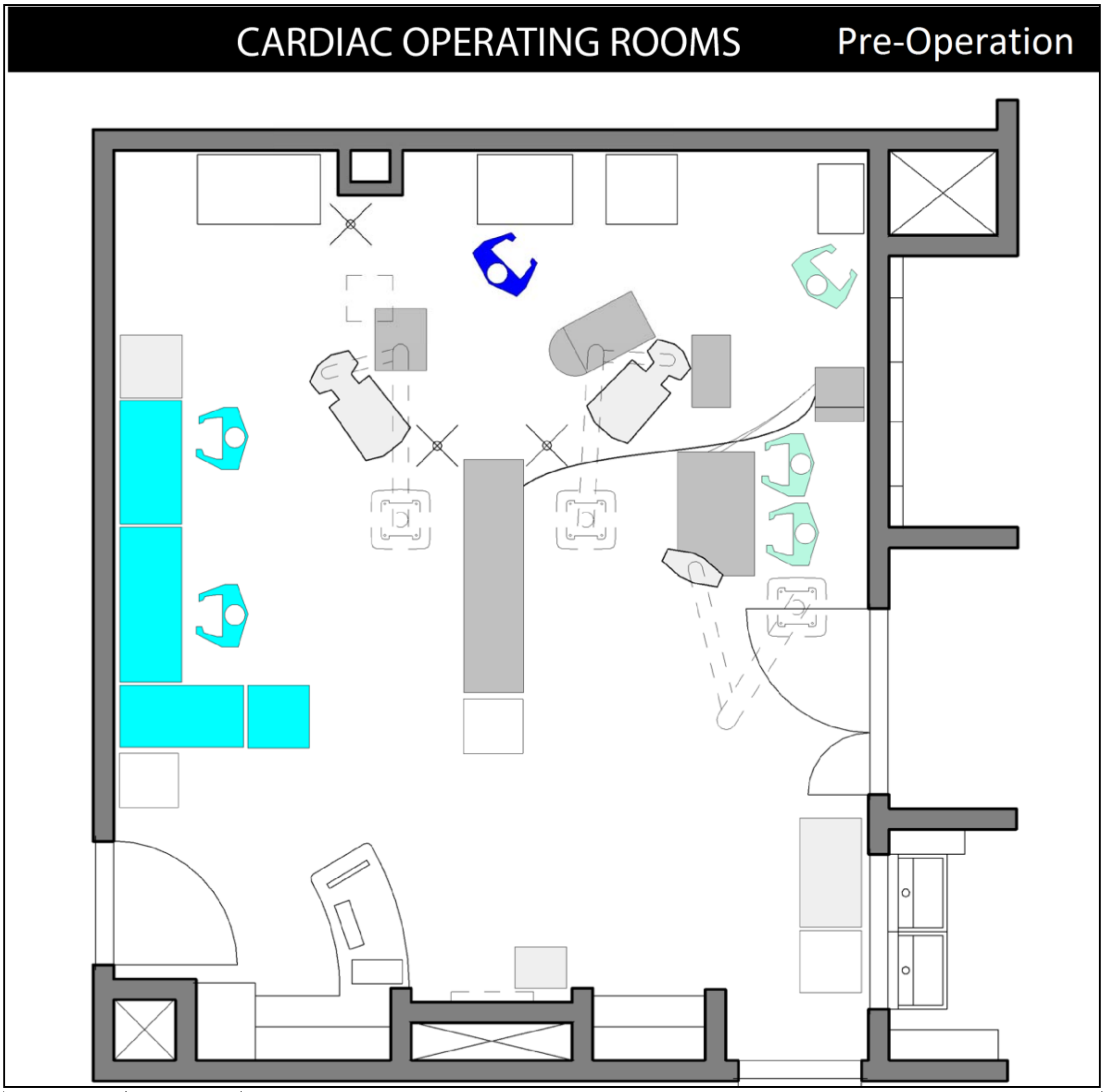
Appendix A

Figure A: Research Gap Matrix

Author(s) (Year)	Summary of Study	Type of Surgery	Terms Used to Describe SFDs	Method of Recording SFDs	Number of Observers & Occupation	Observation Tool?	SFD Recovery Observed?	How was the SFD Recovery data recorded?	SFD Recovery Analysis
de Leval et al. (2000)	Used relation b/t patient-specific variables to outcomes with major and minor failures	Neonatal ASOs	Minor and Major Events	Case Report Reviewing	2 Human Factors (HF), 1 Medical	No	Yes	Compared SFD events to patient outcomes	Frequency and Odds Ratio
Healey et al. (2004)	Generated OTAS and used it in 50 observations to assess performance in OR	General	Team Behavior, Task Completion	Direct Observation	1 Medical, 1 Psychology	Yes, OTAS	No	--	--
Lingard et al. (2004)	Observed communication failures with checklist and failure types	General and vascular	Communication Failures	Direct Observation	3 Observers	No	No	--	--
Catchpole et al. (2006)	Events into 3 categories, performance (NOTECHS) compared to problems	Pediatric Cardiac and Orthopedic	Minor and Major Failures	Direct Observation	1 HF	No	No	--	--
Healey et al. (April-May 2006)	Distractions and interruptions were observed using an ordinal scale and regression analysis	General	Distractions & Interruptions	Direct Observation	2 Observers	No	No	--	--
Undre et al. (2006)	Observed 5 categories with tasklist to analyze adverse events	General	Team Behavior, Task Completion	Direct Observation	1 Medical, 1 Psychology	Yes, OTAS	No	--	--
Wiegmann et al. (2006)	Composed flow disruptions through observing, analyzed issues against another	Cardiac	SFDs	Direct Observation	1 Medical	No	No	--	--
Wong et al. (2006)	Real time reporting of precursor events and recovery across multiple hospitals	Cardiac	Major and Minor Precursor Events	Case Report Reviewing	2 Adjudicators	No	Yes	Recorded Recovery Timing and Qualities	ANOVA
Catchpole et al. (2007)	Events into 3 categories, performance (NOTECHS) compared to problems	Pediatric Cardiac and Orthopedic	Minor and Major Problems	Direct Observation	1 HF	Yes, NOTECHS	No	--	--
Healey et al. (2007)	Quantified distractions by observing and weighing OR task activity	General	Distractions & Interruptions	Direct Observation	1 Medical	No	No	--	--
Wiegmann et al. (2007)	Observed and created 5 SFD categories, then compared categories to medical errors	Cardiac	SFDs	Direct Observation	1 Medical	No	No	--	--
Wong et al. (2007)	Predicted probability of deaths/near misses from number of precursor events	Cardiac	Precursor Events	Case report reviewing	2 Adjudicators	No	Yes	Tallied recovered and unrecovered events	ANOVA
ElBardissi et al. (2008)	Highlighted specific relationships which showed more disruptions than other	Cardiac	Events, SFDs & Errors	Direct Observation	1 Medical	No	No	--	--
Fabri & Zayas-Castro (2008)	Classified medical and human errors but relied on staff to report them	6 Types of Surgery	Human and HF Errors	Self-Reporting	OR Medical Team	No	No	--	--
Sevdalis et al. (2008)	Assess OR staff's self-perceptions that affect surgical processes with 5 SFD types	General	Disruptions	Direct Observation	2 Psychology	Yes, DiSI	No	--	--
Wong et al. (2009)	Reviewed over 1,600 reports and analyzed precursor events over time	Cardiac	Precursor Events	Case Report Reviewing	3 Medical Reviewers	No	Yes	Recovery frequency was totaled over time	ANOVA
Parker et al. (2010)	The SFD Tool (SFDT) was developed to analyze SFDs with inter-rater reliability	Cardiac	SFDs	Direct Observation	1 HF, 1 Medical	Yes, SFDT	No	--	--
Al-Hakim (2011)	Compares number of disruptions to operating time in MIS	Minimally invasive surg.	Disruptions	Direct Observation	2 Industrial Engineers	No	No	--	--
Catchpole (2010)	Failures in OR were correlated to threats and errors to improve standards and safety	Pediatric cardiac	Minor and Major Failures	Direct Observation	1 HF	Yes, NOTECHS	No	--	--
Sutton et al. (2010)	Quantifying gaze disruptions from the surgeon's perspective	Laparoscopic cholecystectomy	Gaze disruptions	Videotape Observation	1 Medical	No	No	--	--

Appendix B

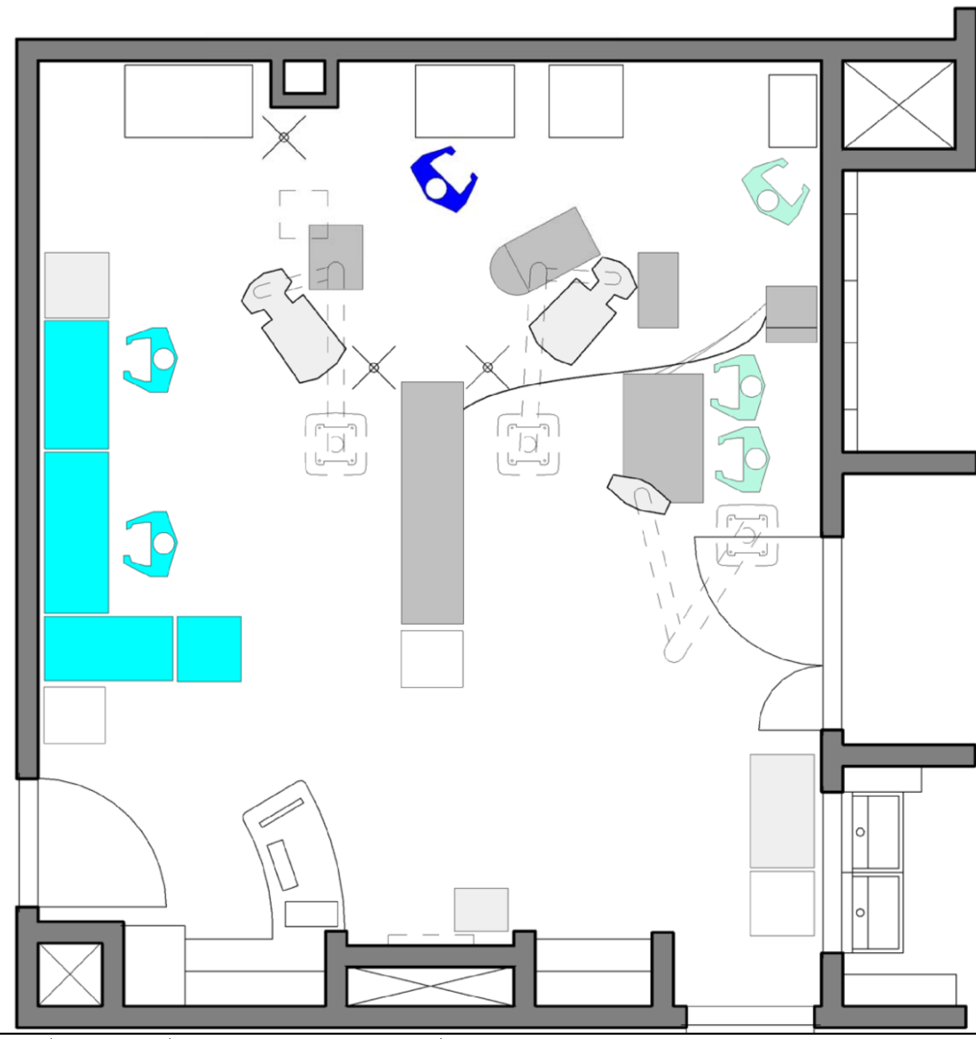
Figure B-1: Preliminary Flow Disruption Evaluation Sheet



Number	Time	Description

Figure B-2: Revised Flow Disruption Evaluation Sheet

CARDIAC OPERATING ROOMS **Pre-Operation**



Number	Time	SFD Recovered? (No/Ind/Team)	Description

Appendix C

Figure C-1: Multinomial Logistic Regression Main Effect Syntax

```
NOMREG DV (BASE=2 ORDER=ASCENDING) BY Anes PreBy Surg PreOp Comm
Inter Layout Usab
  /CRITERIA CIN(95) DELTA(0) MXITER(100) MXSTEP(5) CHKSEP(20)
LCONVERGE(0) PCONVERGE(0.000001) SINGULAR(0.00000001)
  /MODEL
  /STEPWISE=PIN(.05) POUT(0.1) MINEFFECT(0) RULE(SINGLE)
ENTRYMETHOD(LR) REMOVALMETHOD(LR)
  /INTERCEPT=INCLUDE
  /PRINT=PARAMETER SUMMARY LRT CPS STEP MFI.
```

Figure C-2: Multinomial Logistic Regression Interaction Syntax

```
NOMREG DV (BASE=2 ORDER=ASCENDING) BY Anes PreBy Surg Inter Layout
Usab PreOp Comm IxAnes IxPreBy IxSurg LxAnes LxPreBy LxSurg UxAnes UxPreBy
UxSurg CxPreOp CxAnes CxPreBy CxSurg IxPreOp LxPreOp UxPreOp
  /CRITERIA CIN(95) DELTA(0) MXITER(100) MXSTEP(5) CHKSEP(20)
LCONVERGE(0) PCONVERGE(0.000001) SINGULAR(0.00000001)
  /MODEL
  /STEPWISE=PIN(.05) POUT(0.1) MINEFFECT(0) RULE(SINGLE)
ENTRYMETHOD(LR) REMOVALMETHOD(LR)
  /INTERCEPT=INCLUDE
  /PRINT=CLASSTABLE FIT PARAMETER SUMMARY LRT CPS STEP MFI IC
```

Figure C-3: Multinomial Logistic Regression Main Effect Output

DV[a]		B	Std. Error	Wald	df	Sig.	Exp(B)
1 v. 2	Intercept	.698	.300	5.423	1	.020	
	[Anes=Yes]	-.521	.276	3.556	1	.059	.594
	[Anes=zNo]	0[b]	.	.	0	.	.
	[PreBy=Yes]	-.769	.302	6.499	1	.011	.464
	[PreBy=zNo]	0[b]	.	.	0	.	.
	[Surg=Yes]	-.872	.265	10.806	1	.001	.418
	[Surg=zNo]	0[b]	.	.	0	.	.
	[Inter=Yes]	-1.196	.232	26.499	1	.000	.302
	[Inter=zNo]	0[b]	.	.	0	.	.
	[Layout=Yes]	-1.249	.237	27.733	1	.000	.287
	[Layout=zNo]	0[b]	.	.	0	.	.
	[Usab=Yes]	-1.790	.286	39.107	1	.000	.167
	[Usab=zNo]	0[b]	.	.	0	.	.
	[PreOp=Yes]	0[b]	.	.	0	.	.
	[PreOp=zNo]	0[b]	.	.	0	.	.
	[Comm=Yes]	0[b]	.	.	0	.	.
	[Comm=zNo]	0[b]	.	.	0	.	.
3 v. 2	Intercept	.571	.307	3.465	1	.063	
	[Anes=Yes]	.480	.291	2.734	1	.098	1.617
	[Anes=zNo]	0[b]	.	.	0	.	.
	[PreBy=Yes]	.285	.305	.872	1	.350	1.329
	[PreBy=zNo]	0[b]	.	.	0	.	.
	[Surg=Yes]	.117	.283	.171	1	.679	1.124
	[Surg=zNo]	0[b]	.	.	0	.	.
	[Inter=Yes]	-1.579	.197	64.420	1	.000	.206
	[Inter=zNo]	0[b]	.	.	0	.	.
	[Layout=Yes]	-1.540	.199	59.772	1	.000	.214
	[Layout=zNo]	0[b]	.	.	0	.	.
	[Usab=Yes]	-1.946	.230	71.576	1	.000	.143
	[Usab=zNo]	0[b]	.	.	0	.	.

	[PreOp=Yes]	0[b]	.	.	0	.	.
	[PreOp=zNo]	0[b]	.	.	0	.	.
	[Comm=Yes]	0[b]	.	.	0	.	.
	[Comm=zNo]	0[b]	.	.	0	.	.

DV[a]		B	Std. Error	Wald	df	Sig.	Exp(B)
1 v. 3	Intercept	.127	.330	.149	1	.700	
	[Anes=Yes]	-1.001	.327	9.399	1	.002	.367
	[Anes=zNo]	0[b]	.	.	0	.	.
	[PreBy=Yes]	-1.053	.351	9.018	1	.003	.349
	[PreBy=zNo]	0[b]	.	.	0	.	.
	[Surg=Yes]	-.989	.317	9.714	1	.002	.372
	[Surg=zNo]	0[b]	.	.	0	.	.
	[Inter=Yes]	.383	.226	2.868	1	.090	1.467
	[Inter=zNo]	0[b]	.	.	0	.	.
	[Layout=Yes]	.291	.230	1.604	1	.205	1.338
	[Layout=zNo]	0[b]	.	.	0	.	.
	[Usab=Yes]	.156	.297	.277	1	.599	1.169
	[Usab=zNo]	0[b]	.	.	0	.	.
	[PreOp=Yes]	0[b]	.	.	0	.	.
	[PreOp=zNo]	0[b]	.	.	0	.	.
	[Comm=Yes]	0[b]	.	.	0	.	.
	[Comm=zNo]	0[b]	.	.	0	.	.

Figure C-4: Multinomial Logistic Regression Interaction Output

DV[a]		B	Std. Error	Wald	df	Sig.	Exp(B)
1 v. 2	Intercept	.511	.730	.489	1	.484	
	[Anes=Yes]	-.752	.834	.813	1	.367	.471
	[Anes=zNo]	0[b]	.	.	0	.	.
	[PreBy=Yes]	-.511	.869	.345	1	.557	.600
	[PreBy=zNo]	0[b]	.	.	0	.	.
	[Surg=Yes]	-.593	.767	.598	1	.439	.553
	[Surg=zNo]	0[b]	.	.	0	.	.
	[Inter=Yes]	-.424	.841	.254	1	.614	.655
	[Inter=zNo]	0[b]	.	.	0	.	.
	[Layout=Yes]	-1.609	.826	3.801	1	.051	.200
	[Layout=zNo]	0[b]	.	.	0	.	.
	[Usab=Yes]	-1.466	.900	2.654	1	.103	.231
	[Usab=zNo]	0[b]	.	.	0	.	.
	[PreOp=Yes]	0[b]	.	.	0	.	.
	[PreOp=zNo]	0[b]	.	.	0	.	.
	[Comm=Yes]	0[b]	.	.	0	.	.
	[Comm=zNo]	0[b]	.	.	0	.	.
	[IxAnes=Yes]	-.698	.992	.496	1	.481	.497
	[IxAnes=zNo]	0[b]	.	.	0	.	.
	[IxPreBy=Yes]	-.434	1.016	.182	1	.669	.648
	[IxPreBy=zNo]	0[b]	.	.	0	.	.
	[IxSurg=Yes]	-.994	.899	1.223	1	.269	.370
	[IxSurg=zNo]	0[b]	.	.	0	.	.
	[LxAnes=Yes]	.984	.945	1.084	1	.298	2.675
	[LxAnes=zNo]	0[b]	.	.	0	.	.
	[LxPreBy=Yes]	.405	1.006	.162	1	.687	1.500
	[LxPreBy=zNo]	0[b]	.	.	0	.	.
	[LxSurg=Yes]	.221	.899	.060	1	.806	1.247
	[LxSurg=zNo]	0[b]	.	.	0	.	.
	[UxAnes=Yes]	.127	1.070	.014	1	.905	1.135

	[UxAnes=zNo]	0[b]	.	.	0	.	.
	[UxPreBy=Yes]	-2.060	1.436	2.058	1	.151	.127
	[UxPreBy=zNo]	0[b]	.	.	0	.	.
	[UxSurg=Yes]	-.077	.982	.006	1	.937	.926
	[UxSurg=zNo]	0[b]	.	.	0	.	.
	[CxPreOp=Yes]	0[b]	.	.	0	.	.
	[CxPreOp=zNo]	0[b]	.	.	0	.	.
	[CxAnes=Yes]	0[b]	.	.	0	.	.
	[CxAnes=zNo]	0[b]	.	.	0	.	.
	[CxPreBy=Yes]	0[b]	.	.	0	.	.
	[CxPreBy=zNo]	0[b]	.	.	0	.	.
	[CxSurg=Yes]	0[b]	.	.	0	.	.
	[CxSurg=zNo]	0[b]	.	.	0	.	.
	[IxPreOp=Yes]	0[b]	.	.	0	.	.
	[IxPreOp=zNo]	0[b]	.	.	0	.	.
	[LxPreOp=Yes]	0[b]	.	.	0	.	.
	[LxPreOp=zNo]	0[b]	.	.	0	.	.
	[UxPreOp=Yes]	0[b]	.	.	0	.	.
	[UxPreOp=zNo]	0[b]	.	.	0	.	.
3 v. 2	Intercept	-17.577	.825	453.654	1	.000	
	[Anes=Yes]	17.982	.894	404.171	1	.000	64492685.181
	[Anes=zNo]	0[b]	.	.	0	.	.
	[PreBy=Yes]	18.781	.909	427.299	1	.000	1.433E8
	[PreBy=zNo]	0[b]	.	.	0	.	.
	[Surg=Yes]	18.416	.802	527.208	1	.000	99567654.314
	[Surg=zNo]	0[b]	.	.	0	.	.
	[Inter=Yes]	17.258	.947	332.079	1	.000	31269180.694
	[Inter=zNo]	0[b]	.	.	0	.	.
	[Layout=Yes]	16.679	.899	343.878	1	.000	17516531.777
	[Layout=zNo]	0[b]	.	.	0	.	.

[Usab=Yes]	15.705	.323	2369.884	1	.000	6614634.377
[Usab=zNo]	0[b]	.	.	0	.	.
[PreOp=Yes]	0[b]	.	.	0	.	.
[PreOp=zNo]	0[b]	.	.	0	.	.
[Comm=Yes]	0[b]	.	.	0	.	.
[Comm=zNo]	0[b]	.	.	0	.	.
[IxAnes=Yes]	-18.058	1.036	303.694	1	.000	1.438E-8
[IxAnes=zNo]	0[b]	.	.	0	.	.
[IxPreBy=Yes]	-19.068	1.062	322.565	1	.000	5.233E-9
[IxPreBy=zNo]	0[b]	.	.	0	.	.
[IxSurg=Yes]	-19.205	.945	413.253	1	.000	4.565E-9
[IxSurg=zNo]	0[b]	.	.	0	.	.
[LxAnes=Yes]	-17.605	.983	320.543	1	.000	2.261E-8
[LxAnes=zNo]	0[b]	.	.	0	.	.
[LxPreBy=Yes]	-18.527	1.013	334.549	1	.000	8.992E-9
[LxPreBy=zNo]	0[b]	.	.	0	.	.
[LxSurg=Yes]	-18.357	.903	412.940	1	.000	1.066E-8
[LxSurg=zNo]	0[b]	.	.	0	.	.
[UxAnes=Yes]	-16.692	.552	913.047	1	.000	5.632E-8
[UxAnes=zNo]	0[b]	.	.	0	.	.
[UxPreBy=Yes]	-18.826	.691	741.546	1	.000	6.670E-9
[UxPreBy=zNo]	0[b]	.	.	0	.	.
[UxSurg=Yes]	-17.660	.000	.	1	.	2.140E-8
[UxSurg=zNo]	0[b]	.	.	0	.	.
[CxPreOp=Yes]	0[b]	.	.	0	.	.
[CxPreOp=zNo]	0[b]	.	.	0	.	.
[CxAnes=Yes]	0[b]	.	.	0	.	.
[CxAnes=zNo]	0[b]	.	.	0	.	.
[CxPreBy=Yes]	0[b]	.	.	0	.	.
[CxPreBy=zNo]	0[b]	.	.	0	.	.
[CxSurg=Yes]	0[b]	.	.	0	.	.
[CxSurg=zNo]	0[b]	.	.	0	.	.

	[IxPreOp=Yes]	0[b]	.	.	0	.	.
	[IxPreOp=zNo]	0[b]	.	.	0	.	.
	[LxPreOp=Yes]	0[b]	.	.	0	.	.
	[LxPreOp=zNo]	0[b]	.	.	0	.	.
	[UxPreOp=Yes]	0[b]	.	.	0	.	.
	[UxPreOp=zNo]	0[b]	.	.	0	.	.

DV[a]		B	Std. Error	Wald	df	Sig.	Exp(B)
1 v. 3	Intercept	17.087	1.102	240.446	1	.000	
	[Anes=Yes]	-17.734	1.163	232.468	1	.000	1.987E-8
	[Anes=zNo]	0[b]	.	.	0	.	.
	[PreBy=Yes]	-18.291	1.166	246.233	1	.000	1.138E-8
	[PreBy=zNo]	0[b]	.	.	0	.	.
	[Surg=Yes]	-18.009	1.110	263.361	1	.000	1.509E-8
	[Surg=zNo]	0[b]	.	.	0	.	.
	[Inter=Yes]	-16.682	1.193	195.610	1	.000	5.690E-8
	[Inter=zNo]	0[b]	.	.	0	.	.
	[Layout=Yes]	-17.288	1.190	211.020	1	.000	3.104E-8
	[Layout=zNo]	0[b]	.	.	0	.	.
	[Usab=Yes]	-16.171	.956	286.008	1	.000	9.483E-8
	[Usab=zNo]	0[b]	.	.	0	.	.
	[PreOp=Yes]	0[b]	.	.	0	.	.
	[PreOp=zNo]	0[b]	.	.	0	.	.
	[Comm=Yes]	0[b]	.	.	0	.	.
	[Comm=zNo]	0[b]	.	.	0	.	.
	[IxAnes=Yes]	16.359	1.299	158.678	1	.000	12726335.229
	[IxAnes=zNo]	0[b]	.	.	0	.	.
	[IxPreBy=Yes]	17.635	1.302	183.567	1	.000	45563422.424
	[IxPreBy=zNo]	0[b]	.	.	0	.	.
	[IxSurg=Yes]	17.211	1.226	197.226	1	.000	29826374.238

[IxSurg=zNo]	0[b]	.	.	0	.	.
[LxAnes=Yes]	17.588	1.270	191.698	1	.000	43507511.900
[LxAnes=zNo]	0[b]	.	.	0	.	.
[LxPreBy=Yes]	17.932	1.301	190.083	1	.000	61371140.408
[LxPreBy=zNo]	0[b]	.	.	0	.	.
[LxSurg=Yes]	17.578	1.234	202.786	1	.000	43036512.211
[LxSurg=zNo]	0[b]	.	.	0	.	.
[UxAnes=Yes]	15.819	1.117	200.464	1	.000	7416591.535
[UxAnes=zNo]	0[b]	.	.	0	.	.
[UxPreBy=Yes]	15.766	1.503	110.040	1	.000	7029785.174
[UxPreBy=zNo]	0[b]	.	.	0	.	.
[UxSurg=Yes]	16.582	.982	284.984	1	.000	15907399.594
[UxSurg=zNo]	0[b]	.	.	0	.	.
[CxPreOp=Yes]	0[b]	.	.	0	.	.
[CxPreOp=zNo]	0[b]	.	.	0	.	.
[CxAnes=Yes]	0[b]	.	.	0	.	.
[CxAnes=zNo]	0[b]	.	.	0	.	.
[CxPreBy=Yes]	0[b]	.	.	0	.	.
[CxPreBy=zNo]	0[b]	.	.	0	.	.
[CxSurg=Yes]	0[b]	.	.	0	.	.
[CxSurg=zNo]	0[b]	.	.	0	.	.
[IxPreOp=Yes]	0[b]	.	.	0	.	.
[IxPreOp=zNo]	0[b]	.	.	0	.	.
[LxPreOp=Yes]	0[b]	.	.	0	.	.
[LxPreOp=zNo]	0[b]	.	.	0	.	.
[UxPreOp=Yes]	0[b]	.	.	0	.	.
[UxPreOp=zNo]	0[b]	.	.	0	.	.

REFERENCES

Al-Hakim, L. (2011). The impact of preventable disruption on the operative time for minimally invasive surgery. *Surgical Endoscopy*, *25*, 3385-3392.

Allison, P. (2012). *Logistic Regression Using SAS: Theory and Application.* Cary, NC: SAS Publishing.

Bognár, A., Barach, P., Johnson, J., Duncan, R., Birnbach, D., Woods, D., et al. (2008). Errors and the Burden of Errors: Attitudes, Perceptions, and the Culture of Safety in Pediatric Cardiac Surgical Teams. *Annals of Thoracic Surgery*, 1374-1381.

Bracco, D., Favre, J.-B., Bissonnette, B., Wasserfallen, J.-B., Revelly, J.-P. R., & Chiolero, R. (2001). Human errors in a multidisciplinary intensive care unit: a 1-year prospective study. *Intensive Care Medicine*, 137-145.

Carayon, P., Hundt, A. S., Karsh, B. T., Gurses, A. P., Alvarado, C. J., Smith, M., & Brennan, P. F. (2006). Work system design for patient safety: the SEIPS model. *Quality and Safety in Health Care*, *15*(suppl 1), i50-i58.

Carthey, J., de Leval, M., & Reason, J. (2001). The human factor in cardiac surgery: Errors and near misses in a high technology medical domain. *Annals of Thoracic Surgery*, 300-305.

Carthey, J., de Leval, M., Wright, D., Farewell, V., & Reason, J. (2003). Behavioural markers of surgical excellence. *Safety Science, 41*, 409-423.

Catchpole, K. (2009). Errors in the operating theatre--how to spot and stop them. *Journal of Health Services Research & Policy,* 48-51.

Catchpole, K., Giddings, A., de Leval, M., Peek, G., Godden, P., Utley, M., et al. (2006, April-May). Identification of systems failures in successful paediatric cardiac surgery. *Journal of Ergonomics*, *49*(5-6), 567-588.

Catchpole, K., Giddings, A., Wilkinson, M., Hirst, G., Dale, T., & de Leval, M. (2007). Improving patient safety by identifying latent failures in successful operations. *Surgery*, *142*(1), 102-110.

Chiesa, M., & Hobbs, S. (2008). Making sense of social research: How useful is the Hawthorne Effect?. *European Journal of Social Psychology*, *38*(1), 67-74.

Christian, C., Gustafson, M., Roth, E., Sheridan, T., Gandhi, T., Dwyer, K., et al. (2006). A prospective study of patient safety in the operating room. *Surgery*, 159-173.

Cohen, J., Cohen, P., West, S., & Aiken, L. (2003). *Applied Multiple Regression/Corrlelation Analysis for the Behavioral Sciences.* New York: Routledge.

Connelly, E. (1997). *A Resource Package for CRM Developers: Behavioural Markers of CRM Skill From Real World Case Studies and Accidents.* Technical Report, University of Texas, Austin.

Cook, R., & Woods, D. (1994). Operating at the Sharp End: The Complexity of Human Error. In M. Bogner, *Human Error in Medicine* (pp. 255-310). Hillsdale: Lawrence Erlbaum Associates.

Creswell, J. (2007). *Qualitative inquiry & research design: Choosing among five approaches.* Thousand Oaks: Sage Publications.

Creswell, J. (2009). *Research Design: Qualitative, Quantative, and Mixed Methods Approaches.* Thousand Oaks, CA: Sage Publications.

Creswell, J., & Miller, D. (2000). Determining Validity in Qualitative Inquiry. *Theory into Practice*, 124-130.

de Leval, M., Carthey, J., Wright, D., Farewell, V., & Reason, J. (2000). Human factors and cardiac surgery: a multicenter study. *Journal of Thoracic and Cardiovascular Surgery*, *119*, 661-672.

de Leval, M., Francois, K., Bull, C., Brawn, W., & Spiegelhalter, D. (1994). Analysis of a cluster of surgical failures: application to a series of neonatal arterial switch operations. *Journal of Thoracic and Cardiovascular Surgery, 107*, 914-924.

DeFontes, J., & Surbida, S. (2004). Preoperative safety briefing project. . *The Permanente Journal*, 21-27.

Derrington, M., & Smith, G. (1987). A review of studies of anaesthetic risk, morbidity, and mortality. *British Journal of Anaesthesia, 59*, 815-833.

Devers, K. (1999). How will we know "good" qualitative research when we see it? Beginning the dialogue in health services research. *Health Services Research*, 1153-1188.

Drui, A., Behm, R., & Martin, W. (1973). Predesign investigation of the anesthesia operational environment. *Anesthesia & Analgesia*, *52*, 584-591.

Edmondson, A. (2004). Learning from failure in health care: frequent opportunities, pervasive barriers. *Quality and Safety in Health Care*, ii3-ii9.

ElBardissi, A., & Sundt III, T. (2012). Human factors and operating room safety. *The Surgical clinics of North America*, 21-35.

ElBardissi, A., Wiegmann, D., Dearani, J., Daly, R., & Sundt III, T. (2007). Application of the Human Factors Analysis and Classification System Methodology to the Cardiovascular Surgery Operating Room. *Annals of Thoracic Surgery*, *83*, 1412-1419.

ElBardissi, A., Wiegmann, D., Henrickson, S., Wadhera, R., & Sundt III, T. (2008). Identifying methods to improve heart surgery: an operative approach and strategy for implementation on an organizational level. *European Journal of Cardio-thoracic Surgery*, 1027—1033.

Fabri, P., & Zayas-Castro, J. (2008). Human error, not communication and systems, underlies surgical complications. *Surgery*, 557-565.

Faye, H., Rivera-Rodriguez, A. J., Karsh, B-T., Hundt, A. S., Baker, C., & Carayon, P. (2010). Involving intensive care unit nurses in a proactive risk assessment of the medication management process. *Joint Commission journal on quality and patient safety/Joint Commission Resources*, *36*(8), 376.

Flin, R., Martin, L., Goeters, K.-M., Hormann, J., Amalberti, R., Valot, C., et al. (2003). Development of the NOTECHS (non-technical skills) system for assessing pilots' CRM skills. *Human Performance in Extreme Environments, 3*, 95-117.

Flin, R., Salas, E., Strub, M., & Martin, L. (1997). *Decision Making Under Stress.* Aldershot: Ashgate.

French, J. R. P. (1953). Experiments in field settings. In L. Festinger, & D. Katz (Eds.), Research methods in the behavioral sciences (pp. 98–135). New York: Holt, Rinehart and Winston.

Gaba, D. (2000, March). Anaesthesiology as a model for patient safety in health care. *British Medical Journal, 320,* 785-788.

Gawande, A., Thomas, E., Zinner, M., & Brennan, T. (1999). The incidence and nature of surgical adverse events in Colorado and Utah in 1992. *Surgery, 126*(1), 66-75.

Guerlain, S., Adams, R., Turrentine, F., Shin, T., Guo, H., Collins, S., et al. (2004). Assessing Team Performance in the Operating Room: Development and Use of a "Black-Box" Recorder and Other Tools for the Intraoperative Environment. *Journal of the American College of Surgeons*, 29-37.

Hazelhurst, B., Mcmullen, C., & Gorman, P. (2004). Getting the right tools for the job; distributed planning in cardiac surgery. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems And Humans, 34*, 708-717.

Healey, A., Sevdalis, N., & Vincent, C. (2006, April/May). Measuring intra-operative interference from distraction and interruption observed in the operating theatre. *Ergonomics, 49*(5-6), 589-604.

Healey, A., Undre, S., & Vincent, C. (2004). Developing observational measures of performance in surgical teams. *Quality and Safety in Health Care*, *13*, i33-i40.

Healey, A., Undre, S., Sevdalis, N., Koutantji, M., & Vincent, C. (2006, October). The complexity of measuring interprofessional teamwork in the operating theatre. *Journal of Interprofessional Care, 20*(5), 485-495.

Healey, A., Undre, S., Sevdalis, N., Koutantji, M., & Vincent, C. (2006, October). The complexity of measuring interprofessional teamwork in the operating theatre. *Journal of Interprofessional Care*, *20*(5), 485-495.

Helmreich, R. (2000). On error management: lessons from aviation. *British Medical Journal*, *320*, 781-785.

Helmreich, R., & Davies, J. (1996, July). Human factors in the operating room: interpersonal determinants of safety, efficiency and morale. *Clinical Anaesthesiology*, *10*(2), 277-295.

Helmreich, R., & Merritt, A. (1998). *Culture at Work in Aviation and Medicine: National, Organizational and Professional Influences.* Aldershot: Ashgate.

Helmreich, R., & Schaefer, H.-G. (1994). Team Performance in the Operating Room. In M. Bogner, *Human Error in Medicine* (pp. 225-253). Hillsdale, NJ: Lawrence Erlbaum Associates.

Helmreich, R., Butler, R., Taggart, W., & Wilhelm, J. (1995). *Behavioural Markers in Accidents and Incidents: Reference List.* Technical report, The University of Texas, Austin.

Henneman, E., Blank, F., Gawlinski, A., & Henneman, P. (2006). Strategies used by nurses to recover medical errors in an academic emergency department setting. *Applied Nursing Research*, 70-77.

Henrickson-Parker, S., Laviana, A., Wadhera, R., Wiegmann, D., & Sundt III, T. (2010). Development and Evaluation of an Observational Tool for Assessing Surgical Flow Disruptions and Their Impact on Surgical Performance. *World Journal of Surgery, 34*, 353-361.

Henrickson, S., Wadhera, R., ElBardissi, A., Wiegmann, D., & Sundt III, T. (2009, June). Development and Pilot Evaluation of a Preoperative Briefing Protocol for Cardiovascular Surgery. *American College of Surgeons, 208*(6), 1115-1123.

Henrickson-Parker, S., Laviana, A., Sundt, T., & Wiegmann, D. (2009). Developing a Tool for Reliably Identifying Distractions and Interruptions during Surgery. *Proceedings of the Human Factors and Ergonomics Society 53rd Annual Meeting*, 664-668.

Holden, R., Rivera-Rodriguez, A., Faye, H., Scanlon, M., & Karsh, B.-T. (2013). Automation and adaptation: nurses' problem-solving behavior following the implementation of bar-coded medication administration technology. *Cognition, Technology and Work*, 283-296.

Hollnagel, E., Woods, D., & Leveson, N. (2006). *Resilience Engineering: Concepts and Precepts.* Burlington, VT: Ashgate Publishing.

Joint Commission. (2007). Sentinel event policy and procedures. *Retrieved October, 18*, 2007.

Karsh, B., & Holden, R. (2007). New technology implementation in health care. In C. Carayon, *Handbook of Human Factors and Ergonomics in Health Care and Patient Safety* (pp. 393–410). New Jersey: Lawrence Earlbaum.

Karsh, B. T., Holden, R. J., Alper, S. J., & Or, C. K. L. (2006). A human factors engineering paradigm for patient safety: designing to support the performance of the healthcare professional. *Quality and Safety in Health Care*, *15*(suppl 1), i59-i65.

Leape, L. L. (2000). Institute of Medicine: Medical Error Figures Are Not Exaggerated. *The Journal of the American Medical Association*, 95-97.

Lingard, L., Espin, S., Whyte, S., Regehr, G., Baker, G., Reznick, R., et al. (2004). Communication failures in the operating room: an observational classification of recurrent types and effects. *Quality and Safety in Health Care*, 330-334.

Lingard, L., Regehr, G., Orser, B., Reznick, R., Baker, G., Doran, D., et al. (2008). Evaluation of a Preoperative Checklist and Team Briefing Among Surgeons, Nurses, and Anesthesiologists to Reduce Failures in Communication. *Annals of Surgery*, 12-17.

Lunn, J. (1986). *Epidemiology in anaesthesia*. London: Edward Arnold.

Mann, F., Walkup, R., Berryman, C., Bessey, P., Wilson, A., & Vannier, A. (1994). Computer-based videotape analysis of trauma resuscitations for quality assurance and clinical research. *Journal of Trauma*, 226-230.

McCulloch, P., Mishra, A., Handa, A., Dale, T., Hirst, G., & Catchpole, K. (2008). The effects of aviation-style non-technical skills training on technical performance and outcome in the operating theatre. *Quality Safety in Health Care*, 109-115.

McFadden, K. (1997). Predicting pilot-error incidents of US airline pilots using logistic regression. *Applied Ergonomics*, 209-212.

Meister, D. (1999). *The History of Human Factors and Ergonomics.* Mahwah, NJ: Lawrence Erlbaum Associates.

Menard, S. (2002). *Applied Logistic Regression Analysis (Quantitative Applications in the Social Sciences).* Thousand Oaks, CA: Sage Publications.

Miller, D., Fortier, C., & Garrison, K. (2011). Bar Code Medication Administration Technology: Characterization of High-Alert Medication Triggers and Clinician Workarounds. *The Annals of Pharmacotherapy*, 162-168.

Morrow, D., North, R., & Wickens, C. (2005). Reducing and Mitigating Human Error in Medicine. *Reviews of Human Factors and Ergonomics*, 254-296.

Nast, P., Avidan, M., Harris, C., Krauss, M., Jacobsohn, E., Petlin, A., et al. (2005). Reporting and classification of patient safety events in a cardiothoracic intensive care unit and cardiothoracic postoperative care unit. *Cardiopulmonary Support and Physiology*, 1137.e1-e9.

Nemeth, C., Cook, R., O' Connor, M., & Klock, P. (2004). Using cognitive artifacts to understand distributed cognition. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, 34*, 726-735.

Novak, L., Holden, R., Anders, S., Hong, J., & Karsh, B.-T. (2013). Using a sociotechnical framework to understand adaptations in health IT implementation. *International Journal of Medical Informatics*.

Padgett, D. (2008). *Qualitative methods in social work research.* Thousand Oaks, CA: Sage Publications.

Palmer II, G., Abernathy III, J., Swinton, G., Allison, D., Greenstein, J., Shappell, S., et al. (2013). Realizing Improved Patient Care through Human-centered Operating Room Design: A Human Factors Methodology for Observing Flow Disruptions in the Cardiothoracic Operating Room. *Journal of Anesthesiology*.

Parker, S., Laviana, A., Wadhera, R., Wiegmann, D., & Sundt III, T. (2010). Development and Evaluation of an Observational Tool for Assessing Surgical Flow Disruptions and Their Impact on Surgical Performance. *World Journal of Surgery, 34*, 353-361.

Patterson, E., Woods, D., Cook, R., & Render, M. (2007). Collaborative cross-checking to enhance resilience. *Cognition, Technology and Work*, 155-162.

Patterson, E., Woods, D., Roth, E., Cook, R., Wears, R., & Render, M. (2006). Three Key Levers for Achieving Resilience in Medication Delivery with Information Technology. *Journal of Patient Safety*, 33-38.

Phillips, M., & Berner, E. (2004). Beating the System - Pitfalls of Bar Code Medication Administration. *Journal of Healthcare Information Management*, 16-18.

Reason, J. (1990). *Human Error.* New York, NY: Cambridge University Press.

Reason, J. (1995). Understanding adverse events: human factors. *Quality in Health Care*, 80-89.

Reason, J. (2000). Human error: models and management. *British Medical Journal, 320*, 768-770.

Richards, L. (2009). Handling qualitative data: A practical guide. London: Sage Publications.

Rivera, A. (2013). A socio-technical systems approach to studying interruptions: Understanding the interrupter's perspective. *Applied Ergonomics*, 1-10.

Rivera-Rodriguez, A., & Karsh, B.-T. (2010). Interruptions and distractions in healthcare: review and reappraisal. *Quality and Safety in Health Care*.

Robson, C. (2011). *Real world research: a resource for users of social research methods in applied settings*. Chichester: Wiley.

Roth, E., Christian, C., Gustafson, M., Sheridan, T., Dwyer, K., Gandhi, T., et al. (2004). Using field observations as a tool for discovery: analys ing cognitive and collaborative demands in the operating room. *Cognition, Technology & Work, 6*(3), 148-157.

Schaefer HG, H. R. (1994). Human factors and safety in emergency medicine. *Resuscitation*, 221-225.

Schaefer HG, H. R. (1994). The importance of human factors in the operating room. *Anesthesiology*, 479.

Sevdalis, N., Forrest, D., Undre, S., Darzi, A., & Vincent, C. (2008). Annoyances, Disruptions, and Interruptions in Surgery: The Disruptions in Surgery Index (DiSI). *World Journal of Surgery, 32*, 1643-1650.

Smith, P., McCoy, C., & Layton, C. (1997). Brittleness in the Design of Cooperative Problem - Solving Systems: The Effects on User Performance. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, 360-371.

Sutton, E., Youssef, Y., Meenaghan, N., Godinez, C., Xiao, Y., Lee, T., et al. (2010). Gaze disruptions experienced by the laparoscopic operating surgeon. *Surgical Endoscopy*, 1240-1244.

Taylor, C. (1997). Problem solving in clinical nursing practice. *Journal of Advanced Nursing*, 329-336.

Tucker, A. (2004). The impact of operational failures on hospital nurses and their patients. *Journal of Operations Management*, 151-169.

Tucker, A., Edmondosn, A., & Spear, S. (2002). When problem solving prevents organizational learning. *Journal of Organizational Change Management*, 122-137.

Undre, S., Healey, A., Darzi, A., & Vincent, C. (2006, September). Observational Assessment of Surgical Teamwork: A Feasibility Study. *World Journal of Surgery, 30*, 1774-1783.

Undre, S., Sevdalis, N., Healey, A., Darzi, A., & Vincent, C. (2007). Observational Teamwork Assessment for Surgery (OTAS): Refinement and Application in Urological Surgery. *World Journal of Surgery, 31*, 1373-1381.

Vincent, C., Moorthy, K., Sarker, S., Chang, A., & Darzi, A. (2004, April). Systems Approaches to Surgical Quality and Safety From Concept to Measurement. *Annals of Surgery, 239*(4), 475-482.

Vincent, C., Taylor-Adams, S., Chapman, E., Hewett, D., Prior, S., Strange, P., et al. (2000). How to investigate and analyse clinical incidents: Clinical Risk Unit and Association of Litigation and Risk Management protocol. *British Medical Journal, 320*, 777-781.

Warden, J., Borton, C., & Horan, B. (1994). Mortality associated with anaesthesia in New South Wales, 1984-1990. *Medical Journal of Australia, 161*, 585-593.

Westrum, R. (1997). Social factors in safety-critical systems. In R. Redmill, & J. Rajan, *Human Factors in Safety Critical Systems* (pp. 233-256). Oxford: Butterworth-Heinemann.

Wickens, C., & Hollands, J. (2000). *Engineering Psychology and Human Performance.* Upper Saddle River, NJ: Prentice-Hall Inc.

Wiegmann, D., ElBardissi, A., Dearani, J., & Sundt, T. (2006). An Empirical Investigation of Surgical Flow Disruptions and Their Relationship to Surgical Errors. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting* (pp. 1049-1053). Human Factors and Ergonomics Society.

Wiegmann, D., ElBardissi, A., Dearani, J., Daly, R., & Sundt III, T. (2007, July). Disruptions in surgical flow and their relationship to surgical errors: An exploratory investigation. *Surgery, 142*(5), 658-665.

Wong, D., Ali, I., Torchiana, D., Agnihotri, A., Bohmer, R., & Vander Salm, T. (2009). Learning in a new cardiac surgical center: An analysis of precursor events. *Surgery, 145*(2), 131-137.

Wong, D., Torchiana, D., Vander Salm, T., Agnihotri, A., Bohmer, R., & Ali, I. (2007). Impact of cardiac intraoperative precursor events on adverse outcomes. *Surgery, 141*(6), 715-721.

Wong, D., Vander Salm, T., Ali, I., Agnihotri, A., Bohmer, R., & Torchiana, D. (2006). Prospective assessment of intraoperative precursor events during cardiac surgery. *European Journal of Cardio-thoracic Surgery, 29*, 447-455.

Yule, S., Flin, R., Paterson-Brown, S., & Maran, N. (2006). Non-technical skills for surgeons in the operating room: A review of the literature. *Surgery*, 140-149.