EVALUATING THE EFFECTS OF ORGANIZATIONAL POLICIES ON SURGEONS' AVAILABILITY TO OPERATE: A COMPUTER SIMULATION APPROACH

by

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Abstract

Surgical services contribute to a large proportion of a hospital's costs and revenues thus it is important to understand key performance drivers so that resources can be distributed in an informed way. Organizational policies can affect the performance of the peri-operative process, however, there is a lack of knowledge within the health services literature regarding how the organizational policies of a surgical service affect surgeons' availability to perform operations. Additionally, simulation-based research has largely focused on operating room planning and scheduling, not on how surgeons' operating time may be affected by organizational policies.

The objective of this simulation study was to estimate the effects of organizational policies on surgeons' availability to operate in the context of cardiac surgical care. The major finding was that surgeons' availability to operate declines if surgeons are not permitted to be on-call and scheduled in the OR for non-emergency operations on the same day.

List of Abbreviations Used

$\widehat{OR}$	Odds ratio
CVD	Cardiovascular disease
DES	Discrete event simulation
ICU	Intensive care unit
OR	Operating room
SAR	Standardized access ratio

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Chapter 1

Introduction

1.1 Context

Access to care is an important indicator of the functioning of a health care system [25]. In Canada, wait lists are used to manage access to surgical procedures, including coronary bypass surgery (a surgical treatment for persons with coronary syndromes) [27]. Delays and deaths while waiting for coronary bypass surgery have raised concerns about access to coronary surgical care in Canada and it has been shown that delaying operations can lead to worsened clinical outcomes and quality of life [16, 20, 31]. The availability of care providers such as nurses and surgeons can affect timely access to cardiac care and is a critical factor in access to surgical care [4, 16]. This thesis was undertaken in order to assess the effects of two organizational policies on the availability of surgeons to perform regularly scheduled operations.

This thesis was conducted as part of the SIMCARE research program[1]. A key component of the SIMCARE program is a computer simulation model representing the flow of patients with coronary artery disease in a network of cardiac care hospitals in order to examine the impact of proposed organizational changes on access to coronary revascularization [39, 40]. Using patient and hospital level outcomes as measures of interest, the SIMCARE research program has focused on comparing policies in a three surgeon surgical service where surgeon availability is based on known schedules and duties are rotated between the surgeons each week [21, 43, 44, 48, 49].

To date, simulation models in surgical settings examining the availability of surgeons have been focused on clinic-based settings [8]. Models focused around the operating

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[1] This research program is funded by the CIHR strategic initiative entitled "Advancing Theories, Frameworks, Methods and Measurement In Health Services Policy, Population and Public Health Research and Knowledge Translation". The program addresses one of the objectives of that initiative, which is "to develop conceptual frameworks, and methods of analysis for research respecting health services, systems and policies".

room have concentrated on operating room planning and scheduling, that is, managing OR capacity and utilization through improved patient scheduling and wait list management [7, 9, 28]. This research has yet to focus on surgeons' availability to be present in the operating room. Specifically, these models have not focused on how organizational policies affecting the distribution of surgeons' clinical and academic activities can affect their availability to perform operations.

The SIMCARE research program featured three clinical activities relating to surgeon availability as a component of the peri-operative process. This research has focused on the effects that booking systems have on patient flow but has not yet focused on evaluating organizational policies that may affect surgeons' availability [21, 43, 44, 48, 49]. Additionally, the results from existing studies may not apply to hospitals where surgeons have admitting rights at multiple hospitals, or where surgeons have teaching and research responsibilities that may contribute to their unavailability to perform operations. This thesis presents an evaluation of the effects of two organizational policies on surgeons' availability to perform operations. The methodology developed in this study is used to investigate availability in a simulated ten surgeon surgical service and may be generalized to other surgical services.

1.2 Background

The public demands timely access to quality health care at lower costs. Surgical services can provide up to 40% of a hospital's costs and revenues, thus efficiency in the peri-operative process is essential [11, 23]. Quality and efficiency are not mutually exclusive and are often affected by a hospital's organizational structure [26]. Within the context of cardiac surgical care, this includes scheduling methods to book patients for appointments and operations, coordination with external departments such as cardiology and anesthesiology, and policies for discharging patients post-surgery. Inefficiencies and bottlenecks in these processes can result in decreased quality of care and reduced access to care; however, patient care must not be compromised by unsafe practices that improve inefficiencies and reduce costs [3, 26].

Both clinical and organizational policies affect the efficiency of the peri-operative process. Evidence-based clinical guidelines consider the best scientific evidence and propose clinical recommendations, although differences in interpretation can result in differences in clinical practice and variation in care [12]. Organizational policies such as patient booking policies play an important role in ensuring efficient and timely access to healthcare (i.e. efficient patient flow) by smoothing workflow, reducing the number of patients in waiting rooms, and respecting patient and care provider preferences [13].

Additionally, organizational policies have the potential to affect surgeon availability, which plays an important role in ensuring efficient and timely access to care: as the time that surgeons use for interacting with individual patients increases, the expected waiting times for new and existing wait-listed patients increases dramatically [1]. Furthermore, some experts have speculated that a scarcity of trained surgeons within geographic areas can also increase waiting times [18]. However, there is a lack of knowledge in the health services literature regarding how the organizational policies of a surgical service affect surgeons' availability to perform regularly scheduled operations. This knowledge may be particularly valuable in teaching hospitals where surgeons must balance clinical and academic duties since these hospitals are less efficient and therefore more costly than non-teaching hospitals [4].

Computer simulation is increasingly being used to assess the effects of changes in organizational and management initiatives and to inform policy decisions in health care settings [10, 15, 45]. The innate complexity and reactive nature of health care systems is well suited to be modelled using Discrete Event Simulation (DES) [10, **?**]. In DES patient flow models, a series of states that characterize a health care system (or a part of a health care system) are used to model patient pathways.

These models offer a method to evaluate the impact of policy and managerial alternatives in health care settings where interventional studies may not be feasible [15, 39]. They can be used to provide technical assessments that evaluate the effect of policy and management alternatives at both an individual level and a hospital level, allowing for policy development that aims to improve both individual and hospital level outcomes [40]. Such outcomes may include health outcomes and/or organizational outcomes and are often interpreted through benchmarking as a means to facilitate and contextualize policy comparison [19, 22]

In surgical care settings, DES models have yet to focus on how organizational policies affect surgeon availability; by not including the different clinical and academic duties of surgeons into these models, their availability to perform operations may be overestimated. Using DES to evaluate hospital-level outcomes, this thesis will present an estimate of the effects of two organizational policies on surgeons' availability to operate in the context of cardiac surgical care. These effects will be presented in terms of relevant benchmarks to contextualize their significance.

The thesis is structured into seven chapters according to the following framework. Chapter two provides an short introduction to evaluating organizational policies in surgical settings using computer simulation. A review on evaluating the effects of two booking policies for outpatient clinic appointments for coronary bypass surgery while considering the availability of surgeons for operations is provided in chapter three, which also includes a short description of epidemiologic and statistical tools used to evaluate policy interventions. The objectives of the study are presented in chapter four and chapter five describes the technical and statistical methods used to attain the objectives. The results are described in chapter six. In chapter seven, the limitations of this study are considered, and directions for future research are suggested.

Chapter 2

Review of the Literature

2.1 Background

Studying alternative policies in cardiac surgical settings is especially important because the stakes are high: cardiovascular disease (CVD) remains the second leading cause of death in Canada despite mortality rates decreasing nearly 50% during the past 30 years [2, 6]. The impact of CVD is substantial with severe forms of CVD associated with a large negative impact on quality of life (more potential years of life are lost to CVD than all cancers combined) [35, 5]. Moreover, CVD has the largest economic burden on the health care system of any disease category: the direct and indirect costs of CVD in Nova Scotia alone were estimated to exceed $960M per annum during 2002 [2, 5].

One treatment modality for CVD is coronary bypass surgery, which is performed to improve the symptoms associated with CVD, not to improve survival [38, 50]. In Canada, wait lists are used to manage access to coronary bypass surgery. [27]. Expected waiting times for patients are variable and dependent on a multitude of factors including demand for the operation, urgency, service time, and surgical cancellations [46]. As a result, the impact of changes in the delivery of cardiac surgical care (including those affecting surgeon availability) are difficult to study because the system of access to this operation is complex [27, 46].

Due to the complexity surrounding access to bypass surgery, reports often document the effects of a policy change after a full-scale implementation of a new policy; intervention studies in surgical settings are seldom practical for ethical, temporal, or economic reasons [42]. Furthermore, intervention studies are often limited with respect to the type and amount of data that can be collected and it can be difficult to obtain statistical power for small samples.

One way to assess the impact of new policies in surgical settings is to use computer simulation modeling to simulate patient flow through the peri-operative process [15, 37, 48]. DES patient flow models in surgical settings rest on two fundamental assumptions: (1) the simulated trajectories of individuals realistically represents the delivery of health services to a population, and (2) the simulation produces care paths that are likely to occur under the implemented policy [40]. These models are often used to evaluate policies that vary resource availability and/or patient booking and admission practices and offer some advantages to natural intervention studies, for example, a simulation study is able to hold many factors constant during the execution of experiments, thus clarifying the influence of proposed policy interventions [15, 45].

Human health resources such as surgeons are an integral factor in surgical scheduling since their scheduling and availability can have significant effects, both in terms of individual outcomes such as waiting times, and in terms of hospital outcomes such as the cost-effectiveness of a particular policy [8, 7, 14]. Although many simulation studies have evaluated the effects of operating room planning and scheduling, there is a lack of knowledge in the health services literature regarding how the organizational policies of a surgical service affects surgeons availability to perform regularly scheduled operations [9, 7]. The scarcity of literature in this area underlines the importance of further research in this field.

Due to the paucity of literature regarding how organizational policies affect surgeons availability to perform regularly scheduled operations, this literature review focuses on the larger context of evaluating the effects of two booking policies for outpatient clinic appointments for coronary bypass surgery while considering the availability of surgeons for operations.

2.2 Coronary Artery Bypass Surgery: Patient Pathways

According to their initial presentation and the events that lead to surgery, different patients experience different care pathways through the peri-operative process [49]. These pathways are the elective care pathway, the urgent care pathway, and the emergency (emergent) care pathway. The elective pathway refers to the patient pathway for patients who can safely delay assessment and surgery while the urgent care pathway refers to the patient pathway for those patients requiring expedited assessment. The emergent care pathway refers to the patient pathway for those patients who require immediate surgical intervention.

2.3 Relevant Measurement Tools

Several epidemiologic and statistical measurement tools are used to evaluate policy interventions in surgical settings. Tools relevant to this project are outlined at the end of this chapter in Table 2.1.

2.4 Outpatient Clinic Appointments: Pooled versus Individual Booking

The majority of outpatient clinic booking experiments (both analytic and simulation based) focus on evaluating methods to schedule patients to clinic appointment slots as a means of reducing patient waiting times in clinic and increase patient throughput. These experiments have largely demonstrated that patient and physician punctuality, as well as the presence of no-shows, walk-ins, and companions affect the performance of an appointment system [8, 14]. Generally, these studies evaluate outpatient booking systems that schedule patients with a named specialist. A small number of studies evaluate booking methods that schedule patients to the first available physician (individual booking) from a pooled list of specialists (pooled booking), however very few models have been used to evaluate the impact of both individual and pooled booking practices in a single setting [8].

Leach et al (2004) reported on the implementation of a pooled appointment wait list for patients referred to a spinal surgeon [18]. Pooled appointment booking was replacing individual appointment booking to decrease patient waiting times as it is generally thought that smoothing the variation between waiting times for individual physicians will result in shorter waiting times [36]. Data were collected before and after the implementation of the new booking policy. The authors reported that the number of patients waiting more than 26 weeks for a consultation fell from over 75 to zero, while the number of patients waiting less than 26 weeks “declined greatly” (the amount of decline was unspecified). Patient satisfaction was high for the implementation of the pooled appointment lists, however, consulting physicians had reservations about continuity of care. Reported disadvantages of implementing the pooled appointment wait list method were establishing a quorum of surgeons to participate in the new system, a small increase in secretarial workload, and occasional discontinuity of care from consultants.

Vasilakis and Kuramoto (2007) created a DES patient flow model of the peri-operative process, from referral, until discharge from hospital following cardiac surgery as part of the SIMCARE research program [48, 49]. The authors compared pooled and individual methods of booking patients for clinic appointments with one of three surgeons, where surgeons duties were highly structured and availability was limited by other responsibilities (for example, being on-call) [49]. The model created elective, urgent, and emergent patients from multiple priority groups. Ultimately 143,469 simulated elective patients were randomized to the individual appointments group, and 143,675 were randomized to the pooled appointments group. Standardized Access Ratios (SARs) comparing the total number of appointments/operations occurring within 12/52 weeks from referral/appointments, and Odds Ratios ($\widehat{OR}$), indicating the odds of having a clinic appointment/surgery within 6/18 weeks from referral/appointment, were used to assess the performance of both booking methods (all measures were stratified by patient priority groups).

This study demonstrated that patients randomized to the pooled booking group had increased odds of having an appointment compared to those randomized to the individual booking group ($\widehat{OR} = 6.89$ (95% confidence interval [CI]: $6.60 to 7.19$) for priority 2 patients at referral), however, the odds of undergoing surgery were not different ($\widehat{OR} = 0.98$ $(95\% CI : 0.92 to 1.05)$ for priority 2 patients at registration). The SARs were reflective of this finding, as the SARs showed an increase in the number of appointments for the pooled booking group ($SAR = 2.56$ $(95\% CI : 2.53 to 2.59)$ for priority 2 patients at referral) and only a small decrease in the number of operations ($SAR = 0.93$ $(95\% CI : 0.92 to 0.94)$ for priority 2 patients at registration). Statistically significant $\widehat{OR}$s for the odds of undergoing surgery were detected for priority 3 patients only ($\widehat{OR} = 0.57$ $(95\% CI : 0.54 to 0.59)$) and the authors concluded that there was no significant difference in net waiting time between referral and surgery for the two booking methods. An important limitation of this study was that results were not adjusted for hospital- and individual-level factors which may have influenced the measured outcomes [42].

2.5 Organizational Structure of Surgical Services

The organizational (or managerial) structure of a surgical service refers to the way in which surgeons' time is scheduled. For example, a surgical service may have a rigid organizational structure in which activities are pre-determined and shared equally between all surgeons in the service, or the service may have a more autonomous division of duties, where each surgeon is responsible for creating their own schedule. There is a lack of knowledge in the health services literature regarding how the organizational structure of a surgical service affects patient flow.

DES patient flow models in surgical settings have included surgeons as a factor that affects patient flow, especially in the context of the operating room, however, these models have not yet focused on surgeon availability to perform operations. To date, these models have focused mainly on scheduling surgeons to the OR, given a constraint on the total number of hours or OR slots that may be worked in, say, a week, assuming that the surgeon is available to operate at any time, or that the surgeons have predictable periods of unavailability [9, 30]. As such, the availability of surgeons may be systematically overestimated. It is unknown how the organizational structure of a surgical service affects the systems performance.

2.6 Number of Surgeons in a Surgical Service

There is very little health services literature addressing how the number of surgeons in a surgical service affects patient waiting times. A European study analyzed waiting time data for cataract surgery patients from ten countries [24]. This study was limited in many respects, including a lack of data pertaining to the number of ophthalmologists performing cataract surgery (physician density, defined as the number of physicians of any type per 1000 people, was used as a proxy for these data). Although the authors were unable to draw a conclusion about how physician density affects waiting times for cataract surgery, board members of the European Society for Cataract and Refractive Surgery speculated that long waiting times in Sweden could be explained by a lack of trained surgeons in certain areas of the country.

On the other hand, literature from queuing theory notes that it is not the number of surgeons in a surgical service that affects patient waiting time, *per se*, and instead that it is the fraction of time that surgeons use for interacting with patients that affects patient waiting times. As surgeons spend more time with individual patients, the number of patients they can assess during a given period of availability decreases and the expected wait times for patients increases dramatically. [1].

2.7 Remarks

It is widely acknowledged in the field of operations research that improvements to isolated components of a system do not necessarily lead to in improvements to the system as a whole [33]. That is, making changes in one area of the peri-operative process can result in unpredictable outcomes in other areas [49]. It is important to keep the possibility of unintended effects in mind when developing and implementing policy change initiatives, whether in real, analytic, or simulated settings. Furthermore, many policy initiative experiments (simulated and analytical) limit their results to a single hospital or region; often these results are not generalizable to other hospitals or regions.

Additionally, patients and care providers can express differential preferences for new policy initiatives [29]. Although this is often addressed within intervention studies, such preferences are not considered by simulation models; it is important to take these preferences into account when developing policy initiatives.

Table 2.1: Relevant Epidemiologic and Statistical Measures used to Evaluate Policy Interventions

Measurement Tool	Description
Waiting time	In the case of surgical services, this can refer to the time between when a patient is first referred to a specialist by a general practitioner and when the patient is seen for consultation. Waiting time can also refer to the time between when a patient is seen for consultation and when the patient is admitted for surgery [34]. Waiting time definitions can, and often do, differ in terms of start and end points and reporting is not standardized. As such, some waiting time data are reported as a mean, others as a median. Means are greatly affected by skewed data, which occurs when a small number of patients wait for a long time [32].
Odds ratio	Defined as the ratio of the conditional odds of an event occurring in group one (e.g. pooled booking) to the conditional odds of an event occurring in group two (e.g. Individual booking) [41].
Standardized Access Ratio	Defined as the total number of clinic appointments occurring in one booking method (e.g. pooled booking), divided by the total number of clinic appointments in the other booking method (e.g. individual booking). This measure is similar to the Standardized Mortality Ratio used in epidemiology [49].
Individual-level factors and outcomes	Refers to factors occurring at an individual level. These data may represent factors that influence progress through care-pathways (e.g. age, sex, coronary anatomy), or experimental outcomes (e.g. time on an appointment list and time to surgery) than can be used to evaluate the proportion of individuals (often patients) in different study groups [43].
Hospital-level factors and outcomes	Refers to experimental factors that are likely to influence hospital operations (e.g. initial queue size for outpatient consultations). Hospital-level outcomes are used to compare the performance of hospitals in different study groups (e.g. wait list clearance time) [43].

Chapter 3

Objective

The objective of this simulation study was to estimate the effects of organizational policies on surgeons availability to operate in the context of cardiac surgical care.

We compared two policies: the dedicated on-call policy and the multiple responsibility on-call policy. With the dedicated on-call policy, surgeons were not permitted to be on-call and scheduled in the operating room for non-emergent operations on the same day. With the multiple responsibility on-call policy, surgeons were permitted to be on-call and scheduled in the operating room for non-emergent operations on the same day. These organizational policies were compared in a simulated environment with a ten-surgeon surgical service that has an autonomous division of responsibilities.

We compared the effects of these organizational policies on surgeon availability in terms of the following performance measures: the mean number of OR slots filled by all surgeons during the course of a year, the proportion of one year OR schedules that utilized at least 90% of available OR slots, and the mean number of OR slots filled by each surgeon during the week (Monday to Friday) over the course of a year. Accordingly, this simulation study was designed to address the following questions:

1. Does the dedicated on-call scheduling policy result in a lower number of regularly scheduled OR slots filled than the multiple responsibility on-call policy?
2. Does the dedicated on-call scheduling policy result in a lower number of regularly scheduled OR slots for individual surgeons than the multiple responsibility on-call policy?

What is already known about this topic

- There is a lack of knowledge in the health services literature regarding how the organizational policies of a surgical service affects that surgeons' availability to perform regularly scheduled operations.

- Specifically, DES models in surgical care have frequently neglected to incorporate the different duties required of surgeons. Consequently, the availability of care providers may be systematically overestimated.

What this study adds

- This simulation study shows the effects of two organizational policies on the availability of surgeons to perform regularly scheduled operations, and incorporates the different duties required of cardiac surgeons.

What is Known About the Effects of Organizational Policies on Surgeons' Availability to Operate and What This Study Adds

Chapter 4

Methods

This project consisted of two parts: (1) the creation of a simulation model that represents a ten-surgeon surgical service with an autonomous division of surgeon duties, and (2) the comparison of two organizational policies in this setting. This chapter describes the requirements of the model, technical aspects of the model implementation, and the statistical analyses used to compare the two organizational policies outlined in the objectives.

4.1 Modeling Requirements

4.1.1 Characterization

The model used for this project was developed through a cooperative effort with the Division of Cardiac Surgery at the Halifax Infirmary (HI). Ten cardiac surgeons operate in the Division and they have a relatively autonomous division of clinical and managerial duties. The simulation model created during this project was based on the duties and responsibilities of the surgeons in the Division.

Duties and responsibilities of the surgeons were identified through voluntary one-on-one interviews with the surgeons and booking staff, who are intimately familiar with the surgeons' duties and responsibilities. Interviews were held with six of ten surgeons, one senior resident, and three of four identified booking staff. Four surgeons were unavailable for interviews because of scheduling conflicts, and one of the booking staff declined participation. A full copy of the questionnaires for surgeons and booking staff can be found in Appendix A.

The framework to represent the availability of the ten surgeons was developed by abstracting the surgeons duties and responsibilities into a series of parallel clinical and managerial activities that react to internal and external events. Additionally, research and clinic schedules as well as ten weeks of past OR, schedules were made available for this project by the Division; this facilitated the development and validation of clinical and managerial activities for the surgeons, especially those who were not interviewed. The model records the daily activities of the surgeons in external data stores that capture their occurrence and timing.

4.1.2 Duties and Vacation

Each of the ten surgeons performs some operations (operating room duty) and assesses patients in clinic (clinic duty), however, only eight surgeons are responsible for being on call to perform emergent operations (on-call duty). Other responsibilities include operating at a neighbouring paediatric hospital (IWK operating room duty), teaching and research responsibilities, and administrative work. In total, ten reoccurring clinical, academic, and administrative duties were identified in the surgeons' schedules. These activities are described in table 4.1.

All surgeons have four to six weeks of vacation each year. When one of the surgeons is on vacation, the other surgeons assume the extra operating room duty and on-call duty, if necessary.

The duties of each of the ten surgeons included in the model are outlined in Table 4.2. Some surgeons perform their administrative duties concurrently with other responsibilities while other surgeons have protected time for their administrative, teaching, and research duties. Most surgeons have a unique set of responsibilities. For this project, it was essential that the operating (at the modelled hospital), on-call, and ICU supervision duties were accurately described because they directly impacted the outcomes pertaining to the objective of the study (for example, surgeons could not be in the OR or on-call when they have the ICU supervision duty). In cases where it was not possible to accurately describe academic and administrative duties, "other" was used as a catch-all activity.

Table 4.1: Reoccurring Clinical and Managerial Activities Identified in the Ten Surgeon Service that were Included in the Model

Type of Activity	**Activity**	**Description**
Clinical	Cardiovascular Intensive Care Unit Supervision (ICU)	Monitoring patients who are recovering from cardiac surgery in the cardiovascular intensive care unit and intermediate care unit.
	On-call (OC)	Assessing urgent patients and performing emergent operations.
	Operating at the Infirmary (OR)	Operating on regularly scheduled cases at the modelled hospital.
	Operating elsewhere (IWK)	Operating at a nearby hospital.
	Clinic	Performing outpatient consultations in clinic .
Academic	Research	Clinical and other research.
	Teaching	Educating and training medical students and surgical residents.
Administrative	Admin	Performing administrative duties.
Other	Other	Catch-all activity used when further detail was unavailable. Includes the Research, Teaching, and Admin duties; does not include any clinical activities.
	Vacation	On vacation and not able to perform any duties.

4.1.3 Development and Structure

Statecharts, a graphical computer simulation language, was used to create a DES model representing the availability of surgeons in a surgical service with ten surgeons. AnyLogic 6.6 (XJ Technologies, Russia) was used to implement the model and run the simulations. Statecharts allow the definition of detailed characteristics of the organizational structure of a surgical service using states, events, and transitions between the states while calling on the notions of broadcasting, parallelism, and hierarchy [39]. Broadcasting permits multiple statecharts to “hear” and respond to events, while parallelism allows more than one state to be active at the same time during simulation (in real time events that trigger state transitions are executed one

Table 4.2: Individual Surgeon Duties in the Ten Surgeon Model

Activity	**Surgeon 1**	**Surgeon 2**	**Surgeon 3**	**Surgeon 4**	**Surgeon 5**
ICU		✓		✓	✓
OC		✓		✓	✓
OR	✓	✓	✓	✓	✓
IWK	✓		✓		
Clinic		✓		✓	✓
Research		✓	✓	✓	✓
Teaching		✓		✓	✓
Admin		✓	✓	✓	✓
Other	✓		✓		
Vacation	✓	✓	✓	✓	✓

Activity	**Surgeon 6**	**Surgeon 7**	**Surgeon 8**	**Surgeon 9**	**Surgeon 10**
ICU	✓		✓		
OC	✓	✓	✓	✓	✓
OR	✓	✓	✓	✓	✓
IWK					
Clinic	✓	✓	✓	✓	✓
Research	✓		✓	✓	✓
Teaching	✓	✓			
Admin	✓	✓	✓	✓	✓
Other			✓		✓
Vacation	✓	✓	✓	✓	✓

at a time). Hierarchy permits states within states, effectively allowing sub-activities to occur within larger activities. These principles facilitate the development of a surgeon availability model, which capitalizes on all three notions of Statecharts by requiring that surgeons have independent (yet concurrent) activities, change activities given an appropriate cue, and act within the continuum of cardiac surgical care.

The simulation model describes surgeon availability during the weekdays (Monday-Friday). Each surgeon was modeled using one or two Statecharts to represent their rotation of responsibilities[1]. These Statecharts operate autonomously with events broadcast twice daily to trigger surgeons to change their activities.

Surgeon availability in the model was determined by a combination of table-based availability and probabilistic availability.

Table-Based Availability

Some surgeons had protected time for clinics, lab-based research, teaching, and administrative work. Due to their repeating and predictable nature, these duties were amenable to a tabular schedule. As such, specific guards were built into surgeons Statecharts to ensure that time was protected for particular activities when required (for example, to ensure a scheduled clinic day on the last Monday of a month). Appendix B outlines reoccurring duties for all ten surgeons.

The ICU supervision duty and the on-call duty were rotated between the surgeons who have these duties. These responsibilities were also amenable to a tabular schedule and specific guards and conditions were also put in place to ensure that these duties were rotated equitably between surgeons. The ICU and on-call schedule is described in further detail in Appendix C.

Probabilistic Availability

For duties that did not follow a predictable schedule, such as the operating duty, a probabilistic approach was used.

Using this approach, a Bernoulli trial was conducted to evaluated to determine whether a surgeon was available to perform a particular duty in the morning or afternoon. For each trial $P(X = 1) = p$, where the value of p varied based on the order in which the surgeon was assigned their duties[2], and the likelihood that they would be in the OR. The order that the surgeons were assigned their duties was empirically specified, as was the value for p, which increased as the assignment order

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[1] Due to the implementation of AnyLogic Statecharts, surgeons with the on-call duty required a second (parallel) statechart to accommodate the multiple responsibility on-call scheduling method

increased and was updated based on the number of surgeons on vacation.

Variables representing the maximum weekly number of occurrences for a particular duty were set individually for each surgeon based on data collected during the interviews. Additionally, guards were set in place to ensure that surgeons did not exceed their weekly limit. No variables were created to ensure a minimum weekly number of occurrences for a particular duty since no such minimums were found to exist in the model hospital. (The maximum weekly number of occurrences for specific duties are outlined in Appendix D.)

Surgeons' Statecharts

As described in Table 4.2, Surgeon 1 has four duties: operating at the modeled hospital, operating at a neighbouring hospital, other duties, and vacation. This surgeon did not have the on-call responsibility and did not supervise the ICU. The statechart in Figure 4.1 graphically represents these duties as states and includes one additional 'weekend' state for Saturday and Sunday.

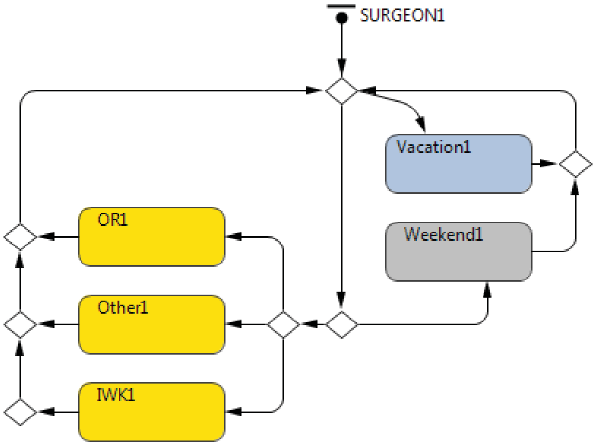

Figure 4.1: Statechart Showing Activities for Surgeon 1

In the model, Surgeon 1 performed operations at the modeled hospital on Monday

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[2] In model time the surgeons are assigned duties concurrently, however, in real time they are assigned duties one at a time. According to the Surgeons' IDs, the order of assignment is: 1, 3, 6, 7, 4, 2, 10, 9, 8, 5.

mornings and performed other activities (such as administrative work and seeing patients for consultation) in the afternoons. This surgeon operated at a neighbouring hospital on Tuesdays through Fridays. These duties were predictable and well described using table-based availability (Table 4.3). Guards were created within the transitions of the statechart for Surgeon 1 to ensure that particular duties were performed on particular days.

Table 4.3: Regularly Scheduled Duties for Surgeon 1

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	OR	Operating at neighbouring hospital (IWK)			
Afternoon	Other	Operating at neighbouring hospital (IWK)			

Surgeon 3 had responsibilities similar to those of Surgeon 1 and these duties were also predictable and well described by table-based availability. The implementation to Surgeon 3 was thus similar to that of Surgeon 1. However, the remaining surgeons in the model did not have schedules that could be fully described using table-based availability and probabilistic availability was used to determine when some duties would occur.

Surgeon 5, for example, has eight duties as identified in Table 4.2: supervising the ICU, being on-call, operating at the modeled hospital, seeing patients in clinic, research, teaching, administrative work, and vacation. The two statecharts in Figure 4.2 graphically represent these duties as states and, similar to Surgeon 1, an additional ‘weekend’ state is included for Saturday and Sunday. In the main statechart for Surgeon 5 the administrative duty is combined with the research duty and with the teaching duty because this surgeon does not have protected time for administrative work. Duties for Surgeon 5 that do have protected time are outlined in Table 4.4. Additionally, the ICU and on-call schedule described in Appendix C outlines which weeks/days Surgeon 5 regularly supervises the ICU and is on-call.

Based on the interview and past OR schedules, it was determined that Surgeon 5 was, on average, scheduled zero to six OR slots each week, spent up to three half-days each week performing research-based activities, and spent up to two half-days each week

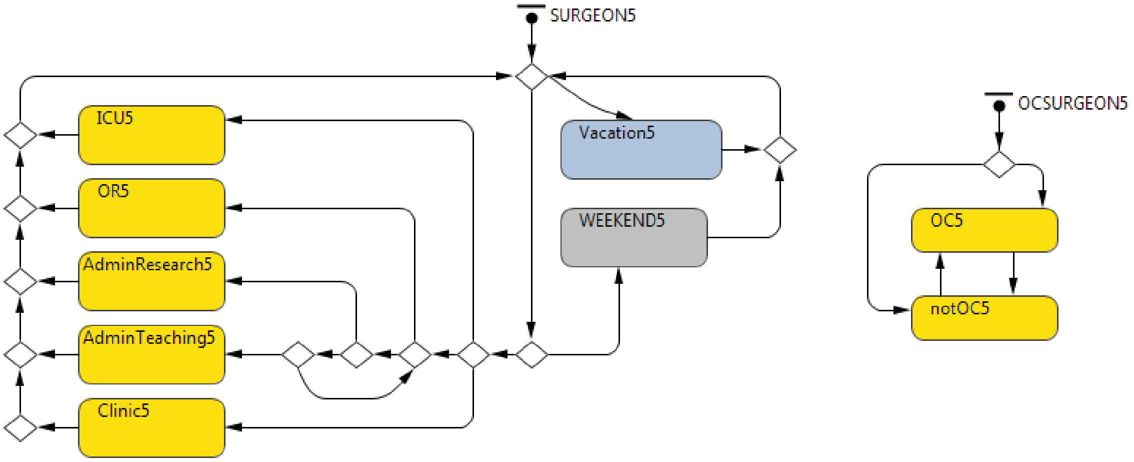

Figure 4.2: Statechart Showing Activities for Surgeon 5

Table 4.4: Regularly Scheduled Duties for Surgeon 5

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	-	-	-	Clinic	-
Afternoon	-	-	Teaching*	-	-

*Second Wednesday of the month

performing teaching-based activities (in addition to the protected teaching time). Administrative work could add an additional half-day's work over the course of one week.

Unprotected time for Surgeon 5 was probabilistically divided between the operating, research, and teaching duties, except during weekends and vacations. On a given morning (or afternoon), in the simulation it is first determined whether the surgeon was on vacation for the week, or supervising the ICU, or had any pre-scheduled activities for that day (such as clinic). If not, the simulation then checked whether there were any open OR slots, and if so, determined whether the surgeon was available to operate. This was done by first ensuring that the surgeon had not exceeded his weekly maximum number of OR slots (described in Appendix D), and then by evaluating a Bernoulli trial $P(X == 1) = p$, where X belongs to a Bernoulli distribution and $p = 0.95$ (or greater if other surgeons were on vacation).

If the surgeon was unavailable, or unable to operate on a given day, then the simulation would determine whether the surgeon would perform research/admin duties or teaching/admin duties. These duties were also determined by first ensuring that the surgeon hasn't exceeded his weekly maximum of research/teaching slots, and then by evaluating a Bernoulli trial, $P(X == 1) = p$, where $p = 0.75$ for research or $p = 0.65$ for teaching. If $X = 0$ in both cases, the simulation re-evaluated whether the surgeon could be scheduled into the OR and repeated the process until a suitable activity was determined.

If there were always an OR slot available for Surgeon 5, it would be expected that he would be scheduled to seven or eight OR slots a week, and one or no half-days a week doing administrative work, and research or teaching. However, Surgeon 5 is last to be assigned a duty, thus is it not guaranteed that empty OR slots will be available. As a result, in the simulation this surgeon is, on average, scheduled to two or three OR slots a week and the remaining time is dedicated to administrative work, and research or teaching.

The statecharts for Surgeons 2, 4, 6, 7, 9, and 10 are similar to those of Surgeon 5. Appendix B outlines reoccurring duties for these surgeons. Duties not listed in this appendix are determined probabilistically.

4.1.4 Output Data/External Data Stores

External data stores were used to collect data pertaining to the availability of individual surgeons during the execution of the simulation model. These stores collected information on the occurrence and timing of simulated events for all simulated surgeons. Unique data stores were created for each surgeon, and to capture responsibility specific information, such as the ICU and on-call schedules. These data stores contained both a surgeon and event identifier. An additional data store was created to collect data pertaining to the number of OR slots filled during a given year. This data store contained a policy indicator, the year, and the number of OR slots filled.

4.1.5 Model Accuracy and Reliability

Model verification and validation ensured that the simulation model had an acceptable degree of accuracy and reliability. Verification is concerned with ensuring the model executes as envisioned, while validation is concerned with ensuring the model is a reasonable representation of reality [17].

Model Verification

The simulation model was built in modules to allow individual surgeons' statecharts to be debugged during development. Verification of the proper execution of each module was ensured through using a combination of animation and program output.

Modules included each individual surgeon, and features such as on-call and ICU responsibilities. Input distributions associated with a module (ex. surgeon availability to operate on a given day) were verified using simulation output to ensure that the proper units and parameters had been specified.

Additionally, runtime exceptions were put in place to stop the simulation in case of undesirable occurrences such as overbooking the operating room, or insufficient coverage of the on-call duty.

Model Validation

Ten weeks of past OR schedules from 2010 were made available for the development of this project. Model development was based on running the simulation from 2011 onward and once the model had been verified, three replications of a ten week period in 2010 were executed to produce simulated data corresponding to the available data. Two sample t-tests were used to compare the mean number of OR slots for each individual surgeon. Paired t-tests were not used because the on-call, ICU, and vacation schedules differed between the two sets of data.

A Turing-like test was also performed: simulated and original (past) availability for the surgeons was shown to one participating surgeon and one of the participating booking staff to determine if it was possible to identify the simulated schedules and to determine if was possible to identify the simulated schedules. The model was considered valid if it was not possible differentiate between the simulated and actual schedules [47].

4.2 Statistical Analysis

4.2.1 Experimental Design for Simulation

The model had multiple cyclic components, including the ICU/on-call schedule, and the vacation schedule. It was determined through analyzing 41 years of simulated output that the largest cyclic component of the model had a period of six years, thus the warm-up period of the model was 6 years. As such, the model was run for six years before data were collected in all analyses.

4.2.2 Policy Analysis

This section describes the statistical analyses used to compare the dedicated on-call scheduling, and multiple responsibility on-call policies. With the dedicated on-call policy, surgeons were not permitted to be on-call and scheduled in the Operating Room for non-emergent operations on the same day. With the multiple responsibility on-call policy, surgeons were permitted to be on-call and scheduled in the Operating Room for non-emergent operations on the same day.

These scheduling policies were compared to evaluate the mean number of OR slots filled by all surgeons during the course of a year, the proportion of one year OR schedules that utilized at least 90% of available OR slots, and the mean number of OR slots filled by each surgeon during the week (Monday to Friday) over the course of a year. Two sample t-tests were used to evaluate both of the mean performance measures, and descriptive statistics were used to measure the proportion of one year scheduled meeting the specified utilization benchmark.

4.2.3 Simulation Experiments

The model was used to simulate the availability of a ten-surgeon surgical service with an autonomous division of surgeon duties. The outcomes of the simulation experiment were compared at the hospital-level to estimate the effects of dedicated on-call and multiple responsibility on-call policies on surgeons' availability to operate.

4.2.4 Effect of Organizational Policies on the Mean Number of OR Slots for the Surgical Service

Mean differences derived from two sample t-tests measured the effect of the dedicated on-call policy on the mean number of regularly scheduled OR slots filled by all surgeons over the course of a year. Additionally, the proportion of one year OR schedules that utilized at least 90% of available OR slots was measured. This analysis examined whether the dedicated on-call policy resulted in a lower number of regularly scheduled OR slots filled than the multiple responsibility on-call policy.

A pilot study was conducted to facilitate sample size calculations. Based on a two-sided test with 90% power, it was determined that six years of data per policy would be required to determine a mean difference of 30 slots per year (one week of OR capacity) at a significance level of 5%.

4.2.5 Effect of Organizational Policies on the Mean Number of OR Slots for Individual Surgeons

Mean differences derived two sample t-tests were also used to measure the effect of the dedicated on-call policy on the average number of regularly scheduled OR slots for each individual surgeon. These analyses examined whether the dedicated on-call policy resulted in a lower number of regularly scheduled OR slots for individual surgeons than the multiple responsibility on-call policy.

A second pilot study was conduced to facilitate sample size calculations for these analyses. Based on a two-sided test with 90% power, it was determined that ten years of data per policy would be required to determine a mean difference of one slot per week at a significance level of 5%.

Chapter 5

Results

5.1 Tests for Model Validation

5.1.1 T-Tests

Comparison of three replications of ten a week period in 2010 and a set of original data from this period showed no statistical difference in the mean number of OR slots assigned to each individual surgeon, as measured by the p-value for two sample t-tests (Table 5.1). These tests had at least 80% power to detect a mean difference of two slots between the simulated and real data at a significance level of 5%, except where indicated.

Table 5.1: Mean Number of OR Slots Assigned to Individual Surgeons For Simulated and Original Data

Surgeon	**Mean number of OR slots**		**Difference**	**95% CI**	***p*-value**
	Simulated	Actual			
1	0.7	0.7	0.0	(-0.3, 0.3)	1.00
2	2.9	2.6	0.3	(-0.8, 1.4)	0.63
3	0.9	0.7	0.2	(-0.1, 0.5)	0.13
4	3.5	3.6	0.1	(-1.5, 1.3)	0.92
5	2.4	2.8	-0.4	(-1.7, 0.7)	0.49
6	3.2	2.5	0.7	(-0.9, 2.3)	0.36
7	4.2	4.1	0.1	(-1.1, 1.2)	0.90
8	2.2	2.7	-0.5	(-1.9, 1.2)	0.55*
9	4.0	4.1	-0.1	(-1.0, 0.9)	0.89
10	2.4	3.1	-0.6	(-1.7, 0.4)	0.23

*70% power, likely the result of a high coefficient of variation (0.91) in the original data set

5.1.2 Turing Test

The surgeon and booking clerk who were shown the simulated and actual OR schedules were unable to correctly identify which was which. As such, the simulated output was considered to be adequate for statistical analysis.

5.2 Policy Analysis

5.2.1 Effect of Organizational Policies on the Mean Number of OR Slots for the Surgical Service

The original data used to validate the simulation model demonstrated that the OR schedule utilized over 90% of the available slots. The simulated number of OR slots scheduled during one year would need to surpass 1404 to meet this benchmark. The mean number of OR slots scheduled in a year under the dedicated on-call policy was 1386, while the mean number of OR slots scheduled in a year under the multiple responsibility on-call policy was 1464 (Table 5.2). Although OR schedules generated under the dedicated on-call policy filled, on average, 78 fewer OR slots every year than the multiple responsibility on-call policy, only 22% (95% CI: 0.01 to 0.56) of OR schedules generated under the dedicated on-call policy met or exceeded the 90% scheduled utilization benchmark, compared to 100% (95% CI: 0.61 to 1.00) of those generated under the multiple responsibility on-call policy.

Table 5.2: Mean Number of OR Slots Filled Over One Year for the Dedicated and Multiple Responsibility On-Call Policies policies

Organizational Policy		**Difference**	**95% CI**	***p* value**
Dedicated	Multiple responsibility			
1385.8	1463.8	-78.0	(-95.0, -61.0)	< 0.01

5.2.2 Effect of Organizational Policies on the Mean Number of OR Slots for Individual Surgeons

The findings suggest that the dedicated on-call policy differentially affects the mean number of OR slots assigned weekly to individual surgeons over the course of a year

(Table 5.3). Surgeons 1, 3, and 8 were unaffected by the policy change, however, surgeon 5 was, on average, assigned more OR slots under the dedicated on-call policy than under the multiple responsibility on-call policy. The remaining surgeons (that is, surgeons 4, 6, 7, 9, and 10), were, on average, assigned fewer OR slots under the dedicated on-call policy.

Table 5.3: Mean Number of OR Slots Filled Weekly by Individual Surgeons for the Dedicated and Multiple Responsibility On-Call Policies

Surgeon	**Organizational Policy**		**Difference**	**95% CI**	***p* value**
	Dedicated	Multiple Responsibility			
1	0.9	0.9	0.0	(-0.1, 0.1)	1.00
2	2.6	2.8	-0.2	(-0.3, -0.1)	< 0.01
3	0.9	0.9	0.0	(-0.1, 0.1)	1.00
4	3.7	4.1	-0.4	(-0.5, -0.3)	< 0.01
5	2.7	2.3	0.4	(0.3, 0.5)	< 0.01
6	2.5	2.8	-0.3	(-0.4, -0.2)	< 0.01
7	3.6	4.0	-0.4	(-0.5, -0.3)	< 0.01
8	3.1	3.1	0.0	(-0.1, 0.1)	0.64
9	3.8	3.9	-0.1	(-0.2, -0.01)	0.04
10	2.7	3.0	-0.3	(-0.4, -0.2)	< 0.01

Chapter 6

Discussion

The major finding of this thesis was that surgeons' availability to operate tends to decline if surgeons are not permitted to be on-call and scheduled in the OR for non-emergent operations on the same day. Specifically, this thesis showed that in a ten surgeon surgical service, only 22% of OR schedules generated under the dedicated on-call policy met or exceeded a 90% scheduled OR utilization benchmark, compared to 100% of those generated under the multiple responsibility on-call policy. This thesis also showed that the decrease in OR slots did not affect all surgeons equally, however, this result is difficult to separate from model artifact.

6.1 Methodological Considerations

Several limitations related to the development of the simulation model may have affected the results. Notably, there were few existing data with which to validate the model, despite that this model was based on the actual duty of division of surgeons at the Halifax Infirmary. As a result, the two sample t-tests for model validation were limited in their ability to detect small differences (those less then two) in the mean number of OR slots scheduled to surgeons between the simulated and actual schedules. However, consultation with participants further validated the simulated OR schedules and this helped to overcome this limitation.

Additionally, it is important to highlight that the order that surgeons were assigned their duties was empirically determined and was fixed. Furthermore, the probability that they were assigned to the OR on a particular day was also empirically determined. These parameters were found to be effective in producing reliable and valid output compared on the actual data, however, they are likely to have affected the effect estimates for individual surgeons. This is discussed further below.

The scope of the model in this thesis is focused on the surgical service and does not include patients or the larger peri-operative process. This precludes the model from estimating the effects of the policies on patient-level outcomes such as waiting times and health status, which are integral factors to consider in the evaluation of organizational policies in surgical care settings. Furthermore, the simulation model cannot evaluate patient and provider preferences, which must also be taken into consideration when evaluating policy alternatives.

Lastly, in constructing the simulation model, simplifying assumptions were made to facilitate development:

- Surgeons' schedules were created in half-day blocks
- Surgeons did not have any concurrent duties except with the on-call duty.
- The ICU supervision duty was not performed currently with the on-call duty.
- The on-call schedule was rotated as equitably as possible between surgeons so that no surgeon had more than 2 on-call shifts during the week (Monday-Friday).
- Each surgeon took four to six weeks of vacation a year in blocks of at least one week.
- Surgeons did not take vacation during weeks that they were responsible for ICU supervision.
- There were no seasonal "slow-downs" in the number of available OR slots.

The first assumption was made with the surgeons in the Division after discussing a suitable time-frame for modelled activities. It was agreed that schedules made in whole-day blocks was unrealistic, but that schedules made in hourly blocks was impractical due to the level of detail required.

The majority of the remaining assumptions were developed from the information gathered in interviews and were made to represent frequently occurring activities. For example, although surgeons multi-task "as much as possible", it was reported during the interviews that their clinical duties are seldom performed concurrently.

For example, surgeons have set times for outpatient clinics, and it is highly uncommon to be on-call during a week that one is supervising the ICU, although they may be on-call at any other time (which is permitted within the model).

Regarding the last assumption, there are summer and winter slow-downs in the Halifax Infirmary and many surgeons take their vacation during this time. These slow-downs were not included in the simulation, however, the surgeons' vacation schedules had a tendency to create an artificial slow down as monthly trends in the number of OR slots filled decreased in the summer and winter months.

6.2 Implications

Surgical coronary revascularization can be described as a complex system of clinical and managerial components and DES allows for such a system to be modelled in a realistic manner. This project focuses on surgeon availability and contributes to the understanding of how organizational policies can affect the availability of surgeons to perform regularly scheduled operations. Specifically, this thesis presented the effects of two organizational policies on surgeons availability to operate in the context of cardiac surgical care.

The findings provide evidence that the dedicated on-call policy reduces the mean number of OR slots filled for the surgical service, as there were significant differences in the mean total number of OR slots filled in a year between the two scheduling policies. Notably, the results of this study showed that OR schedules generated under the multiple responsibility on-call policy meet a 90% scheduled utilization benchmark much more often than the dedicated on-call policy. Importantly, the 78 scheduled OR slot difference between the two organizational policies translated into over two weeks of available OR time (30 OR slots were available each week). Thus, two weeks of OR capacity were lost under the dedicated scheduling policy. The effect this would have on patient scheduling and individual health outcomes was outside the scope of the this thesis but is an important factor in the evaluation of organizational policies.

Regarding the effect the policies had on individual surgeons, is not wholly unexpected that the dedicated scheduling policy differentially affects the mean number of OR slots assigned weekly to individual surgeons over the course of a year. Surgeons 1 and 3, for example, do not have the on-call duty. As outlined in Chapter 4 and Appendix B, their duties are deterministic in the model and for this reason it should come as no surprise that a change in the on-call scheduling did not affect their availability. However, with respect to the rest of the surgical service, it appears as if the observed effect size is closely related to the order in which surgeons are assigned duties, with those being assigned duties first seeing the largest decrease in the average weekly number of OR slots assigned to them. Of note is that Surgeon 5 (the last surgeon to be assigned a duty) was, on average, assigned more OR slots weekly than the other surgeons under the dedicated on-call policy. In fact, all other surgeons experienced no change, or a decrease in the mean number of OR slots assigned weekly. It is likely that the reported effect estimates for individual surgeons can be improved through further model development.

On a larger scale, this research has important implications for policy makers as it facilitates the future development and comparison of policy alternatives. The model created for this thesis is somewhat scalable, allowing different centres to be modelled by permitting slightly smaller surgical teams with unique responsibilities. Additionally, the model can inform policy decisions regarding surgeon scheduling on a surgical service level, by allowing hospital-level outcomes to be evaluated and compared to existing policies before the implementation of alternative policies.

6.3 Future Studies

Based on the results of this study, it is possible that the dedicated scheduling policy differentially affects the mean number of OR slots assigned weekly to individual surgeons over the course of a year based on the order in which they are assigned their duties, however, this is difficult to separate from model artifact. As this is a policy under consideration by at least one hospital, further research in this area to refine effect estimates for individual surgeons could provide important knowledge regarding which surgeon-level factors cause this effect (and which sorts of changes may offset lost OR time).

The simulation model created during this project is scalable and was created with the larger peri-operative process in mind. That is, through future development, this model may serve as a component in larger models of the peri-operative process for policy analysis in cardiac surgical settings. Such models would likely be patient flow models, which encompass the pre-operative, operative, and post-operative phases of the peri-operative process. These models models can facilitate the future development and comparison of important policy alternatives in cardiac surgical settings and can produce results not only on a hospital-level, but on an individual-level as well.

6.4 Conclusion

Using discrete event simulation, this study showed that organizational policies can affect surgeons' availability to operate in the context of cardiac surgical care and that these policies can significantly effect the total number of OR slots filled by all surgeons in a surgical service. Such policies may not affect all surgeons equally, however further research is needed to improve the estimate of such effects. The simulation model developed in this thesis can be used to investigate other policy alternatives within this setting, or can be expanded to evaluate policy alternatives within the larger peri-operative process.

Appendix A

Interview Questions for Surgeons and Booking Staff

The purpose of this questionnaire was to gather information related to the organizational structure of the surgical team at the Halifax Infirmary. This information was used in confidence to facilitate the development of a ten-surgeon simulation model that was used for policy analysis of managerial and organizational changes in surgical settings.

Table A.1: Interview Questions for Surgeons

Questions for Surgeons

1. What are your regular activities (duties/responsibilities) during the week?
    - Operating
    - On call
    - Clinic (seeing patients for consultations)
    - Teaching
    - Research
    - Administrative
    - ICU Supervision
    - Other (list)
2. When/for how much time do you perform each activity?
3. Which activities do you perform concurrently? (ex. ICUsupervision and teaching)
4. Do you operate at the IWK?
    - If yes, how often? (Which days of the week?)
5. Do you communicate with other surgeons to coordinate your responsibilities?
6. How many weeks vacation do you take in a year?
    - How often/when do you take your vacations?
7. How often are you away for other reasons? (conferences, dentist appointments, etc)
8. From your experience, what parts of the peri-operative process affect patient flow?
9. Have I missed anything?

Table A.2: Interview Questions for Booking Staff

	Questions for Booking Staff
1.	How do you decide who is booked to the OR?
2.	How often is the surgeons' OR schedule published?
3.	Do you know the proportion of the time that each surgeon spends in the OR?)
4.	How many surgeons may go on vacation at once?
5.	Does there exist a weekly schedule with all responsibilities for each surgeon? – If yes, how is this schedule determined?
6.	From your experience, what parts of the peri-operative process affect patient flow?
7.	Have I missed anything?

Appendix B

Reoccurring Duties for Modeled Surgeons

This appendix outlines reoccurring duties for each of the ten modeled surgeons.

Table B.1: Regularly Scheduled Duties for Surgeon 1

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	OR	Operating at neighbouring hospital			
Afternoon	Other	Operating at neighbouring hospital			

Table B.2: Regularly Scheduled Duties for Surgeon 2

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	Teaching	-	Clinic*	Clinic	-
Afternoon	Teaching	-	Clinic*	Research	-

*Last Wednesday of the month

Table B.3: Regularly Scheduled Duties for Surgeon 3

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	Teaching/Admin	Operating at neighbouring hospital			OR
Afternoon	Teaching/Admin	Operating at neighbouring hospital			Other

Table B.4: Regularly Scheduled Duties for Surgeon 4

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	-	-	-	-	Clinic
Afternoon	Clinic	-	-	Clinic	-

Table B.5: Regularly Scheduled Duties for Surgeon 5

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	-	-	-	Clinic	-
Afternoon	-	-	Teaching*	-	-

*Second Wednesday of the month

Table B.6: Regularly Scheduled Duties for Surgeon 6

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	Clinic	-	-	-	-
Afternoon	Research	-	Research*	-	Clinic**

*Second Wednesday of the month

*Last Friday of the month in April, August, and November

Table B.7: Regularly Scheduled Duties for Surgeon 7

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	-	-	-	-	-
Afternoon	-	-	-	Clinic*	-

*Last Thursday of the month

Table B.8: Regularly Scheduled Duties for Surgeon 8

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	-	Research	-	-	-
Afternoon	-	Research	Clinic*	-	-

*Second Wednesday of the month

Table B.9: Regularly Scheduled Duties for Surgeon 9

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	-	-	-	-	-
Afternoon	-	-	-	Clinic*	-

*Third Thursday of the month

Table B.10: Regularly Scheduled Duties for Surgeon 10

	Weekday				
	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	Admin	-	-	-	-
Afternoon	Admin	Clinic	-	-	-

Appendix C

ICU and On-Call Schedule

This appendix outlines the on-call and ICU schedule for the ten-surgeon model.

Eight of the ten surgeons have on-call responsibilities. Five of these surgeons are additionally charged with supervising the Cardiovascular ICU for one week periods (three anesthesiologists are also responsible for ICU supervision). Surgeons cannot be on-call during weeks that they are responsible for supervising the ICU.

The on-call and ICU duties are rotated between surgeons every eight weeks. Eight weeks of the on-call and ICU schedule are outlined below in Table C.1. Surgeons are represented by their surgeon number (i.e. surgeon 2 is represented by a 2), and the anesthesiologists with the ICU supervision responsibility are represented by A1, A2, and A3.

Table C.1: Eight Week ICU and On-Call Schedule for the Model

Week	ICU	On call					
		Mon.	Tues.	Wed.	Thurs.	Fri.	Replacement (in case of absence)
0	2	4	5	6	8	7	9, 10
1	4	5	6	8	7	9	2, 10
2	5	6	8	7	9	10	2, 4
3	6	8	7	9	10	2	4, 5
4	8	7	9	10	2	4	5, 6
5	A1	9	10	2	4	5	6, 7, 8
6	A2	10	2	4	5	6	7, 8, 9
7	A3	2	4	5	6	8	7, 9, 10

Appendix D

Maximum Weekly Number of Occurrences for Surgeons' Duties

This appendix outlines the maximum weekly number of occurrences for specific duties for each surgeon. These counts were used to ensure that surgeons did not exceed their weekly limit for duties that were determined probabilistically and were measured in half-days.

Some surgeons have more than 10 occurrences of a combination of duties during the week to allow for a variable weekly distribution of activities (governed by probability distributions outlined in Chapter 4). Other surgeons, including all those with fewer than 10 occurrences of a combination of duties during the week, have weekly clinics and other regularly scheduled activities that contribute to their weekly activities.

Table D.1: Maximum weekly number of occurrences for specific duties for each surgeon. (Used to ensure that surgeons did not exceed their weekly limit for duties that were determined probabilistically.)

Activity	**Surgeon 1**	**Surgeon 2**	**Surgeon 3**	**Surgeon 4**	**Surgeon 5**
OR	1	4	1	6	6
OC	0	2	0	2	2
Research	0	0	0	5	4
Teaching	0	2	0	2	5

Activity	**Surgeon 6**	**Surgeon 7**	**Surgeon 8**	**Surgeon 9**	**Surgeon 10**
OR	4	5	6	5	4
OC	2	4	2	4	4
Research	6	0	4	0	0
Teaching	2	2	6	2	2

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