Evaluating the two-table surgery policy

An alternative policy to improve operating room performance

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Management summary

Background

The management of the Surgical Day Care Centre (SDCC) of University Medical Centre Groningen (UMCG) is looking for possibilities to increase efficiency of their operating centre. In the current surgery policy, one surgeon is allocated to each operating room (OR). We call this the one-table surgery policy (OT-policy). However, a surgeon is not required during activities like preparation of patients and cleaning the OR. To use this time effectively in an OR, we introduce the two-table surgery policy (TT-policy). In this policy, one surgeon consecutively performs surgeries in two ORs. This policy may improve operating room performance (e.g. increasing number of patients treated). Also, quality of care and surgeon specialisation may increase since a surgeon may perform a type of surgery more frequently. The aim of this research is:

"To determine conditions under which it is more efficient to apply the TT-policy rather than the OT-policy"

Approach

We evaluate the OT-policy and TT-policy by means of a simulation study. We evaluate both policies with respect to patient throughput (number of patients treated), surgeon productivity (number of patients a surgeon treated), average time per surgery, surgeon utilisation (occupied in the OR), anaesthetist utilisation, and patient waiting time. We also roughly evaluate cost efficiency of each policy.

Dutch national guidelines require that the surgeon is present during the time-out and sign-out procedure (pre- and post-surgery safety check). For patient safety, we assume that the surgeon will not switch to another patient after a time-out procedure in the TT-policy, although he is not required during these phases. We found these guidelines to limit the benefits of the TT-policy with respect to surgeon utilisation and patient throughput. In order to show potential benefits, we also evaluate the TT-policy where the surgeon is not required during the time-out and sign-out procedure.

We identify that the expected surgery duration, and variability in surgery and anaesthesia duration may impact performance of the TT-policy. We hypothesise that this policy performs best with surgeries up to 20 minutes with low variability. To test this hypothesis, we vary the expected surgery duration (up to 50 minutes) and variability in surgery and anaesthesia duration.

Results

The TT-policy results in an increase in surgeon productivity between 17.2% and 52.0% compared to the OT-policy. The TT-policy shows best relative performance with surgeries up to 20 minutes and high variability. Contrary to our expectation, the TT-policy shows best performance with high variability since the OT-policy is more sensitive to variability. Hence, the unavailability of the surgeon between the time-out procedure and surgery phase acts like a buffer to account for variability. Due to the increasing surgeon productivity, surgeon utilisation also increases significantly. Moreover, patient waiting time decreases in the TT-policy. Average patient throughput decreases with 33.3% in the TT-policy. Also cost efficiency is likely to decrease in this policy. Using one anaesthetist in each OR further increases surgeon productivity and surgeon utilisation, but the OT-policy is superior with respect to patient throughput and cost efficiency. Consequently, surgeon productivity in the TT-policy increases considerably and this policy can therefore be used when surgeon availability is scarce.

When relaxing requirements that the surgeon is present during the time-out and sign-out procedure, surgeon productivity in the TT-policy increases between 63.0% and 93.5% compared to the OT-policy. As a result, surgeon utilisation also increases significantly. Patient throughput is slightly lower (on average, 9.3%), but cost efficiency may increase for surgeries up to 40 minutes since this policy requires only one surgeon. Patient waiting time increases, especially for relatively long surgeries. This policy shows best relative performance with surgeries up to 20 minutes and low variability. Using one anaesthetist in each OR further increases performance of the TT-policy and can increase patient throughput (up to 7.3%) with surgeries up to 20 minutes and low variability. Patient waiting time in this policy may increase considerably, especially with surgeries of more than 30 minutes. Hence, the TT-policy can improve operating room performance compared to the OT-policy when the surgeon is not required during the time-out and sign-out procedure.

Recommendations

When surgeon availability is scarce and other resources are sufficiently available, we recommend to use the TT-policy instead of the OT-policy with surgeries up to 50 minutes. This policy increases surgeon productivity and may increase revenues when an OR is not used in the OT-policy. To maximise surgeon productivity, one anaesthetist should be used in each OR.

We also recommend to consider alternative task allocations during the time-out and sign-out procedure so that efficiency gains of the TT-policy can be achieved while patient safety is ensured. Possibly, sufficient experienced surgery assistants (Physician Assistants or surgeons in training) can perform both procedures while the surgeon can be consulted in case of difficulties.

Management samenvatting

Achtergrond

Het management van het Operationeel Dag Behandeling Centrum (ODBC) in het Universitair Medisch Centrum Groningen (UMCG) zoekt naar mogelijkheden voor efficiëntieverbeteringen van hun operatiecentrum. In het huidige "één-tafel systeem" (OT-policy) is één chirurg toegewezen aan iedere operatiekamer (OK). Een chirurg is echter niet benodigd tijdens de voorbereiding van patiënten en het schoonmaken van een OK. Om deze tijd effectief in de OK te benutten introduceren we het "twee-tafel systeem" (TT-policy). In dit systeem opereert een chirurg achtereenvolgens in twee OKs. Het "twee-tafel systeem" kan OK prestaties verbeteren (bijv. het aantal geopereerde patiënten verhogen). Tevens kan dit systeem de zorgkwaliteit verhogen en leiden tot specialisatie van de chirurg omdat een chirurg een operatietype mogelijk vaker uitvoert. Het onderzoeksdoel is geformuleerd als:

"Het bepalen van voorwaarden waaronder het 'twee-tafel systeem' efficiënter is dan het 'één-tafel systeem'"

Aanpak

We evalueren het "één-tafel systeem" en "twee-tafel systeem" met behulp van een simulatiemodel. Beiden systemen beoordelen we op het totaal aantal geopereerde patiënten, het aantal geopereerde patiënten per chirurg, gemiddelde tijd per operatie, benutting van de chirurg, benutting van de anesthesioloog en wachttijd voor de patiënt. Ook geven we een indicatie van de kostenefficiëntie van ieder systeem.

Nederlandse richtlijnen vereisen aanwezigheid van de chirurg tijdens de time-out en sign-out procedure. Uit patiëntveiligheid-oogpunt nemen we aan dat een chirurg in het "twee-tafel systeem" niet overloopt naar een andere patiënt na een time-out procedure, hoewel de chirurg niet is benodigd tijdens deze fasen. We hebben bepaald dat deze richtlijnen de benutting van de chirurg en het aantal geopereerde patiënten in het "twee-tafel systeem" beperken. Om mogelijke voordelen te bepalen evalueren we ook het "twee-tafel systeem" waarbij de chirurg niet is vereist tijdens de time-out en sign-out procedure.

We hebben bepaald dat de verwachte operatieduur en variabiliteit in de operatie- en anesthesieduur de prestaties van het "twee-tafel systeem" mogelijk beïnvloeden. We hypothetiseren dat het "twee-tafel systeem" het best presteert voor operaties tot 20 minuten met weinig variabiliteit. Om deze hypothese te testen variëren we de operatieduur (tot 50 minuten) en variabiliteit in de operatie- en anesthesieduur.

Resultaten

Het "twee-tafel systeem" resulteert in een toename van het aantal geopereerde patiënten per chirurg van 17.2% tot 52.0% in vergelijking met het "één-tafel systeem". Het "twee-tafel systeem" presteert relatief het best met operaties tot 20 minuten en hoge variabiliteit. De hoge variabiliteit is tegen onze verwachting in maar komt doordat het "één-tafel systeem" gevoeliger is voor variabiliteit dan het "twee-tafel systeem". Dat de chirurg niet beschikbaar is tussen de time-out procedure en operatiefase fungeert dus als een buffer om variabiliteit op te vangen. Door een toename van het aantal geopereerde patiënten per chirurg neemt ook benutting van de chirurg aanzienlijk toe en wachttijd van de patiënt af. Het totaal aantal geopereerde patiënten neemt echter met gemiddeld 33.3% af. Ook de kostenefficiëntie neemt hoogstwaarschijnlijk af. Het gebruik van één anesthesioloog in iedere OK resulteert in een verdere verhoging van het aantal geopereerde patiënten per chirurg en benutting van de chirurg, maar het totaal aantal geopereerde patiënten en kostenefficiëntie wordt (waarschijnlijk) niet verhoogd in vergelijking met het "één-tafel systeem". Het "twee-tafel systeem" verhoogt het aantal geopereerde patiënten per chirurg dus aanzienlijk en is geschikt als beschikbaarheid van chirurgen schaars is.

Als de chirurg niet vereist is tijdens de time-out en sign-out procedure, neemt het aantal geopereerde patiënten per chirurg in het "twee-tafel systeem" toe met 63.0% tot 93.5% in vergelijking met het "één-tafel systeem". Ook benutting van de chirurg neemt aanzienlijk toe. Het totaal aantal geopereerde patiënten is iets lager (gemiddeld 9.3%), maar omdat dit systeem slechts één chirurg vereist wordt de kostenefficiëntie mogelijk verbetert. Dit systeem presteert relatief het best met operaties tot 20 minuten en lage variabiliteit. Het gebruik van één anesthesioloog in iedere OK resulteert in verder verbeterde prestaties van het "twee-tafel systeem" en kan het totaal aantal geopereerde patiënten doen toenemen (tot 7.3%) voor operaties tot 20 minuten en lage variabiliteit. De wachttijd voor de patiënt kan aanzienlijk toenemen, voornamelijk bij operaties langer dan 30 minuten. Het "twee-tafel systeem" kan dus worden gebruikt om OK prestaties te verbeteren als de chirurg niet benodigd is tijdens de time-out en sign-out procedure.

Aanbevelingen

Als chirurgen zeer beperkt beschikbaar zijn en andere resources voldoende beschikbaar zijn, bevelen we aan om het "twee-tafel systeem" toe te passen voor operaties tot 50 minuten. Dit systeem verhoogt het aantal geopereerde patiënten per chirurg. Daarmee kunnen meer inkomsten worden gegenereerd als een OK in het "één-tafel systeem" niet gebruikt wordt. Om het aantal geopereerde patiënten per chirurg te maximaliseren is één anesthesioloog in iedere OK benodigd.

Daarnaast bevelen we aan om mogelijkheden te verkennen omtrent de invulling van de time-out en sign-out procedure waarbij efficiëntievoordelen van het "twee-tafel systeem" worden gerealiseerd terwijl patiëntveiligheid gewaarborgd blijft. Mogelijkerwijs kan een ervaren operatieassistent (Physician Assistant of AIOS) beide procedures uitvoeren waarbij de chirurg kan worden geraadpleegd in geval van onduidelijkheden.

Preface

This thesis finalises my Master programme Industrial Engineering & Management at University of Twente. I highly enjoyed to participate in the IE&M programme. It has been a very interesting study programme in a variety of environments. Until the second semester of the second year I did not expect to conduct my Master thesis in healthcare. This experience however showed me that this is a positive challenging environment concerning process optimisation. I wish to use this section to thank some people for their support during this research.

My first gratitude goes out to my UMCG supervisors Peer Goudswaard, Tjibbe Hoogstins and Igor van der Weide. Thank you for the opportunity to conduct this Master thesis at UMCG and all your support and useful remarks throughout this research. It was a pleasure to work with you. I also wish to thank Marja Groot-Heupner and Ina van Alteren of the Surgical Day Care Centre. Your input and experience have been very useful for this research and to see surgeries in practice greatly contributed to my understanding of the surgery process. I am also grateful to all other UMCG employees who contributed to this research.

Further, I wish to thank my UT supervisors Erwin Hans and Ingrid Vliegen. I am grateful for your continuous support and you have shown me very useful insights. Besides, Erwin, your enthusiasm has really supported me during this period. It was an honour to work with you.

Special thanks goes to mr. J. Jeuring of hospital ‘Refaja ziekenhuis’ and dr. H.J. Heijmans of ‘ZGT’ for their contribution to this research. I am very glad that you shared your experience with the two-table surgery policy and it was even possible to see this policy in practice at hospital ‘Refaja ziekenhuis’. Hopefully this research can be conducive to you.

Finally, I wish to thank my parents for all their support during my study career. I am very grateful that you made it possible for me to study and have inspired and supported me throughout the years.

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Thom Boersma

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1. Introduction

Healthcare institutions are under pressure to improve quality of care and to decrease costs by working more efficient (Vanberkel, Boucherie, Hans, Hurink, & Litvak, 2010). One of the key resources in a hospital is the operating room (OR) department. Surgical interventions in this department causes between 60% and 70% of all admissions (Hans & Nieberg, 2007). In addition, there is a shift from inpatient care to outpatient care and day care (Williamson, 2008). As a result, demand for outpatient care and day care will grow. Therefore, this thesis focuses on improving OR performance in a day care centre at University Medical Centre Groningen (UMCG).

UMCG has three primary functions: healthcare, medical education and scientific research. This thesis focuses on the healthcare function and in particular OR performance. In the current surgery policy, one surgeon is allocated to each scheduled OR-day. We label this classic design the one-table surgery policy (OT-policy). However, a surgeon is not required during activities like preparation of patients and cleaning the OR. Subsequently, the available capacity of surgeons is not used optimally in the OT-policy. Therefore, we introduce a policy where one surgeon consecutively performs surgeries in two ORs on a certain day. We call this the two-table surgery policy (TT-policy). For safety reasons, surgeries are not performed simultaneously in this policy. The TT-policy offers a potential increase in operating room performance, e.g. when the number of patients treated increase, cost efficiency increases or patient waiting time decreases. Also, quality of care and surgeon specialisation may increase since a surgeon may perform a type of surgery more frequently. Moreover, when surgeon availability is scarce, this policy can reduce the waiting list. Hulshof et al. (2012) call this policy the Doctor-to-Patient (DtP) policy. They have conducted a comparable study in an outpatient clinic. Hospitals ‘RIVAS’ and ‘Groene Hart Ziekenhuis’ have applied the results in redesigning their outpatient clinics. However, the focus of their study is a consultation process of patients whereas the core of this research is the surgical procedure. Subsequently, more processes and more variability are included. This research aims to determine under which conditions the TT-policy is more efficient than the OT-policy.

This chapter provides background information of the UMCG and describes the research approach of this study. Section 1.1 outlines the organisation and shows some statistics of UMCG. Section 1.2 describes the research problem. To fulfil this research successfully, Section 1.3 formulates the research objective. Section 1.4 defines the research questions and outlines this thesis. This section also describes the research design. Section 1.5 gives the theoretical framework of this research.

1.1 Research context

UMCG is one of the eight University Medical Centres in the Netherlands and employs more than 11,000 professionals. It was established in 2005 as a joint activity of the University of Groningen and the Academic Hospital Groningen. It is currently one of the largest hospitals in the Netherlands. UMCG focuses on ‘healthy and active ageing’. To give an impression of its size, Table 1 shows some statistics of UMCG in 2012.

Table 1: Statistics of University Medical Centre Groningen (UMCG) in 2012[1]

Characteristic	Number
Beds	1,339
Occupancy rate (percentage)	69%
Admissions	36,695
Average inpatient stays (days)	8.3
Total inpatient days	306,045
Consultations	535,045
Consultations Emergency Department	37,651
Outpatient treatments	34,269

This research is conducted within the department Operations Management & Innovation. This department improves varying processes, ranging from IT to logistic processes, in collaboration with other departments.

The focus of this research is the Surgical Day Care Centre (SDCC) department. In this department, patients arrive, undergo surgery, and are sent home on the same day. Surgeons perform only elective surgeries at SDCC. These surgeries usually have a low degree of complexity.

1.2 Problem description

The management of SDCC is looking for possibilities to increase efficiency of their operating centre. In addition, surgeons feel that there are inefficiencies in the current surgery policy with respect to their effective working time. To this end, there is a request whether it can be more efficient to apply the TT-policy rather than the OT-policy and if so, under which conditions.

Therefore, in an effort to increase efficiency of the operating centre at SDCC, we investigate the performance of the TT-policy in different situations.

1.3 Research objective

This research focuses on the viability of using one surgeon in two ORs. For SDCC, it is valuable to obtain insight in conditions under which surgeries in the TT-policy can be performed more efficiently than in the OT-policy. Therefore, we formulate the research objective as follows:

The aim of this research is to determine conditions under which it is more efficient to apply the TT-policy rather than the OT-policy.

1.4 Research questions and outline

To achieve the defined research objective, we pose the following research questions:

1. *What is the current surgical procedure and what is the TT-policy?*

   In Chapter 2, we outline the current surgery process at SDCC and the TT-policy.

[1] https://www.umcg.nl/NL/UMCG/overhetumcg/organisatie/feiten_en_cijfers/Pages/feitenCijfers.aspx (accessed 28 June 2014).

2. *Which performance indicators should we use to compare the efficiency of the OT-policy to the TT-policy?*

   In Chapter 3, we define Key Performance Indicators (KPIs) to evaluate the OT-policy and TT-policy in terms of efficiency. To support this selection, we review the literature. The indicators will be selected together with UMCG.

3. *How can we objectively assess the OT-policy and the TT-policy prospectively?*

   In Chapter 3, we also consider various modelling techniques to evaluate the OT-policy and the TT-policy. We select the most appropriate technique and use it for this research.

4. *Which factors may impact performance of the TT-policy?*

   In Chapter 4, we define factors that may impact performance of the TT-policy. We include these factors in our analysis. To support this selection, we review the literature on (broad and detailed) conditions and use experience of hospitals 'Refaja ziekenhuis' and 'ZGT'. These hospitals apply and have applied the TT-policy, respectively.

5. *What model can we construct for a sound analysis of the conditions found?*

   In Chapter 5, we construct a model using the technique selected in Chapter 3. We use this model to analyse the factors defined in Chapter 4. Steps in model construction are conceptual design, data gathering, technical design, verification, validation and experimental design.

6. *Under which conditions is the TT-policy more efficient than the OT-policy?*

   In Chapter 6, we analyse the results from the model with respect to each key performance indicator and define conditions a surgery type should fulfil in order to be able to use the TT-policy efficiently.

7. *How can we implement the results at UMCG?*

   In Chapter 7, we address practical issues related to the implementation of the TT-policy.

1.5 Theoretical framework (scope)

Based on the problem description and research objective, we focus on a TT-policy at SDCC. The results of the TT-policy will be compared to the results of the OT-policy.

The framework of Hans, Van Houdenhoven and Hulshof (2012) is used to position our research. In their framework for healthcare planning and control, they distinct four hierarchical levels of planning and four managerial areas. Figure 1 shows this framework with generic example planning and control functions.

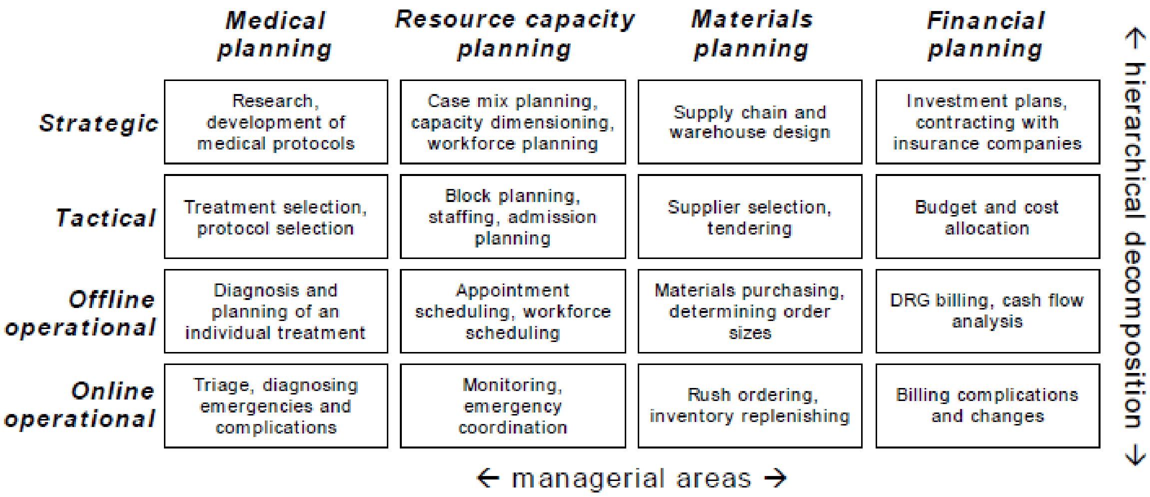

Figure 1: Framework for healthcare planning and control (Hans et al., 2012)

Clearly, this research lies in the resource capacity planning. Now we shortly explain activities within each level of the resource capacity planning to determine the appropriate research level. On a strategic level, a hospital determines the capacity dimensioning of the OR department. On a tactical level, a hospital divides the available OR time over all specialties and plans surgeons and surgical staff. On an offline operational level, a hospital schedules elective patients and assigns staff to a specific OR. Ad hoc decisions to deal with unexpected delay or arrivals of emergency patients relate to the online operational level. Since this research focuses on an alternative capacity policy, it lies in the *strategic level* of *resource capacity planning*.

2. Current situation at SDCC and TT-policy

This chapter describes the current surgery process at Surgical Day Care Centre (SDCC) and explains the TT-policy. Section 2.1 briefly introduces SDCC. Section 2.2 addresses the surgery process. Section 2.3 describes the TT-policy. Section 2.4 points out legislation related to the TT-policy and its implications. Section 2.5 draws a chapter conclusion.

2.1 Introduction

The focus of this research is SDCC. At this department, patients usually arrive, undergo surgery and leave the same day. We define these surgeries as SDCC surgeries. These surgeries typically have a short duration and a low degree of complexity. Hence, these surgeries are well-predictable and variability in surgery duration is limited due to a relatively small risk of intraoperative complications. However, currently, approximately 20% of all surgeries at SDCC are inpatient surgeries. Specialties schedule inpatients at SDCC due to insufficient capacity at the inpatient operating theatre department. Inpatient surgeries generally have a higher degree of complexity and subsequently more variability compared to typical SDCC surgeries.

SDCC has four ORs and one treatment room available. However, the treatment room is not suitable for surgeries due to safety regulations. In addition, no operating table is present in OR1. Each day of the week, this OR is occupied by eye surgery and therefore specialised equipment is installed. Consequently, both the treatment room and OR 1 cannot be used in the TT-policy.

An OR-day at SDCC ends when all scheduled surgeries are performed. A surgery is only cancelled when a patient does not show up or when a patient has not fasted. Thus, no surgeries are cancelled due to (expecting to) work in overtime.

2.2 Surgery process SDCC

This section describes the current surgery process at SDCC. Patients who undergo surgery at SDCC all have a very similar process flow. After arriving a patient goes to the holding. If appropriate, the anaesthetist provides regional anaesthesia here; general anaesthesia is provided in the OR. When the OR is available, the patient goes to this room and the surgical procedure starts with the time-out procedure (pre-surgery check for patient safety). After the surgical procedure the patient goes to the recovery room. When the patient is in good physical state, this patient is eligible for discharge and can go home.

Baumgart et al. (2007) distinguish five phases in the perioperative process: transport and admission to OR suite, anaesthesia induction, surgery, anaesthetic emergence and transport to post-anaesthetic care units. To distinguish different activities and staff requirements, we extend their differentiation to seven operating room phases at SDCC: time-out procedure, anaesthesia induction, prepare surgery, surgery, sign-out procedure, anaesthetic emergence and turnover. This order is typical for general anaesthesia (the order slightly changes when using regional anaesthesia). A patient goes to the recovery room as soon as the anaesthetic emergence phase has finished (i.e. the patient is awake). Hence, the turnover phase is not part of a patient’s process flow. Figure 2 shows the flowchart of day care patients at SDCC and the seven operating room phases. The figure shows whether the patient is present and which crew members perform primary tasks during each phase.

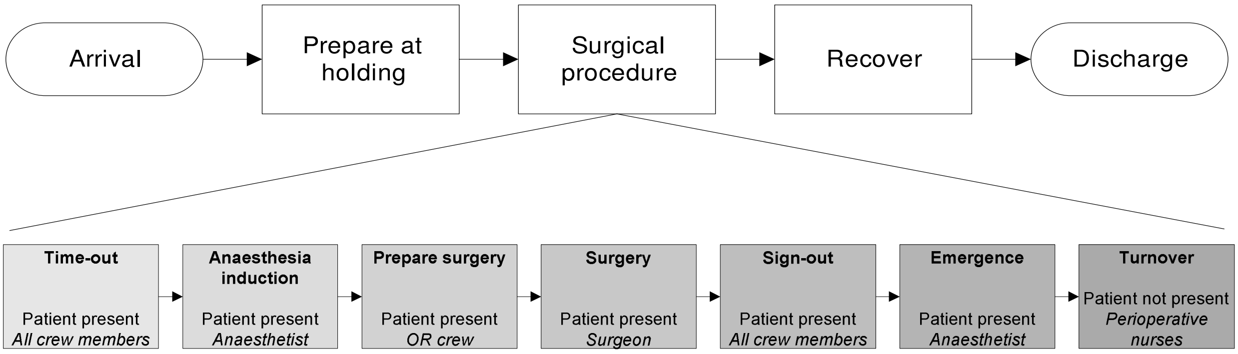

Figure 2: Patient's flowchart of day care patients and the seven operating room phases at SDCC when applying general anaesthesia

SDCC currently applies the OT-policy. In the OT-policy one surgeon is allocated to each OR. An entire OR crew consists of (at least) the following members:

- One surgeon;
- One surgery assistant;
- One anaesthetist;
- One anaesthesia assistant;
- Two perioperative nurses.

Each crew member except for the anaesthetist is available right away during each operating room phase in the OT-policy. For efficiency purposes, anaesthetists usually apply a two-table policy at SDCC: each anaesthetist is responsible for anaesthesia in two ORs. We label this the two-table anaesthesia policy. This is possible since an anaesthetist is only required during the time-out, anaesthesia induction and anaesthetic emergence phase, and when complications emerge. The anaesthesia assistant performs tasks during the other operating room phases. When complications emerge simultaneously in both ORs, a second anaesthetist is called. We include this two-table policy of anaesthetists in our study.

Each OR crew member wears sterile clothing, a mask and protective cap in an OR. Before entering an OR, each member washes and disinfects their hands. In addition, each member of the sterile team (i.e. surgeon, surgery assistant and instrument nurse) put on a long gown, (vinyl) gloves and a surgery mask before starting a surgery. In contrast, an anaesthetist does not include additional safety measures. He only disinfects his hands a couple of times a day and puts on a new mask when necessary. These measures take negligible amount of time.

To gain insight in the application of the TT-policy, we analyse all seven operating room phases. The following sub sections describe the main activities and responsibilities in each phase.

2.2.1 Time-out procedure

When a patient is on the operating table, the surgeon and anaesthetist first perform a so-called time-out procedure. This protocol checks whether the right patient is on the table, the intervention, the patient’s allergies, etc. If no problems arise, the surgeon explains the further procedure.

According to Dutch guidelines, the surgeon must perform the time-out procedure (Nederlandse Vereniging voor Anesthesiologie (NVA), & Nederlandse Vereniging voor Heelkunde (NVvH), 2011). The entire OR crew must be present during this phase so that all crew members are aligned. We further address these guidelines in Section 2.4.

2.2.2 Anaesthesia induction

After completing the time-out procedure, the anaesthetist and anaesthesia assistant provide anaesthesia and attach monitoring devices. Simultaneously, perioperative nurses prepare one or more necessary sets of instruments. This phase ends when the patient is under anaesthesia.

During this phase, the anaesthetist must be present in the OR (Nederlandse Vereniging voor Anesthesiologie (NVA), 2004). An anaesthetist does not switch to another patient after a time-out procedure for patient safety (similar to a surgeon in the TT-policy). Thus, the anaesthesia induction phase is performed immediately after the time-out procedure.

2.2.3 Prepare surgery

This phase consists of preparation activities before a surgery can start. When the patient is under anaesthesia, the crew moves the patient into the right position. In addition, the crew checks whether the instruments and devices are working properly and cover the patient and disinfect the patient’s skin to reduce infection risk. Also, the OR crew and sterile team take required safety measures.

2.2.4 Surgery

In this phase, the surgeon and surgery assistant perform the actual operation. This phase starts when the surgeon makes initial incision(s) (“opening”). We do not treat further steps in this phase since these are mostly a medical matter and highly dependent on the type of surgery. Generally, the last steps before finishing a surgery are reconnecting tissue (“suturing”) and completing the operation and reconnecting external tissue ("closing"). Before “closing” the surgeon checks whether all materials and instruments are at hand. Perioperative nurses perform two roles during surgery phase: circulating nurse and instrument nurse.

A surgery assistant performs tasks under direction of the surgeon and aids him or her in performing surgical operations, e.g. exposing the surgical site and performing certain parts of the surgery. An important note is that UMCG is a teaching hospital and therefore most surgery assistants at SDCC are surgeons in training. The activities a surgeon in training can perform depend on the level and progress of training.

2.2.5 Sign-out procedure

After "closing", the OR crew performs a so-called sign-out procedure where the crew discusses details of both the surgery and anaesthesia. These may impact a patient's post-operative care. Again, the surgeon must perform the sign-out procedure. The anaesthetist may be absent during this phase; the anaesthetist can transfer tasks to the anaesthesia assistant (Nederlandse Vereniging voor Anesthesiologie (NVA), & Nederlandse Vereniging voor Heelkunde (NVvH), 2011). The anaesthetist is usually not present during the sign-out procedure. The need depends on the type of surgery and possible complications. However, the anaesthetist can also provide any post-surgery instructions during the anaesthetic emergence phase.

2.2.6 Anaesthetic emergence

After the sign-out procedure, providing anaesthesia is stopped so that the patient will wake up after some time. Also, devices are detached. Simultaneously, perioperative nurses remove all disposables and instrument set(s) used. Furthermore, the surgeon executes some administrative registrations of the surgery. Finally, when the patient is awake he is moved back on a bed into the recovery room.

During this phase, the anaesthetist must be present (Nederlandse Vereniging voor Anesthesiologie (NVA), 2004). The anaesthetic emergence phase does not start until the anaesthetist is present in the OR. The anaesthetist may, for instance, induce anaesthesia in the opposite OR and may subsequently not be available right away. The time a patient is under anaesthesia can therefore increase. This increase is however very limited and does not affect patient safety.

2.2.7 Turnover

When the patient is moved to the recovery room, perioperative nurses clean and prepare an OR for the next surgery. When both the OR and the team are ready, they call a new patient. After the patient arrives in the OR, crew members lift him or her on the operating table. Now the seven phases repeat.

2.3 Two-table surgery policy

This section outlines the TT-policy and its dependencies. Since a surgeon is not required during the anaesthesia induction, prepare surgery, anaesthetic emergence and turnover phase, surgeon capacity is currently not used optimally from an operations management perspective. To use this time effectively in the OR, we introduce the TT-policy. Section 2.3.1 describes and illustrates this policy in detail. We point out relevant dependencies of the TT-policy in Section 2.3.2.

2.3.1 Description

This section describes and illustrates the TT-policy. This policy differs from the OT-policy in surgeon availability: one surgeon performs surgeries in two ORs in the TT-policy. While the surgeon performs a surgery, the crew of the opposite OR prepares a patient to undergo surgery. Ideally, these phases finish simultaneously so that a surgeon moves to the opposite OR and starts the next surgery right away. In that case surgeon and OR crew waiting time is minimised.

Figure 3 illustrates the OT-policy and TT-policy with a pre-surgery process (i.e. time-out, anaesthesia induction and prepare surgery phase), surgery and post-surgery process (i.e. sign-out, anaesthetic emergence and turnover phase) of 30 minutes. The time for the surgeon to travel to the opposite OR and take safety measures is 15 minutes. For convenience, we assume that the surgeon is only required during surgery (Section 2.4 addresses this assumption). The number of patients treated is equal to the OT-policy but the TT-policy requires only one surgeon to perform all surgeries, subsequently resulting in a significant cost reduction.

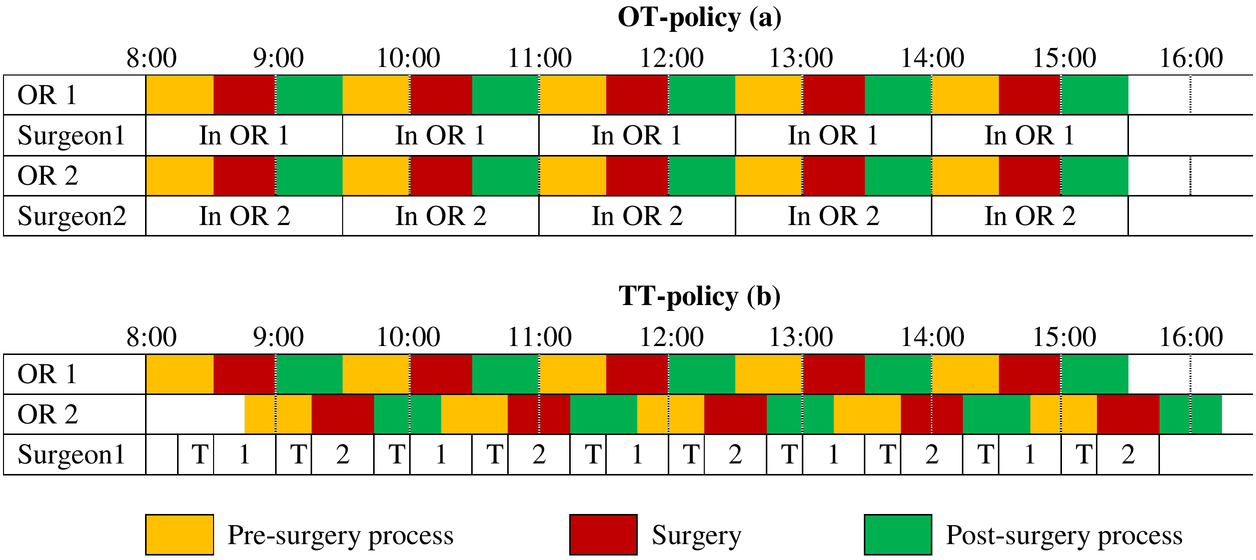

Figure 3: Illustration of (a) the OT-policy and (b) the TT-policy. T indicates the time required for the surgeon to travel and to take safety measures (for convenience, one anaesthetist is available in each OR)

2.3.2 Threats to performance of the TT-policy

In this section we outline various points that may affect performance of the TT-policy. First, large variability in the duration of one or more operating room phases may affect performance of the TT-policy. Also, the ratio of the duration of the surgery duration to the duration of the other phases is important. When the surgery duration is much larger than the sum of the other phases, less patients can be treated compared to the OT-policy.

Second, the time a patient is admitted to an OR may impact performance of the TT-policy. This release policy involves a trade-off between possible OR crew and surgeon waiting time. The time a patient is admitted to an OR can depend on the availability of staff members for the time-out procedure, a pre-determined schedule or as soon as the OR is available. The first option can reduce patient and OR staff waiting time but requires close communication. The second option may result in OR staff or patient waiting time. The third option may result in significant patient waiting time. Further research can determine the optimal release policy.

Third, as we state in Chapter 2.1, roughly 20% of all surgeries at SDCC are inpatients. These surgeries have a higher degree of complexity and subsequently more variability in surgery duration than regular SDCC surgeries. Thus, inpatient surgeries are less predictable. As variability is an important treat to the TT-policy, we focus on regular SDCC surgeries.

Fourth, the two-table anaesthesia policy may impact performance of the TT-policy. This interaction may result in an increasing OR crew and/or surgeon waiting time, subsequently decreasing efficiency. Maximising performance of the TT-policy may require one anaesthetist in each OR. Therefore, we evaluate the use of one anaesthetist in two ORs and one anaesthetist in each OR in each policy. Section 5.6.1 further addresses the experimental design.

2.4 Legislation related to TT-policy

This section addresses Dutch national guidelines related to requirements and responsibilities during the perioperative process. These guidelines attempt to aid in patient safety. In short, the guidelines state that the patient and entire OR crew must be present during the time-out and sign-out procedure. The surgeon is responsible for the execution and reporting of both phases. The time-out procedure should be performed before the anaesthesia induction phase. The anaesthetist may be absent during the time-out procedure when using regional anaesthesia and performing a pre time-out (which can take place outside the OR). In addition, the anaesthetist may be absent during the sign-out procedure and transfer tasks during this phase to the anaesthesia assistant (Nederlandse Vereniging voor Anesthesiologie (NVA), & Nederlandse Vereniging voor Heelkunde (NVvH), 2011).

These guidelines restrict the application of the TT-policy. Section 2.4.1 and Section 2.4.2 discuss the restrictions when using general anaesthesia and regional anaesthesia, respectively. Section 2.4.3 outlines implications for our analysis.

2.4.1 Restrictions with general anaesthesia

When applying the TT-policy including guidelines, the surgeon is waiting between the time-out procedure and surgery phase. This disturbs the performance of the TT-policy. Theoretically, a surgeon can use this time to perform activities in the opposite OR. However, we argue that this affects patient safety due to an increasing probability of making mistakes (i.e. switching to another patient after a time-out procedure may lead to wrong interventions). Hence, for patient safety, we assume that the surgeon will not switch to another patient after a time-out procedure in the TT-policy, although he is not required during the anaesthesia induction and prepare surgery phase.

2.4.2 Restrictions with regional anaesthesia

When applying regional anaesthesia, the anaesthetist and anaesthesia assistant can perform a pre time-out procedure. An advantage is that the anaesthetist can induce anaesthesia outside the OR. Hence, the OR crew can perform the turnover phase during anaesthesia induction. The order of the seven operating room phases therefore change: the OR crew can consecutively perform the time-out procedure, prepare surgery and surgery phase. Subsequently, surgeon's waiting time potentially reduces compared to applying general anaesthesia.

The number of surgeries using regional anaesthesia at SDCC is limited (14% of all surgeries between January 6th and October 24th 2014). We cannot create an OR schedule only with patients that undergo regional anaesthesia. Therefore, we focus on surgeries with general anaesthesia.

2.4.3 Implications of legislation

The national guidelines require that the surgeon is present during the time-out and sign-out procedure. We hypothesise that the guidelines limit the number of patients that can be treated and that the TT-policy offers most potential when excluding these requirements. Therefore, we include the following three surgery policies:

1. One-table policy including guidelines (current situation, in short OT-policy);
2. Two-table policy including guidelines (TT/+g-policy);
3. Two-table policy excluding guidelines (TT/-g-policy).

When excluding guidelines we ignore requirements that the surgeon is present during the time-out and sign-out procedure. Although not allowed under current legislation, we include this policy to show potential benefits. This, in turn, can lead to consider an alternative task partition during the time-out and sign-out procedure so that efficiency gains of the TT-policy can be achieved while patient safety is ensured. We further address the experimental design in Section 5.6.1. Table 2 shows the (required) presence of OR crew members in each operating room phase in each policy.

Table 2: Required presence of OR crew members in each operating room phase

	Time-out	Anaesthesia induction	Prepare surgery	Surgery	Sign-out	Anaesthetic emergence	Turn-over
Surgeon (OT-policy and TT/+g-policy)	x			x	x		
Surgeon (TT/-g-policy)				x			
Surgery assistant	x		x	x	x		
Anaesthetist	x	x				x	
Anaesthesia assistant	x	x	x	x	x	x	
Perioperative nurses	x		x	x	x		x

2.5 Conclusion

This chapter has reviewed the current surgery process at Surgical Day Care Centre (SDCC). At this department, patients generally arrive, undergo surgery and leave the same day. Formerly, these interventions have a low degree of complexity. Currently, however, also more complex patients such as children and inpatients undergo surgery at SDCC.

We distinguish seven phases in an operating room (OR): time-out procedure, anaesthesia induction, prepare surgery, surgery, sign-out procedure, anaesthetic emergence and turnover. Currently, all OR crew members except of the anaesthetist are available for each operating room phase right away. In this policy one surgeon is allocated to each OR. We refer to this policy as the one-table surgery policy (OT-policy). However, a surgeon is not required during various operating room phases. To use this time effectively, we have introduced the TT-policy. In this policy, one surgeon consecutively performs surgeries in two ORs. As soon as the surgeon finishes a surgery he moves to the opposite OR where a new patient is prepared and starts a new surgery. We primarily focus on surgeries with general anaesthesia as this is the only type of anaesthesia that is applied on a sufficiently large scale to fill an entire surgery programme.

Current guidelines require that the surgeon is present during the time-out and sign-out procedure next to the surgery phase. However, the TT-policy offers greatest potential benefits when excluding these requirements. To identify potential benefits we evaluate the TT-policy including as well as excluding these requirements in our analysis (TT/+g-policy and TT/-g-policy, respectively). The results of the TT/-g-policy can lead to consider an alternative task partition during the time-out and sign-out procedure so that efficiency gains of the TT-policy can be achieved while patient safety is ensured.

The next chapter formulates a mathematical model of the OT-policy and TT-policy, defines key performance indicators and selects an appropriate modelling technique to evaluate both policies.

3. Steps to evaluate the OT-policy and TT-policy

This chapter determines important requirements to evaluate the OT-policy and the TT-policy. Section 3.1 formulates the mathematical model. Section 3.2 defines key performance indicators. Section 3.3 selects the appropriate modelling technique to evaluate both policies. Section 3.4 draws a chapter conclusion.

3.1 Mathematical model formulation

This section formulates the mathematical model of both the OT-policy and the TT-policy. This model is valid when applying general anaesthesia. We do not define a mathematical model for any other type of anaesthesia since these are applied on a very limited scale only. We define the following variables:

N = Number of patients treated, $n = 1,..,N$
X_n = Random variable for duration of time-out phase of patient n
A_n = Random variable for duration of anaesthesia induction phase of patient n
P_n = Random variable for duration of prepare surgery phase of patient n
S_n = Random variable for duration of surgery phase of patient n
U_n = Random variable for duration of sign-out phase of patient n
E_n = Random variable for duration of anaesthetic emergence phase of patient n
Z_n = Random variable for duration of turnover phase after surgery of patient n
O_n = Time patient n enters the OR (OR 1 when n is odd and OR 2 when n is even numbered)
B_n = Time time-out procedure of patient n starts
C_n = Time anaesthesia induction of patient n starts
I_n = Time prepare surgery phase of patient n starts
G_n = Time surgery phase of patient n starts
K_n = Time sign-out procedure of patient n starts
M_n = Time anaesthetic emergence of patient n starts
D_n = Time turnover phase after surgery of patient n starts (i.e. time patient n leaves the OR)
T_n = Random variable for surgeon's safety measures for surgery n
V = Random variable for anaesthetist's and surgeon's travel time between OR 1 and OR 2
H_n = Time surgeon is available for time-out of patient n
Y_n = Time surgeon is available for surgery of patient n
J_n = Time anaesthetist is available for time-out of patient n
L_n = Time anaesthetist is available for anaesthetic emergence of patient n

$X_n, A_n, P_n, S_n, U_n, E_n, Z_n, T_n, V \geq 0$, for $n = 1,..,N$.

The mathematical model formulation depends on the policy we apply. For both policies we make some assumptions. We handled some of these earlier in this thesis, but repeat these assumption here for convenience. The assumptions are:

1. Activities are non-preemptive;
2. Patients undergo surgery in a fixed sequence (1,2,..,N). To minimise the time patients are under anaesthesia, the anaesthetist also uses this sequence;

3. No patients do not show up (no-show) or arrive late (tardy arrival);
4. Each patient enters the OR as soon as it is available (patient 1 and 2 enter OR 1 and OR 2 at 8 AM, respectively. Since a surgeon starts in OR 1 in the TT-policy, this release policy results in patient waiting time in OR 2);
5. The anaesthetist performs the anaesthesia induction phase immediately after the time-out procedure;
6. The anaesthetist performs requests of the time-out procedure and anaesthetic emergence phase on a First Come First Serve (FCFS) base;
7. The anaesthetist is not present during the sign-out procedure. We assume that if information of the anaesthetist is required, this is provided during the anaesthetic emergence phase (which does not take any additional time);
8. The anaesthetist does not incur safety measures before entering an OR;
9. The surgeon performs the sign-out procedure immediately after surgery;
10. For safety reasons, the surgeon does not switch to another patient after a time-out procedure in the TT-policy including guidelines, although the surgeon is not required during the anaesthesia induction and prepare surgery phase (see Section 2.4.1);
11. The surgeon performs remaining requests on a FCFS base;
12. The surgeon incurs safety measures only before starting a surgery. In the OT-policy and TT/+g-policy, the surgeon (and sterile team) performs these measures during the anaesthesia induction and/or prepare surgery phase. This does not result in additional time ($T_n \leq A_n + P_n$). In the TT/-g-policy the surgeon starts these measures during the prepare surgery phase or as soon as the surgeon is available.

The mathematical model reflects these assumptions. Section 3.1.1 outlines the mathematical model of the OT-policy. Section 3.1.2 outlines the model for the TT/+g-policy. Section 3.1.3 outlines the model for the TT/-g-policy. In each policy, without loss of generality, surgeries of odd numbered patients are in OR1 whereas even numbered patients receive treatment in OR2.

3.1.1 One-table surgery policy

This section presents the mathematical model formulation of the OT-policy. The first patient is admitted to each OR at 8 AM. Subsequent patients enter the OR when the turnover phase of the previous patient has finished:

O_n = 8 AM, where n = 1, 2.
$O_n = D_{n-2} + Z_{n-2}$, where n = 3,..,N.

The time-out procedure of patient n starts when the patient is in the OR and the anaesthetist is available:

$B_n = \max\{O_n, J_n\}$, for n = 1,..,N.

Since one surgeon is allocated to each OR in the OT-policy, we do not include surgeon availability in the start time of the time-out procedure. In the two-table anaesthesia policy, the anaesthetist is available at 8:00 AM to perform the time-out procedure in OR 1:

J_n = 8:00 AM, where n = 1.

For remaining patients, the time the anaesthetist is available (in the two-table anaesthesia policy) for the time-out procedure depends on the activity he performs to the previous patient. The anaesthetist induces anaesthesia in the sequence patients undergo surgery to minimise time patients are under anaesthesia (see assumption 2). In mathematical notation:

$$J_n = \begin{cases} C_{n-1} + A_{n-1} + V, & \textit{if anaesthesia induction of patient n-1 is prior activity} \\ M_{n-1} + E_{n-1} + V, & \textit{if anaesthetic emergence of patient n-1 is prior activity} \end{cases}, \quad \text{where } n = 2,..,N.$$

In the one-table anaesthesia policy, both anaesthetists are available at 8:00 AM for the time-out procedure in OR 1 and OR 2:

J_n = 8:00 AM, where n = 1, 2.

For remaining patients, the time the anaesthetist is available (in the one-table anaesthesia policy) for the time-out procedure is equal to the finishing time of the anaesthetic emergence:

$J_n = M_{n-1} + E_{n-1}$, where n = 3,..,N.

A surgeon is available for the time-out procedure of patient n ($n \geq 3$) after the sign-out phase of patient n-2. The surgeons in both ORs are available at 8:00 AM for the time-out procedure of patient 1 and 2:

H_n = 8 AM, where n = 1, 2.
$H_n = F_{n-2} + U_{n-2}$, where n = 3,..,N.

Recall from Section 2.2.2 that the anaesthesia induction, prepare surgery, surgery, and sign-out phase start immediately after the previous phase has finished:

$K_n = B_n + X_n + A_n + P_n + S_n$, where n = 1,..,N.

The surgeon is available for the surgery phase of patient n when the time-out procedure has finished:

$Y_n = B_n + X_n$, where n = 1,..,N.

Subsequently, the anaesthetic emergence phase starts when the sign-out procedure has finished, and the anaesthetist is available. The start time therefore equals:

$M_n = \max\{K_n + U_n, L_n\}$, where n = 1,..,N.

The time the anaesthetist is available to perform the anaesthetic emergence phase again depends on the prior activity:

$$L_n = \begin{cases} C_n + A_n, \textit{ if anaesthesia induction of patient n is prior activity} \\ M_{n-1} + E_{n-1} + V, \textit{ if anaesthetic emergence of patient n-1 is prior activity} \\ C_{n+1} + A_{n+1} + V, \textit{ if anaesthesia induction of patient n+1 is prior activity} \end{cases}, \text{ where } n = 1,..,N.$$

The turnover phase starts when the anaesthetic emergence phase has finished (is equal to the time a patient leaves the OR):

$D_n = M_n + E_n$, where $n = 1,..,N$.

3.1.2 Two-table surgery policy including guidelines

This section formulates the mathematical model of the TT/+g-policy. Recall that the guidelines require that the surgeon is present during the time-out and sign-out procedure. The surgeon is idle during the anaesthesia induction and prepare surgery phase since performing a surgery after the time-out procedure of another patient may increase mistakes. In addition, according to assumption 4, the surgeon performs the sign-out procedure immediately after surgery. Further, the anaesthetic emergence phase starts immediately after the sign-out procedure to minimise the time a patient is under anaesthesia (an anaesthetist may also perform the time-out procedure in the opposite OR after the sign-out procedure, all resources except the anaesthetist are now available, but this increases the time a patient is under anaesthesia). As a result, the phases between the time-out procedure and the anaesthetic emergence phase are performed consecutively in the TT/+g-policy. A patient can only incur waiting time for the time-out procedure.

The first patient is admitted to each OR at 8 AM. Subsequent patients enter the OR when the turnover phase of the previous patient has finished:

O_n = 8 AM, where $n = 1,2$.
$O_n = D_{n-2} + Z_{n-2}$, where $n = 3,..,N$.

The start time of the time-out procedure only depends on patient and anaesthetist availability since the activity of the surgeon prior to the time-out procedure (sign-out procedure) ends before the activity of the anaesthetist prior to the time-out procedure (anaesthetic emergence) and travel time is equal. Hence, the surgeon is available when the anaesthetist is available. Starting time of the time-out procedure therefore equals the time the patient and anaesthetist are available:

$B_n = \max\{O_n, J_n\}$, where $n = 1,..,N$.

Because the time-out procedure until the anaesthetic emergence phase are performed consecutively, the anaesthetist is available for the time-out procedure as soon as it has finished the anaesthetic emergence phase in the opposite OR including travel time:

J_n = 8 AM, where n = 1.
$J_n = M_{n-1} + E_{n-1} + V$, where n = 2,..,N.

The time the surgeon is available for the time-out procedure equals the time the sign-out procedure in the opposite OR has finished plus travel time (without safety measures since the safety measures are only required before surgery):

H_n = 8:00 AM, where n = 1.
$H_n = F_{n-1} + U_{n-1} + V$, where n = 2,..,N.

Because the time-out procedure until the anaesthetic emergence phase are performed consecutively, the mathematical notation of the start time of the anaesthesia induction, prepare surgery, surgery, and sign-out phase is equal to the OT-policy. The anaesthetic emergence phase starts immediately after the sign-out procedure. The anaesthetist is available for the anaesthetic emergence phase when the anaesthesia induction phase has finished:

$L_n = C_n + A_n$, where n = 1,..,N.

The time the turnover phase starts (and the patient leaves the OR) is also equal to the formulation of the OT-policy.

3.1.3 Two-table surgery policy excluding guidelines

This section formulates the mathematical model of the TT/-g-policy. Recall that the surgeon is not required during the time-out and sign-out procedure in this policy.

The mathematical formulation is very similar to the formulation of the OT-policy. Hence, we refer to Section 3.1.1 for this formulation. The formulation of the TT/-g-policy only differs from the OT-policy with respect to the start time of the time-out procedure and the time surgeon is available for surgery.

The start time of the time-out procedure of patient n depends on the time the anaesthetist is available (of which the formulation agrees with the OT-policy):

$B_n = J_n$, where n = 1,..,N.

The surgeon is available for surgery of patient 1 at 8 AM. For subsequent patients, the surgeon is available for surgery after it has finished safety measures. These measures start as soon as the prepare surgery phase of patient n starts (see assumption 12) or the surgeon has finished surgery of patient n-1:

Y_n = 8:00 AM, where n = 1.
$Y_n = \max\{I_n, F_{n-1} + V\} + T_n$, where n = 2,..,N.

3.2 Key performance indicators selection

This section defines key performance indicators (KPIs) to evaluate the OT-policy and the TT-policy. We measure performance in both policies with respect to operating room performance. Inspired by the comprehensive literature review of Cardoen, Demeulemeester and Beliën (2010), we select appropriate indicators.

OR performance is measured by various indicators in the literature. Waiting time and utilisation of resources are commonly addressed (Cardoen et al., 2010). Denton and Gupta (2003) measure both patient and surgeon waiting time. Utilisation of the operating theatre is often measured (Lebowitz, 2003). Dexter, Macario, Traub, Hopwood and Lubarsky (1999) define OR utilisation as “the time an OR is used (occupancy plus setup and clean-up) divided by the length of time an OR is available and staffed”. Also doctor utilisation has been subject of research (Hulshof et al., 2012). Gupta (2007) applies an analogy of this measure: surgeon waiting time. A further applied measure to indicate OR performance is patient throughput (Vanberkel & Blake, 2007).

Berg et al. (2010) have conducted a similar study of multiple procedure rooms per endoscopist. They have used patient throughput, procedure room utilisation, endoscopist utilisation, and utilisation of intake nurses and recovery beds as performance measures.

Inspired by these measures, patient throughput, average time per surgery, surgeon utilisation, anaesthetist utilisation, and patient waiting time quantify performance of most important and/or expensive stakeholders in the OR. Therefore, we use these measures as performance indicators. We also roughly indicate the cost efficiency of each policy. Below we explain each KPI.

<u>Patient throughput</u>
Patient throughput is the number of patients who undergo surgery in two OR-days in regular OR time (960 minutes). Regular OR time in each OR at SDCC is from 08:00 AM to 4:00 PM. In the TT-policy in practice, it may be more efficient to shift regular OR time of one OR (see Section 7.1).

<u>Average time per surgery</u>
Average time per surgery is the total time required to finish all surgeries (including turnover) divided by the number of surgeries on an OR-day.

Surgeon utilisation

We consider surgeon utilisation on two OR-days. In our analysis a surgeon is either utilised or waiting in an OR. To compare the OT-policy and TT-policy properly, we define surgeon utilisation as the time the surgeon is occupied relative to the time required to finish all surgeries:

$$\text{Surgeon utilisation} = \frac{\text{Surgeon working time - Surgeon waiting time}}{\text{Surgeon working time}}$$

Surgeon working time equals the time between 8:00 AM and the last surgery has finished. In each policy, we consider time for safety measures as utilised since these activities are required (although non-value added). In addition, the TT-policy, time required to travel between both ORs is also considered as utilised. As a result, when a surgeon treats the same number of patients (or more) in the TT-policy and the OT-policy, surgeon utilisation increases.

In both the OT-policy and the TT/+g-policy, a surgeon may have to wait for the time-out procedure and surgery phase of patient n (the sign-out procedure starts immediately after surgery, see Section 3.1). Hence, surgeon waiting time in these policies is defined by:

$$\text{Surgeon waiting time} = \sum_{n=1}^{N} (B_n - H_n + G_n - Y_n - T_n)$$

In the TT/-g-policy, a surgeon is only required during the surgery phase. Hence, surgeon waiting time in this policy is defined by:

$$\text{Surgeon waiting time} = \sum_{n=1}^{N} (G_n - Y_n - T_n)$$

Anaesthetist utilisation

We consider anaesthetist utilisation on two OR-days. In our analysis an anaesthetist is either utilised or waiting in an OR. To compare the OT-policy and TT-policy properly, we define anaesthetist utilisation as the time the anaesthetist is occupied relative to the time required to finish all surgeries:

$$\text{Anaesthetist utilisation} = \frac{\text{Anaesthetist working time - Anaesthetist waiting time}}{\text{Anaesthetist working time}}$$

In each policy anaesthetist working time equals the time between 8:00 AM and the last surgery has finished. The anaesthetist may have to wait for the time-out procedure or anaesthetic emergence phase of patient n (anaesthesia induction starts immediately after the time-out procedure, see Section 3.1). Therefore, anaesthetist waiting time in each policy is defined by:

$$\text{Anaesthetist waiting time} = \sum_{n=1}^{N} (B_n - J_n + M_n - L_n)$$

Patient waiting time

We consider patient waiting time in an OR. In the OT-policy, each patient may only have to wait for the anaesthetist. Hence, a patient can incur waiting time for the time-out procedure and anaesthetic emergence phase:

Patient waiting time = $B_n - O_n + M_n - (F_n + U_n)$, for n = 1,..,N

In the TT/+g-policy, a patient can only incur waiting time for the time-out procedure since all operating room phases are performed consecutively. Hence, patient waiting time is defined by:

Patient waiting time = $B_n - O_n$, for n = 1,..,N

In the TT/-g-policy, a patient can incur waiting time for the time-out procedure, and surgery and anaesthetic emergence phase. Therefore, patient waiting time is defined by:

Patient waiting time = $B_n - O_n + G_n - (C_n + A_n + P_n) + L_n - F_n$, for n = 1,..,N

Cost efficiency

We roughly estimate the cost efficiency (i.e. the average costs per surgery) of each policy. We do not evaluate cost efficiency of each policy in detail as costs included strongly depend on the stakeholder. We leave comparing policies in terms of costs therefore up to decision makers. Our estimation of the cost efficiency is based on a rough calculation of annual OR costs at SDCC, and approximate annual surgeon and anaesthetist costs.

To determine the true cost efficiency of each policy, we present a cost model to determine the average costs per surgery. We include direct costs of operating room space, anaesthesia and the surgeon. The average costs per surgery are defined by:

$$\text{Average costs per surgery} = \frac{\text{Total costs}}{\text{Number of surgeries performed}}$$

Where Total costs = $C_o*H_o + C_a*H_a + C_s*H_s$, with

C_o = Price per OR-hour of operating room space (including OR staff)
C_a = Price per OR-hour of anaesthesia
C_s = Price per OR-hour of surgeon
H_o = OR-hours of operating room space used
H_a = OR-hours of anaesthesia used
H_s = OR-hours of surgeon used

Obviously, a policy is superior to another policy with respect to costs efficiency when the average costs per surgery are lower.

3.3 Modelling technique selection

This section evaluates different modelling techniques to achieve our research objective. According to Edward et al. (2008) Operational Research roughly uses mathematical modelling, queueing theory and simulation to support decision-making processes in complex coordination and execution of operational problems. We consider each technique below.

Mathematical modelling
Mathematical models aim to optimise one or more objective values (Williams, 1999). However, the aim of this research is not to optimise one or more variables but to evaluate a range of values, subsequently determining conditions under which the TT-policy is more efficient than the OT-policy. Hence, mathematical modelling is inappropriate to achieve our research objective.

Queueing theory
From a queueing theory perspective, both the OT-policy and the TT-policy have two servers and one queue. A setup is required for each patient (the turnover phase) and each patient goes through the six phases of patient's process flow (see Figure 2). In both policies one anaesthetist moves between both servers. In addition, in the TT-policy one surgeon travels between both servers and, depending on the operating room phase, has to incur safety measures. Some phases can only start when one or both of these resources are available. Including these dependencies makes a stochastic model increasingly complex. Therefore we conclude that queueing theory is inappropriate for this research.

Simulation
Simulation modelling can be applied to "estimate the operational characteristics of a system as well as to observe the consequences of changes in planning or policies prior to when decisions are actually implemented, hence reducing the financial risks" (Jun, Jacobson, & Swisher, 1999). In addition, simulation is a useful tool to perform what-if analyses (Dooley, 2001), which corresponds to our research objective. Furthermore, simulation offers some 'soft' advantages over mathematical modelling and queueing theory: it is a powerful visual tool to show decision-makers a realistic production of policies at work (De Angelis, Felici, & Impelluso, 2003). Also, UMCG demands a model that can easily include future developments or changes. A simulation model provides this flexibility.

Similar studies also use simulation as modelling technique (Section 4.1.1 describes these studies). Hulshof et al. (2012) have applied discrete-event simulation to compare the DtP-policy and the PtD-policy, and to measure doctor utilisation in the DtP-policy. In addition, Berg et al. (2010) have used discrete-event simulation to evaluate colonoscopy screening efficiency when varying the number of available procedure rooms per endoscopist.

We conclude that simulation is the appropriate modelling technique to evaluate the OT-policy and the TT-policy. By changing input parameters we can test a range of values and subsequently achieve our research objective.

3.4 Conclusion

In this chapter we have formulated mathematical models for the OT-policy, TT/+g-policy and TT/-g-policy. In addition, based on performance indicators in the literature, evaluate each policy on patient throughput, surgeon productivity, average time per surgery, surgeon waiting time, anaesthetist waiting time, patient waiting time and overtime. Moreover, we have considered different modelling techniques to evaluate each policy with respect to operating efficiency. Based on prior research and appropriateness of each technique towards our research objective, we have selected simulation modelling to evaluate each policy.

The next chapter defines factors that may impact performance of the TT-policy. We include these factors in our analysis.

4. Factors potentially impacting TT-policy performance

This chapter defines factors that potentially impact performance of the TT-policy. We analyse these factors to determine whether each factor impacts the efficiency and under which conditions the TT-policy is more efficient than the OT-policy. Section 4.1 reviews the literature and uses experience of hospitals 'Refaja ziekenhuis' and 'ZGT', which apply and have applied the TT-policy, respectively, to obtain factors that may impact performance of the TT-policy. Section 4.2 selects factors we include in our analysis. Section 4.3 draws a chapter conclusion.

4.1 Factors from literature and practice

This section obtains factors that potentially impact performance of the TT-policy. Section 4.1.1 reviews the literature. Section 4.1.2 analyses experience of hospitals 'Refaja ziekenhuis' and 'ZGT'. Section 4.1.3 draws a conclusion from both sources.

4.1.1 Literature review

This section reviews the literature related to the two-table (or multi-table) surgery policy. We describe our search strategy in Appendix A.

The Aravind Eye Care System is a famous example of an institution applying a TT-policy. This system, originating from India, provides high-quality, high-volume and cost-effective eye care services. One of the pillars is 'assembly line surgery': each ophthalmologist has two operating tables next to each other. Trained para-medical staff prepares a patient on one table while the surgeon is operating on the other table. After completing a surgery, the ophthalmologist remains in its seat and swings the arm of the microscope over the next table and starts the next procedure (Natchiar, Thulasiraj, & Sundaram, 2008). This enhances ophthalmologist utilisation and improves quality. Aravind's quality of care is comparable to that in top hospitals in India as well as in Western countries (Rangan & Thulasiraj, 2007). Also productivity increases significantly due to this 'assembly line surgery': from 2008, an Aravind surgeon performs on average 2,000 or more surgeries annually, against the Indian national average of 250 (Bhandari, Dratler, Raube, & Thulasiraj, 2008).

Hulshof et al. (2012) evaluate the use of multiple consultation rooms for each doctor in an outpatient clinic. They have determined the switching curve of one room (PtD-policy) and multiple rooms (DtP-policy). This curve depends on the ratio of doctor travel time to pre-consultation time and post-consultation time. They have shown that the DtP-policy outperforms the PtD-policy when the average doctor travel time between rooms is lower than the sum of the average pre-consultation time and the average post-consultation time. This is however not realistic in a surgery context. They have also indicated that the switching curve is insensitive to the average consultation time and coefficient of variation (CV) of all processes.

Berg et al. (2010) have tested the effect of the number of procedure room on colonoscopy screening efficiency. They have concluded that having two procedure rooms available for each endoscopist is an upper bound: "more than 2 procedure rooms per endoscopist results in low procedure room utilisation with no increase in patient throughput". They have noted that this threshold depends on the mean time per endoscopy compared to the mean time a patient is in the procedure room.

We conclude that there is a gap in the literature about conditions and in-depth description of the two-table (or multi-table) surgery policy, both from healthcare and industry perspective. Due to a lack of academic literature on this topic we are unable to obtain an answer to research question 4 from the literature.

4.1.2 Examples from practice

We have conducted interviews with practitioners who have experience with a TT-policy, namely ‘Refaja Ziekenhuis’ in Stadskanaal and ‘ZGT’ in Hengelo, The Netherlands. During these interviews we discussed the practical implementation and limitations as well as factors impacting the efficiency of this policy. This section describes the results.

Refaja Ziekenhuis
On Friday October 10, 2014 we have interviewed an OR planner of hospital ‘Refaja Ziekenhuis’, in Stadskanaal. Here, orthopaedic surgery applies a TT-policy once every two weeks. During these sessions, mainly arthroscopic knee surgeries are performed. Sometimes different types of surgeries are included but this reduces efficiency due to adjustments to the operating table.

When applying the TT-policy, up to 25 surgeries can be performed. Most patients undergo spinal anaesthesia. In this case the surgeon can consecutively perform the time-out procedure and start surgery. Two perioperative nurses are present in each OR. In addition, one flexible nurse assists one of the OR crews when needed. One of the perioperative nurses performs “closing”. The hospital is happy with the results of the TT-policy: they report negligible waiting lists and throughput time of at most one week for arthroscopic knee surgeries.

According to the OR planner, the TT-policy can be used with well-predictable surgeries and is particularly useful when treating patients with ASA classification 1 and 2. However, increased surgeon utilisation can result in OR crew waiting time, subsequently impacting the efficiency. In addition, general anaesthesia limits the efficiency benefits due to the requirement that the surgeon is present during time-out procedure (see Section 2.4). Capacity of the holding and recovery department can also limit the number of patients that can be treated.

ZiekenhuisGroep Twente (ZGT)
On Tuesday November 18, 2014 we have interviewed an oncological surgeon of hospital ‘ZGT’, in Hengelo. Ten years ago, ‘ZGT’ has used the TT-policy several times on Saturdays to decrease their waiting list by temporarily increasing their capacity by means of a TT-policy. They have a very positive experience with this policy as the goal was achieved.

At ‘ZGT’ surgeries of at most 30 minutes were included. The number of surgeries performed varied between 20 and 24. Both patients and staff members were carefully selected to participate in the programme. There were no problems with the interaction of the TT-policy and the two-table anaesthesia policy due to the predictability of all phases. No time was scheduled between two consecutive surgeries. One break of 30 minutes was scheduled, that also acted like a buffer to account for variability. An important note is that the time-out and sign-out procedure were not required at that time. Currently, ZGT does not use this policy in their regular surgery programme because there are no financial incentives beyond their agreements with healthcare insurance companies.

According to the oncological surgeon, the TT-policy is only efficient when performing high volume, low complexity surgeries. Therefore, only patients with ASA classification 1 and 2 are appropriate to use in this policy. In addition, the time-out procedure disturbs the performance of the TT-policy and is therefore inappropriate to use in this policy. Moreover, there should be a clear division of labour and patients should be released to an OR according to a well-defined schedule. All OR crew members should discuss this schedule at the start of the day. A surgeon should do any paperwork at the end of the day, not during a session.

4.1.3 Conclusion

We conclude that the factors affecting performance of the TT-policy are scarce and that there is a gap in the literature at this point. From Berg et al. (2010) we obtain that the ratio of the surgery duration to the procedure duration impacts the policy's efficiency. Hulshof et al. (2012) have shown that the DtP-policy outperforms the PtD-policy when the average doctor travel time between rooms is lower than the sum of the average pre-consultation time and the average post-consultation time. This is however not realistic in a surgery context. They have also indicated that the switching curve is insensitive to the average consultation time and coefficient of variation (CV) of all processes.

From the examples from practice we derive that the TT-policy is particularly useful with well-predictable surgeries up to 30 minutes. Consequently, only patients of ASA classification 1 and 2 should be used in these sessions. In addition, a factory focus and patients who need the same type of surgery are important to maximise results. Moreover, guidelines, which require that the surgeon is present during the time-out and sign-out procedure, limit the benefits of the TT-policy. The benefits are likely to increase when these guidelines can be relaxed.

4.2 Factors included in analysis

This section defines factors that potentially impact performance of the TT-policy. We include these factors in our analysis. We hypothesise that the following factors impact performance of the TT-policy:

1. Expected surgery duration;
2. Variability in the duration of each operating room phase.

The expected surgery duration results from Berg et al. (2010). We consider the ratio of surgeon cycle (surgeon is required) to OR cycle (surgeon is not required). The surgery duration impacts this ratio since the (expected) duration of the other operating room phases are fixed. Hulshof et al. (2012) have indicated that variability has negligible impact on relative performance of the DtP-policy. However, more processes and more variability are included in a surgical procedure. Therefore, we include this factor in our analysis.

Patients have an equal surgery duration and variability in the duration of each operating room phase in each policy so that we can compare performance of both policies properly. We outline both factors in the next sections.

4.2.1 Expected surgery duration

As we have the dependency of one surgeon in two ORs, the time a surgeon leaves an OR until he is available in the OR again should be used efficiently. During this time the current surgery should be finished and the next patient prepared. We define the surgeon cycle as the time between the moment a surgeon leaves an OR and he is available in the OR again. In the TT/-g-policy the surgeon cycle is defined by the surgery duration in the opposite OR plus twice the travel time. In mathematical notation:

Surgeon cycle = $T_n + S_n + T_{n+1}$, for n = 1,..,N-1

After the surgeon leaves an OR, the time until the surgeon is available again should be used to finish the current surgery and prepare the next patient. We refer to this time as the OR cycle. In the TT/-g-policy the OR cycle equals all phases besides the surgery phase. In mathematical notation:

OR cycle = $U_n + E_n + Z_n + X_{n+1} + A_{n+1} + P_{n+1}$, for n = 1,..,N-1

The ratio of surgeon cycle to OR cycle affects performance of the TT-policy. For the surgeon, the optimal ratio of surgeon cycle to OR cycle is 1:1. We show this ratio in Figure 3(b). This ratio may not be optimal in practice due to the interaction with the two-table anaesthesia policy. In the TT/+g-policy, the definition of both surgeon and OR cycle changes. We illustrate the importance of the ratio by showing the effect of different ratios. Figure 4 shows a ratio of surgeon cycle to OR cycle of 2:1. Clearly, OR crew utilisation (except the surgeon) and patient throughput decreases in the TT-policy compared to the OT-policy since the OR crew is waiting for the surgeon.

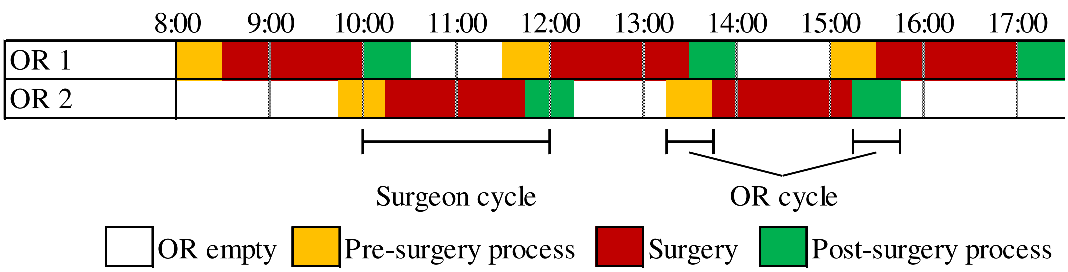

Figure 4: Ratio 2:1 of surgeon cycle to OR cycle in the TT-policy (pre-surgery and post-surgery process take 30 minutes, surgery takes 90 minutes and travel time and safety measures for the surgeon take 15 minutes)

Figure 5 shows a ratio of 1:2. In this case utilisation of both ORs is high and productivity is equal to the OT-policy. The surgeon is however waiting considerable amount of time, but only half of the time compared to the OT-policy.

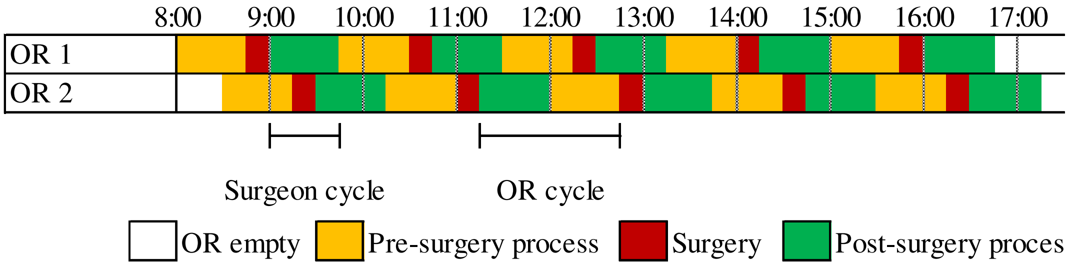

Figure 5: Ratio 1:2 of surgeon cycle to OR cycle in the TT-policy (pre-surgery and post-surgery process take 45 minutes, surgery takes 15 minutes and travel time and safety measures for the surgeon take 15 minutes)

The (expected) surgery duration impacts the ratio of surgeon cycle to OR cycle since the (expected) duration of the other operating room phases are fixed (see Section 5.2). Therefore, we analyse this ratio by varying the expected surgery duration (i.e. the duration of the surgery phase, see Section 2.2.4). Based on among the experience of hospital 'ZGT', we hypothesise that the TT-policy shows best performance with surgeries up to 20 minutes.

4.2.2 Variability in the duration of each operating room phase

As we have derived from the applications in practice, a TT-policy is particularly beneficial with well-predictable surgeries. Large variability decreases performance of the TT-policy (due to increasing waiting time) and increases the probability of working in overtime. Duration of the surgery and anaesthesia phase show most variability. Therefore, we evaluate variability in these operating room phases. We measure the variability of each phase by means of the coefficient of variation (CV). Hence, we evaluate the CV surgery and CV anaesthesia. We hypothesise that the TT-policy shows best performance with relatively low variability.

To account for variability in the duration of each operating room phase, planned slack can be used between two surgeries. The surgeon can use this slack to travel to the OR and take required safety measures. Planned slack includes a buffer to account for variability in the duration of each operating room phase. We distinguish two types of planned slack: static and dynamic slack. Static slack is a fixed amount of time between two surgeries. The amount of slack in this case is an organisational choice. Figure 5 shows static slack of 15 minutes. Clearly, unnecessary large amount of slack decreases OR utilisation and patient throughput. Including too little amount of slack, on the other hand, increases patient waiting time, OR crew waiting time and working in overtime to finish all scheduled surgeries. When using dynamic slack, the amount of slack may depend on the probability of working in overtime and the variability of the surgery duration. This is similar to OR scheduling where planned slack is included in the construction of Master Surgical Schedule to avoid the probability of working in overtime (Van Oostrum et al., 2008). To maximise patient throughput, we do not include slack in our analysis. We further address this assumption in Section 5.4.

4.3 Conclusion

In this chapter we have reviewed the literature related to factors potentially impacting performance of the TT-policy. We have concluded that there is a gap in the literature on this point. Also, we have used the experience of hospitals ‘Refaja Ziekenhuis’ and ‘ZGT’ with the TT-policy. Based on these outcomes, we have defined the following two factors that potentially impact performance of the TT-policy:

1. Expected surgery duration;
2. Variability in the duration of each operating room phase.

We include these factors in our analysis to determine conditions under which the TT-policy is more efficient than the OT-policy. In the next chapter we develop our simulation study.

5. Simulation study

This chapter constructs the simulation model. Section 5.1 draws a conceptual model. Section 5.2 analyses data to derive a statistical distribution for each operating room phase. Section 5.3 gives the technical design of the simulation model. Section 5.4 lists the assumptions in the model. Section 5.5 verifies and validates the model constructed. Section 5.6 addresses the experimental design. Section 5.7 draws a chapter conclusion.

5.1 Conceptual model

This section describes the conceptual simulation model. Based on Mes & Bruens (2012), we create a conceptual model of the OT-policy and TT-policy. We identify events that trigger decisions and processes. Figure 6 shows the conceptual model.

We use a (generic) conceptual model for both the OT-policy and the TT-policy. These policies only differ with respect to the number of allocated surgeons. We include the two-table anaesthesia policy in our model.

New day event
Upon the start of each day, the new day event is triggered that generates patients. The number of patients is such that the available OR time in each OR is (approximately) filled, based on the sum of the expected duration of the seven operating room phases. Section 5.4 further addresses this rule. Then the OR-day execution event is called.

OR-day execution event
The next patient to undergo surgery in the OR is selected and moved to the OR. Subsequently, the next operating room phase of this patient is determined. Then it is checked whether all required crew members are available and if so, required crew members are moved to the operating table (for visual enhancement and including time) and the operating room phase starts. If a required resource (i.e. anaesthetist and/or surgeon) is not available, this phase cannot start and the patient has to wait until the resource is available. After finishing an operating room phase the OR crew members become available event is triggered. When one or more phases (except the turnover phase) are remaining, the next operating room phase is determined and the process repeats. If the anaesthetic emergence phase has finished, the patient goes to the recovery room and the turnover phase starts in the OR. After finishing the turnover phase, we verify whether all patients scheduled in an OR have been treated. If this is true, the OR-day has finished. If not, the next patient is moved to the OR.

OR crew members become available event
After finishing an operating room phase, one or more resources may become available (including the assumptions in Section 3.1). When a phase is waiting for a required resource, this event checks whether all required crew members are available and if so, required crew members are moved to the operating table and the operating room phase starts.

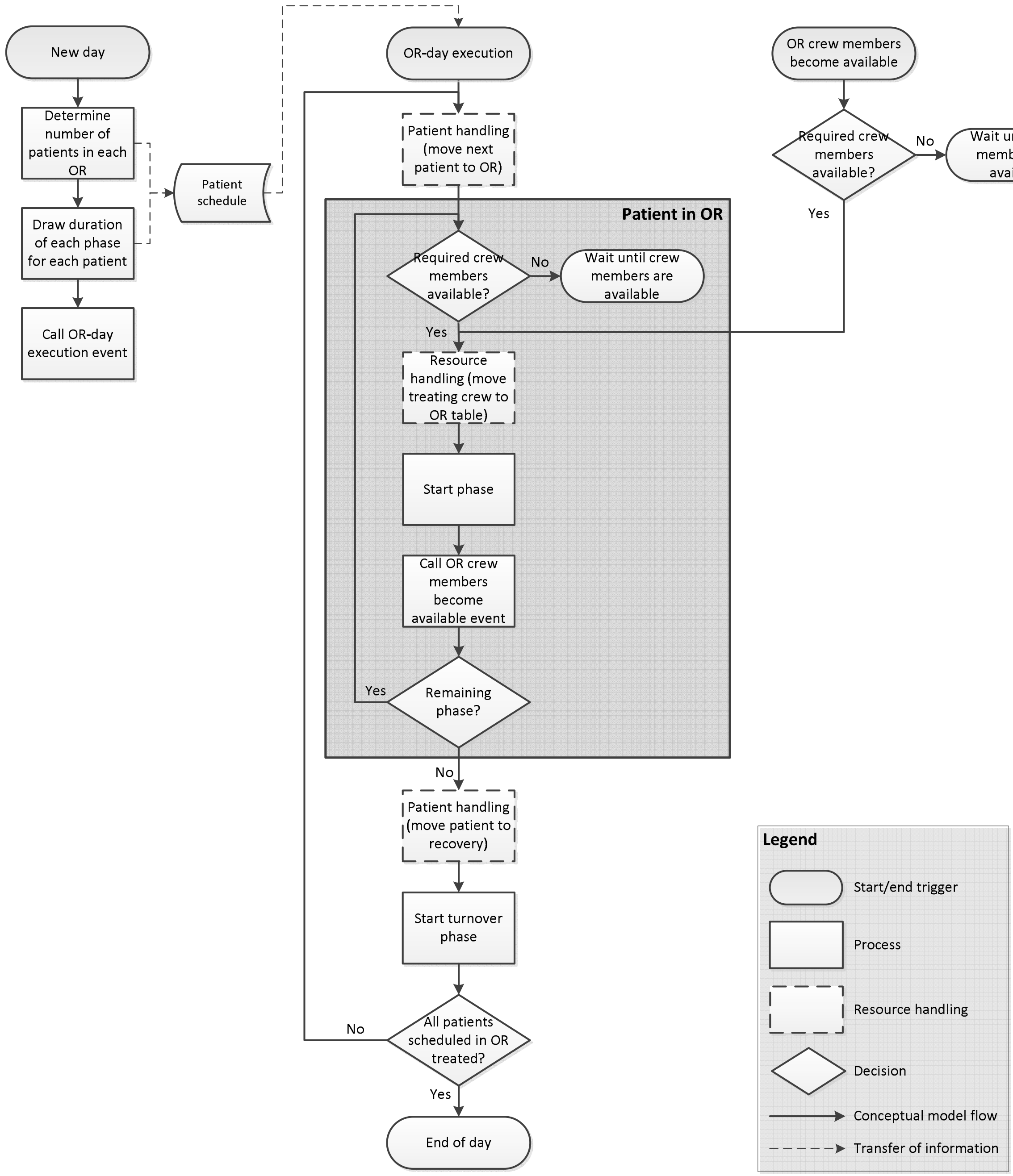

Figure 6: Conceptual simulation model of the OT-policy and TT-policy

5.2 Data analysis

This section describes the data analysis process to determine an appropriate statistical distribution for each operating room phase. The data originates from the time registration system of surgeries, which is filled in by OR crew members. The OR crew records the following times of each surgery: patient entering the OR, start anaesthesia induction, end anaesthesia induction, start surgery, end surgery and patient leaving the OR. Since these times do not fully reflect the seven operating room phases we defined, we have to make certain assumptions to include proper data in our simulation model.

We extract data from the 6th of January 2014 until the 24th of October 2014. We focus on regular SDCC surgeries (see Section 2.1) because variability of these surgeries is limited (compared to inpatient surgeries). We also focus on general anaesthesia since this is the only type of anaesthesia applied on a sufficiently large scale to fill an entire surgery programme (see Section 2.4.3). Further, in accordance with Section 4.1.3, we focus on patients with ASA classification 1 and 2. This results in 1632 records (59.6% of all records). The data from the time registration system is discrete. Obviously, durations in practice are real and therefore we use continuous statistical distributions.

We use the data analysis process as described by Robinson (2004). First, we create a histogram to inspect the shape of the distribution of the empirical data. Second, we select the distribution that best models the duration of a certain phase by means of the ExpertFit software package of Averill M. Law & Associates. This tool also determines corresponding model parameters. Third, we test the goodness-of-fit using Minitab software. The next sections describe the data analysis process per operating room phase.

5.2.1 Time-out procedure

We obtain the duration of the time-out procedure including some related activities from the time registration system. This duration reflects the time between the time the patient enters the OR and start anaesthesia induction. We remove records with negative and zero duration of the time-out procedure (12 records in total). Figure 7 shows the resulting histogram.

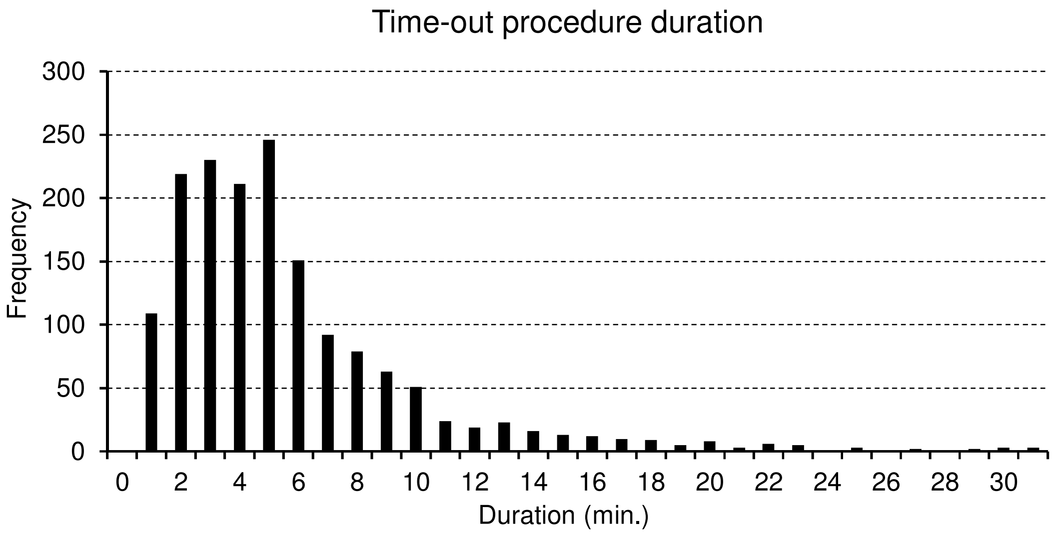

Figure 7: Histogram of the duration of the time-out procedure (N = 1620, January 6, 2014 - October 24, 2014)

The data shows large variability in time-out procedure duration. Therefore, we use expert opinion of the head of the SDCC department. She argues that the duration of the time-out procedure is between 1 and 5 minutes and is independent of the type of surgery. Recorded durations exceeding this estimate can be explained by waiting time due to breaks or unavailability of staff members. Therefore, we use a triangular distribution with a minimum duration of 1 minute, maximum duration of 5 minutes and expected duration of 3 minutes.

5.2.2 Anaesthesia induction

The time between start anaesthesia induction and end anaesthesia induction represents the duration of the anaesthesia induction phase. Subsequently, we derive a statistical distribution from the data to model the duration of this phase. To do so, we remove zero durations and one outlier that is almost certainly due to an unrepresentative circumstance. This results in the removal of 5 records. The data shows a significant difference in the duration of the anaesthesia induction phase when the surgery duration is between 5 and 15 minutes and 16 and 55 minutes. The head of the SDCC department confirms this difference. Therefore, we use a different distribution for both surgery durations. Figure 8 shows the histogram and distribution of the duration of the anaesthesia induction for surgery durations between 5 and 15 minutes.

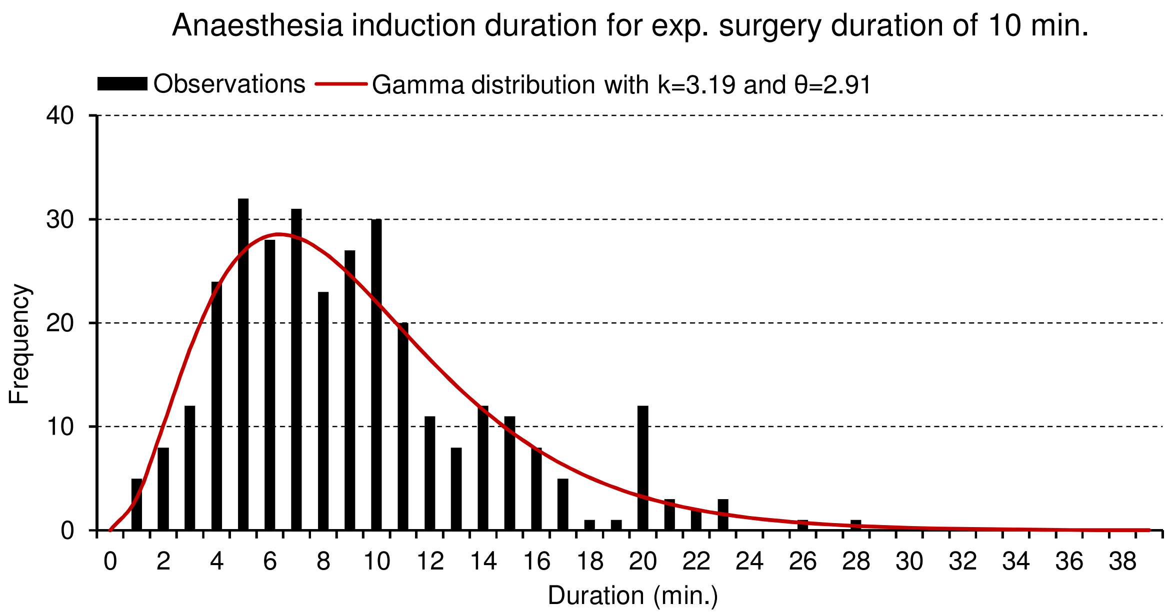

Figure 8: Histogram of the duration of the anaesthesia induction phase for an expected surgery duration of 10 minutes (N = 320, January 6, 2014 - October 24, 2014)

No statistical distribution fits with sufficient accuracy. However, we feel that empirical data does not represent reality as, for instance, the number of records with a duration of 10 and 20 minutes is unlikely to be realistic. The number of records can be explained by a rounded estimation after the surgery has finished. Table 3 shows distributions for different expected surgery durations. Both distributions do not fit the data at common levels of significance. However, these distributions best model the duration of the anaesthesia induction phase. Possible complications during anaesthesia induction are included by means of durations derived from the tail of the distribution.

Table 3: Statistical distributions of the anaesthesia induction phase for different expected surgery durations

Surgery duration (min.)	Average duration anaesthesia induction (min.)	Standard deviation duration anaesthesia induction (min.)	Distribution
5-15	9.29	5.30	Gamma, shape 3.19 and scale 2.91
16-55	11.40	6.73	Gamma, shape 3.57 and scale 3.20

5.2.3 Prepare surgery

The data does not record the duration of the prepare surgery phase separately. This duration is included in the surgery duration. Therefore, we asked the head of SDCC. She points out that the duration of this phase depends on the type of surgery and that preparation of surgeries potentially suitable for a TT-policy are between 2 and 10 minutes, with an expected duration of 6 minutes. Hence, we use a (generic) triangular distribution to model the duration of this phase.

5.2.4 Surgery

The time recorded between the end anaesthesia induction and end surgery includes the prepare surgery, surgery and sign-out phase. We determine an appropriate statistical distribution to model the duration of these phases. However, the mean and variability of this duration and subsequent parameters of the distribution are not relevant, as we vary both the mean and variability in our experiments (see Section 4.2.1 and 4.2.2).

We assume that the distribution found for the sum of the prepare surgery, surgery and sign-out phase is also valid for the surgery duration since the duration of both the prepare surgery and sign-out phase are short and well-predictable. We remove one zero duration from the data set. Figure 9 shows the resulting histogram.

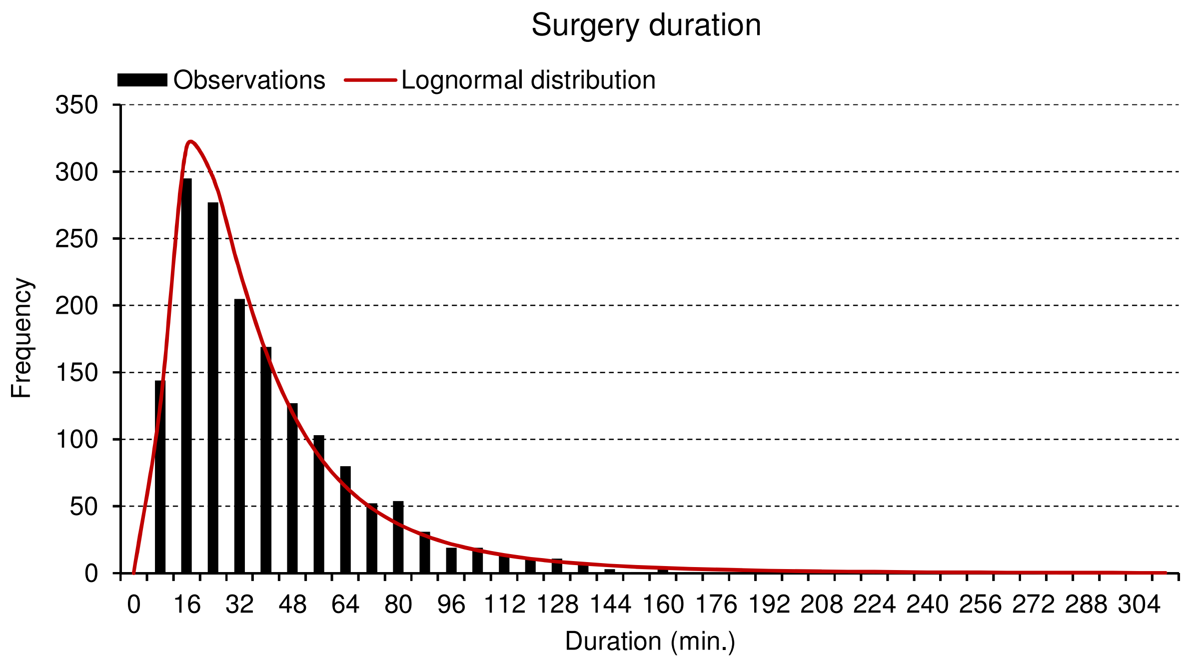

Figure 9: Histogram of the duration of the surgery phase including prepare surgery phase and sign-out procedure (N = 1631, January 6, 2014 - October 24, 2014)

We identify that the distribution is asymmetric and right-skewed. It turns out that a lognormal distribution best resembles the duration of the prepare surgery, surgery and sign-out phase. This agrees with Strum, May and Vargas (2000), who state that the lognormal distribution best models the surgery duration. A shift of the lognormal distribution results in a 3-parameter lognormal distribution, which even better describes the surgery duration according to Stepaniak, Heij, Mannaerts, De Quelerij and De Vries (2009). This shift is however highly dependent on the type of surgery. Since our research is generic we use a shift of zero. Therefore, we use the lognormal distribution to model the surgery duration. Possible complications during surgery are included by means of durations derived from the tail of the distribution.

5.2.5 Sign-out procedure

The data does not record the duration of the sign-out procedure separately (it is included in the surgery duration). We asked the head of the SDCC department for expert opinion. As a result, we use a triangular distribution with minimum duration of 0.5 minutes, maximum duration of 1.5 minutes and expected duration of 1 minute. The duration is independent of the type of surgery.

5.2.6 Anaesthetic emergence

The time between end surgery and patient leaves the OR reflects the duration of the anaesthetic emergence phase. Subsequently, we derive a statistical distribution from the data to model the duration of this phase. We remove 11 zero durations. Figure 10 shows the resulting histogram. The data shows that the duration of this phase is independent of the surgery duration.

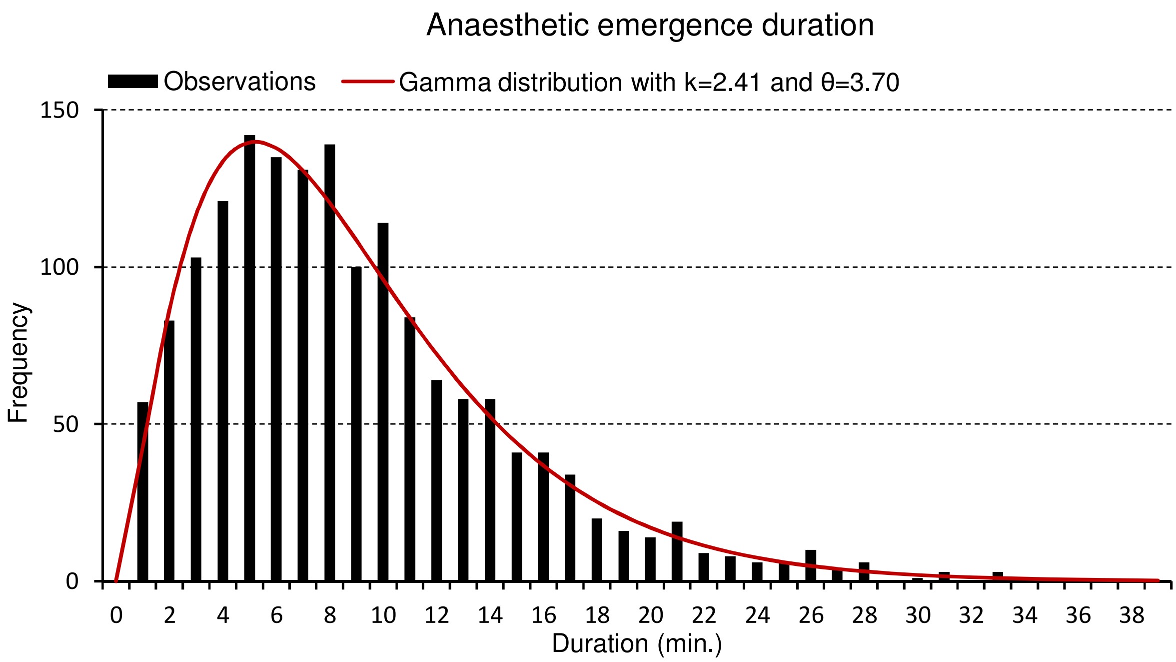

Figure 10: Histogram of the duration of the anaesthetic emergence phase (N = 1621, January 6, 2014 - October 24, 2014)

The data has a mean of 8.93 minutes and a standard deviation of 5.72 minutes. Again, no statistical distribution fits the entire data set with sufficient accuracy. However, we feel that using empirical data does not represent reality, for instance because the increase in records of 10 minutes is unnatural. Again, this is likely because of a rounded estimation after the surgery has finished. Therefore, we select a statistical distribution that best models the anaesthesia induction duration. A gamma distribution with shape parameters (k) 2.41 and scale parameter (θ) 3.70 best models the duration of the anaesthesia induction phase. We also show this distribution in Figure 10.

5.2.7 Turnover

The time a patient leaves an OR until the next patient can enter the OR represents the duration of the turnover phase. The data is however not reliable at this point. This is probably the result of breaks, surgeon unavailability, surgery cancellation, etc. Therefore, we asked the head of the SDCC department for expert opinion. She points out that the duration of the turnover depends on the type of surgery and that the turnover phase of surgeries potentially suitable for a TT-policy is between 5 and 15 minutes, with an average of 10 minutes. Hence, we use a triangular distribution to model the duration of this phase.

5.2.8 Travel time

We include time between an anaesthetist or surgeon leaves an OR until a phase where the resource is required in the opposite OR can start. This duration includes both time required to move between both ORs and safety measures possibly required. We refer to the duration of both activities as travel time. This is valid in both the TT-policy and two-table anaesthesia policy.

The time required to move between both ORs is equal among surgeons and anaesthetists. We assume a fixed 20 seconds for the travel time between two ORs (located next to each other). Recall from Section 2.2 that only the sterile team has to take safety measures before starting a surgery. Because any data of this duration is unavailable, we asked the head of the SDCC department for expert opinion. As a result, we use a triangular distribution with a minimum duration of 4 minutes, maximum duration of 8 minutes and expected duration of 6 minutes for safety measures.

In both the OT-policy and the TT/+g-policy, the sterile team take these safety measures during the prepare surgery phase. In the TT/-g-policy, on the other hand, the safety measures may result in additional time of the surgical procedure. If possible, a surgeon anticipates in reality by taking safety measures during the prepare surgery phase. We include this in our model. When the surgeon is not available during the prepare surgery phase, the surgeon moves to the OR and takes safety measures as soon as possible.

5.3 Technical design

This section presents the technical design of our simulation model. We used Flexsim Healthcare 4.3.10 software of Flexsim Software Products, Inc. to construct the simulation model. This software is particularly useful for healthcare instances due to the ease of use, animations, etc. Section 5.3.1 describes the patient creation process. Section 5.3.2 describes the patient flow through the simulation model. Section 5.3.4 describes the staff members and their characteristics in the model. Section 5.3.3 describes the operating room phases and implications in the model.

5.3.1 Patient generation

The available time in each OR is divided by the expected duration of all seven operating room phases and rounded downwards if necessary to generate patients. Section 5.4 further addresses this rule. For convenience, all patients enter the SDCC department at the start of the day to model that patients show up and do not arrive tardy. Upon creation, each patient is assigned to a patient track, i.e. the operating room phases, OR and required staff members. The model draws the duration from the statistical distribution of each phase and saves this duration in a so-called patient label (patient characteristic).

5.3.2 Patient flow

For completeness and visual purposes, we include the holding department, two operating rooms and the recovery department in our model. Since the holding and recovery department are outside the scope of this research, processing time in both departments is zero so that these processes do not impact the OR process and interfere with the actual research objective. Upon arrival, a patient goes to the holding department where two beds are located, one for each OR. If the bed corresponding to the operating room the patient is assigned to is occupied, the patient remains in the waiting room. If an OR becomes available, the patient is moved from the holding department to this OR. Now the operating room phases start. The next patient now moves from the waiting room to the available bed on the holding department. When the anaesthetic emergence phase has finished, the patient is moved to the recovery room and leaves. When the patient has left the OR, the turnover phase starts. When this phase has finished, a new patient enters the operating room until all patients are served.

5.3.3 Operating room phases

When a patient arrives in an operating room, this triggers a request for all staff members required during the time-out procedure. All required staff members move to the operating table as soon as the resource is available and the procedure starts when all required staff members are present (see Section 2.4.3). The duration of each operating room phase is obtained from the corresponding patient label. When a certain phase finishes, this triggers a requests for each staff member required during the next operating room phase.

5.3.4 Staff members

In each operating room an OR crew consisting of one perioperative nurse (representing all perioperative nurses usually present in an OR), one surgery assistant and one anaesthesia assistant is present. In addition, one or two anaesthetists are allocated, depending on the anaesthesia policy (see Section 5.6). Moreover, two surgeons are allocated, of which one is blocked in case of simulating the TT-policy. To represent reality, both the surgeon and anaesthetist remain in the OR where it has finished the last activity when the resource is not required at a certain point in time.

5.4 Assumptions

This section presents the assumptions underlying our model. We also apply the assumptions of Section 3.1. The assumptions are as follows:

1. The two ORs are located adjacently;
2. There is sufficient demand to fill each OR-day;
3. Regular OR time is from 8:00 AM to 16:00 PM;
4. To compare policies properly, equal patients are generated in each policy (equal number of patients and durations);
5. All patients arrive at the beginning of the day (no no-shows or tardy arrivals);
6. The next patient enters an OR immediately after the turnover phase has finished (i.e. no planned slack is included);
7. Each patient is allocated to a predetermined OR. For efficiency purposes, it may be necessary to reallocate one or more patients. However, only in the TT-policy a patient can be rescheduled since one surgeon, who prepared this surgery, is used here. For convenience, patients are rescheduled so that when at least two patients await surgery in a certain OR while the opposite OR is available, the patient from the waiting room is moved straight to the available OR. This policy suffices for our research aim;
8. Patients have an equal duration of each operating room phase in each policy (by using Common Random Numbers) so that differences are not due to randomness;
9. One type of surgery is performed on an OR-day (e.g. knee arthroscopies) so that surgery durations can be drawn from one statistical distribution;

10. The anaesthetist and surgeon do not visit patients on the holding or recovery department, i.e. both resources are solely required for activities in an OR;
11. A second anaesthetist is available straightaway when complications emerge simultaneously in both ORs in the two-table anaesthesia policy;
12. Requests for resources have an equal priority in each operating room phase;
13. Resources remain in an OR until presence is required in the opposite OR in the TT-policy and two-table anaesthesia policy;
14. Sufficient resources (e.g. as instrument sets) are available to complete all surgeries;
15. Sufficient bed and personnel capacity is available at the holding department;
16. Sufficient bed and personnel capacity is available at the recovery department.

Assumption 6 may result in a large patient waiting time in the TT-policy. Minimising patient waiting time is beyond the scope of this research. Further research may focus on developing a more efficient release policy.

Currently, each specialty determines the number of patients to schedule on the available OR-day(s). For convenience, we use a simple rule to determine the number of patients to schedule. This rule fills the available OR time based on the expected duration of all operating room phases. If necessary, this number is rounded downwards. For instance, the expected duration of all operating room phases for an expected surgery duration of 10 minutes is 48.22 minutes (see Section 5.2). The number of patients to schedule in each OR is then equal to 9 ($\lfloor 480/48.22 \rfloor$). We evaluate the robustness of the results with this rule in our sensitivity analysis. This rule may result in overtime or underutilisation in each policy. Creating a more reliable OR schedule in the TT-policy is outside the aim of this research and can be the centre of further research.

5.5 Verification & validation

This section describes the verification and validation process of our simulation model. The verification process is concerned with determining if a simulation program is working as intended (Law, 2007). Verifying the model has been an iterative process throughout the model construction phase. Initially, we built a simple model, which is gradually made more detailed. Each model expansion is verified towards the conceptual model by means of visual checks of the model and parameters, and debugged when necessary.

The validation process determines whether the simulation model is an accurate representation of the system, for the particular objectives of the study (Law, 2007). As we do not simulate a realistic OR schedule we cannot compare output of our model with available data. We can however validate our model on some points. First, surgery durations included in our analysis vary from 10 to 50 minutes. Figure 9 shows that these durations occur frequently at SDCC and are therefore valid. Second, variability used in our analysis also originates from the data and subsequently is valid. Third, we used expert opinion of the head of the SDCC department to validate our model assumptions and determine the duration of various operating room phases. She has confirmed the assumptions. Fourth, we validated the results of patient throughput in regular time, average time per surgery, surgeon utilisation and anaesthetist utilisation with the head of the SDCC department. Therefore, we conclude that the results are realistic.

5.6 Experimental design

This section presents the experimental design of our research. This design determines different experiments, the replication length, warm-up period and the number of replications of each experiment. Section 5.6.1 describes all experiments we conduct to achieve our research objective. Section 5.6.2 describes the replication length of each simulation replication and the warm-up period. Section 5.6.3 describes the number of replications in each experiment.

5.6.1 Experiments

This section describes the experiments we include in our research. We vary factors that potentially impact performance of the TT-policy in each policy (see Section 4.2). Each combination represents one experiment. From Section 2.4.3, we evaluate the OT-policy, TT/+g-policy and TT/-g-policy. In addition, Section 2.3.2 indicates that maximising performance of the TT-policy may require on anaesthetist in each OR. Hence, we evaluate the following policies:

1. OT-policy including guidelines with one anaesthetist (current situation, in short OT/1a-policy);
2. TT-policy including guidelines with one anaesthetist (TT/+g/1a-policy);
3. TT-policy excluding guidelines with one anaesthetist (TT/-g/1a-policy).
4. TT-policy including guidelines with one anaesthetist in each OR (TT/+g/2a-policy);
5. TT-policy excluding guidelines with one anaesthetist in each OR (TT/-g/2a-policy).

Also, using, one anaesthetist in each OR in the OT-policy (OT/2a-policy) may increase performance. We briefly compare the OT/2a-policy, which is frequently proposed in practice, with the OT/1a-policy to determine benefits. Appendix B shows the results. Excluding guidelines in the OT-policy does not provide benefits since the start time of the time-out and sign-out procedure in this policy does not depend on surgeon availability. Hence, we do not consider the OT-policy excluding guidelines. In the remainder of this section we explain the values of the test factors included in our experimental design.

<u>Expected surgery duration</u>
In Section 4.2.1 we hypothesised that the TT-policy shows best performance with surgeries up to 30 minutes. The expected surgery duration (see Section 2.2.4) impacts the ratio of surgeon cycle to OR cycle since the (expected) duration of the other operating room phases are fixed. Figure 4 shows that a ratio of 2:1 in the TT-policy results in OR crew waiting time and reduces patient throughput compared to the OT-policy. Figure 5 indicates that a ratio of 1:2 is more efficient when using a TT-policy because patient throughput is equal while requiring only one surgeon. Therefore, we include an expected surgery duration of 10 to 50 minutes, with steps of 10 minutes. In the TT/-g-policy, these durations correspond to a ratio of surgeon cycle to OR cycle of approximately 1:2 to 3:2.

<u>Variability in the duration of each operating room phase</u>
From Section 4.2.2, we vary variability in the duration of the surgery and anaesthesia phase(s). We consider both relatively high and low variability in our analysis. Variability in the anaesthesia induction and anaesthetic emergence phase is limited (e.g. CV of the anaesthetic emergence

phase is 0.55). Therefore, for these phase we include a range of the CV from 0.2 to 1.0, with steps of 0.2. The CV of the anaesthesia induction and anaesthetic emergence phase is equal in each experiment because both phases are part of the OR cycle.

To get an impression of the variability in surgery durations we examine some surgery types potentially suitable for the TT-policy. Table 4 shows the results.

Table 4: Variability in surgery durations for surgery types potentially suitable for the TT-policy (N = 1632, January 6, 2014 - October 24, 2014)

Specialty	Surgery type (# records)	Average duration (min.)	Standard deviation (min.)	CV
ENT surgery	Nose surgery (31)	20.97	15.15	0.72
ENT surgery	Ear surgery (22)	29.68	17.60	0.59
ENT surgery	Pharynx surgery (168)	15.82	11.02	0.70
Plastic surgery	Hand surgery (30)	47.31	26.03	0.55
Orthopaedic surgery	Knee surgery (22)	35.88	16.12	0.45

From the table, the CV varies from 0.45 to 0.72. We know that some surgeries show very small variability (e.g. cataract surgeries). Therefore, we include a range of the CV from 0.1 to 0.9, with steps of 0.2 for the surgery phase in our analysis.

In total, these combinations result in 625 experiments.

5.6.2 Simulation replication length

The simulation model starts at 8:00 AM and ends when the last patient leaves the recovery department. This “natural” event specifies the length of each replication. Hence, the simulation is terminating (Law, 2007) and the simulation replication length equals one business day. As we gather information during the entire day, we do not use a warm-up period.

5.6.3 Number of replications

To obtain statistical significant results, we replicate each experiment multiple times. To determine the required number of replications we use the replication/deletion approach as described by Law (2007). We use a confidence level of 95% with a relative error of 0.1%. We evaluate the number of replications with respect to patient throughput within regular time, surgeon utilisation and average time per surgery in each policy when using both highest and lowest expected surgery duration and CV. We find that 85 replications are sufficient.

5.7 Conclusion

In this chapter we have constructed our simulation study. We have created a conceptual simulation model. In addition, we have determined an appropriate statistical distribution for each operating room phase. To do so, we used data from the time registration system and if data was unavailable, we used expert opinion of the head of the SDCC department. Further, we have constructed a simulation model with Flexsim Healthcare software. We have verified and validated this model. Finally, we have developed the experimental design. We include the following five policies in our analysis:

1. OT-policy including guidelines with one anaesthetist (current situation, OT/1a-policy);
2. TT-policy including guidelines with one anaesthetist (TT/+g/1a-policy);
3. TT-policy including guidelines with two anaesthetists (TT/+g/2a-policy);
4. TT-policy excluding guidelines with one anaesthetist (TT/-g/1a-policy);
5. TT-policy excluding guidelines with two anaesthetists (TT/-g/2a-policy).

In each policy, we vary the expected surgery duration from 10 to 50 minutes with steps of 10 minutes, the CV surgery from 0.1 to 0.9 with steps of 0.2 and the CV anaesthesia from 0.2 to 1.0 also with steps of 0.2. Hence, we include 625 experiments in our analysis. To obtain statistical significant results we use 85 replications of for each experiment.

The next chapter analyses results from the simulation model.

6. Analysis of results

This chapter analyses results of our simulation model. This model includes the same patients and variability in each policy. We vary the expected surgery duration, CV surgery and CV anaesthesia and evaluate each surgery policy. Appendix C shows patient throughput, surgeon utilisation and patient waiting time in each policy for an expected surgery duration of 10, 30 and 50 minutes and CV surgery of 0.1, 0.5 and 0.9.

We treat the average result of each experiment (i.e. the average of 85 replications). We denote the results of experiments in each policy by experiment E(expected surgery duration; CV surgery; CV anaesthesia). A star (*) refers to the set of all values. Hence, E(10;*;*) refers to all results with an expected surgery duration of 10 minutes, irrespective of the CV surgery and CV anaesthesia, and E(10;0.1;*) specifies all results with an expected surgery duration of 10 minutes and CV surgery of 0.1. As an indication, Table 5 gives the notation and number of experiments for example sets of results.

Table 5: Notation and number of experiments for example sets of results

Notation	Expected surgery duration (min.)	CV surgery	CV anaesthesia	# experiments
E(*;*;*)	All	All	All	125
E(10;*;*)	10	All	All	25
E(10;0.1;*)	10	0.1	All	5
E(10;0.1;0.6)	10	0.1	0.6	1

Section 6.1, 6.2, 6.3, 6.4 and 6.5 evaluate the performance of each policy with respect to the key performance indicators we defined: patient throughput, average time per surgery, surgeon utilisation, anaesthetist utilisation and patient waiting time, respectively. Section 6.6 performs a sensitivity analysis. Section 6.7 evaluates the (overall) performance of each TT-policy and the OT/1a-policy.

6.1 Patient throughput

This section evaluates patient throughput in each policy. We have defined patient throughput as the number of patients who undergo surgery on two OR-days in regular OR time (960 minutes, see Section 3.2). Section 6.1.1 presents the results. Section 6.1.2 evaluates the sensitivity of each policy to the expected surgery duration, CV surgery and CV anaesthesia. Section 6.1.3 shows under which conditions patient throughput increases significantly compared to the OT/1a-policy. Section 6.1.4 evaluates surgeon productivity in each policy. Section 6.1.5 roughly compares the cost efficiency of each TT-policy to the OT/1a-policy. Finally, Section 6.1.6 evaluates the use of one anaesthetist in each OR in the TT/+g-policy and TT/-g-policy with respect to patient throughput.

6.1.1 Results

This section presents the results of patient throughput in each policy. Table 6 shows the results. In Section 2.4.3, we hypothesised that the guidelines, which require that the surgeon is present during the time-out and sign-out procedure, limit the benefits of the TT-policy. Table 6 clearly shows that patient throughput in the TT/+g/1a-policy and TT/+g/2a-policy is (considerably) lower than the OT/1a-policy. This is mainly caused by the (additional) surgeon dependency and the restriction that the surgeon does not switch to another patient after a time-out procedure. For an expected surgery duration of 10 minutes, patient throughput in the TT/+g/2a-policy is only slightly lower than the OT/1a-policy (approximately 10%). Hence, selecting one of both policies for surgeries of approximately 10 minutes may depend on surgeon and/or anaesthetist availability. Table 6 also indicates that the performance of the TT/+g/1a-policy and TT/+g/2a-policy compared to the OT/1a-policy decreases as the expected surgery duration increases. Hence, we conclude that both policies are not a good alternative to the OT/1a-policy with respect to patient throughput.

In Section 2.4.3, we also hypothesised that the TT-policy is most beneficial when excluding guidelines. The results confirm this expectation: patient throughput in the TT/-g/2a-policy can increase compared to the OT/1a-policy (up to 7.3%) whereas it is only slightly lower in the TT/-g/1a-policy (at least 3.3%). Since the TT/-g/1a-policy requires only one surgeon and patient throughput is only slightly lower, this policy may improve cost efficient compared to the OT/1a-policy. Section 6.1.5 further addresses cost efficiency of each policy. The TT/-g/2a-policy is comparable to the Aravind Eye Care System where the surgeon is the only dependent resource. As eye surgeries in this system have relatively short duration and small variability our results confirm the effectiveness of this system.

Table 6: Average number of patients treated on two OR-days in regular OR time (960 minutes) in each policy (min/max)

Experiment[2]	OT/1a	TT/+g/1a	TT/+g/2a	TT/-g/1a	TT/-g/2a
E(10;*;*)	16.6 *(16.1/17.4)*	12.0 *(11.9/12.2)*	15.2 *(15.0/15.4)*	15.8 *(15.2/16.3)*	17.4 *(17.1/17.8)*
E(20;*;*)	13.1 *(12.8/13.4)*	9.0 *(8.9/9.2)*	10.7 *(10.6/10.8)*	12.3 *(11.8/12.7)*	13.2 *(12.8/13.9)*
E(30;*;*)	11.4 *(11.1/11.9)*	7.5 *(7.2/7.7)*	8.6 *(8.4/8.8)*	10.5 *(9.8/11.5)*	10.9 *(10.3/11.7)*
E(40;*;*)	9.8 *(9.5/10.0)*	6.3 *(6.1/6.6)*	7.2 *(7.0/7.4)*	8.8 *(8.2/9.2)*	8.9 *(8.5/9.2)*
E(50;*;*)	9.1 *(8.9/9.2)*	5.6 *(5.4/5.8)*	6.1 *(6.0/6.4)*	7.5 *(7.2/7.6)*	7.6 *(7.4/7.7)*

6.1.2 Evaluating sensitivity of the TT-policy compared to the OT/1a-policy

This section evaluates the sensitivity of patient throughput in each policy to the expected surgery duration, CV surgery and CV anaesthesia. First, we evaluate each policy separately. Second, we compare the sensitivity of each TT-policy to the OT/1a-policy.

[2] See Table 5 for explanation of the notation.

We conduct a multiple regression analysis to determine the sensitivity of each policy. Appendix D shows the results. All policies show a good model fit with the three factors. Table 6 shows that patient throughput in each policy decreases as the expected surgery duration increases, which is intuitive since the available time is filled with less patients when the expected processing time of each patient increases. The multiple regression analysis also shows this result. In addition, the CV surgery has negligible impact on patient throughput in the OT/1a-policy, TT/+g/1a-policy and TT/+g/2a-policy, because patients cannot be ready for surgery simultaneously. The TT/-g/1a-policy and TT/-g/2a-policy, on the other hand, are slightly more sensitive to the CV surgery: patient throughput decreases as the CV surgery increases. Contrary to our expectations, the CV anaesthesia has very small impact on patient throughput in each policy (the impact is not significant in the TT/+g/2a-policy). This can be explained by the relatively short durations of both phases.

In the remainder of this section we compare the sensitivity of each TT-policy to the OT/1a-policy. Figure 11 shows the effect of an increasing expected surgery duration on patient throughput in each TT-policy compared to the OT/1a-policy. In Section 4.2.1, we hypothesised that the TT-policy shows best performance with surgeries up to 30 minutes. The figure indeed shows that each TT-policy compared to the OT/1a-policy shows best performance with surgeries up to 30 minutes. Note that patient throughput in the TT-policy decreases at most 40% while using only one surgeon, subsequently increasing surgeon productivity. Section 6.1.4 further addresses surgeon productivity.

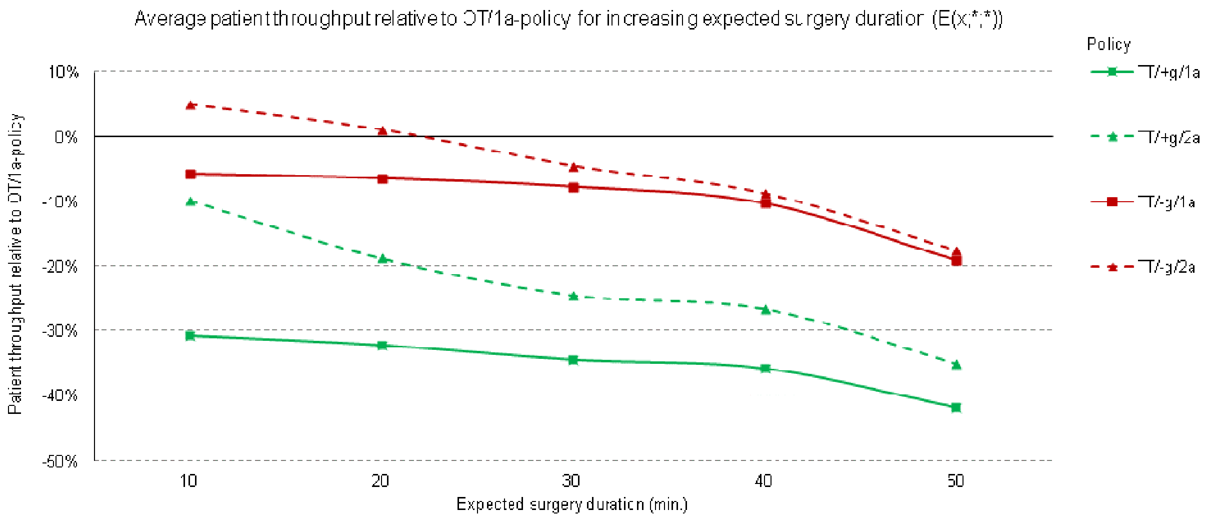

Figure 11: Effect of increasing expected surgery duration on the number of patients treated on two OR-days in regular OR time (960 minutes) in each TT-policy compared to OT/1a-policy (E(x;*;*)), for a fill rate of 1

Figure 12 shows the effect of an increasing CV surgery on patient throughput in each TT-policy compared to the OT/1a-policy. Impact of the CV surgery in each policy is small. Different than we expected, the TT/+g/1a-policy and TT/+g/2a-policy are less sensitivity to the CV surgery than the OT/1a-policy: performance increases slightly as the CV surgery increases. Note however that patient throughput decreases considerably (at least 20%) in both policies, regardless of the CV surgery. The lower sensitivity can be explained by a stable patient throughput in the TT/+g/1a-policy and TT/+g/2a-policy while patient throughput in the OT/1a-policy decreases slightly as the

CV surgery increases. Hence, the unavailability of the surgeon during the anaesthesia induction and prepare surgery phase acts like a buffer to account for variability. Performance of the TT/-g/1a-policy and TT/-g/2a-policy compared to the OT/1a-policy shows a slight decrease as the CV surgery increases. Hence, both policies show best relative performance with low variability, which confirms our hypothesis in Section 4.2.2. Future technology may result in shorter surgery durations and/or lower variability. Subsequently, the TT/-g/1a-policy as well as the TT/-g/2a-policy may be more beneficial in future situations.

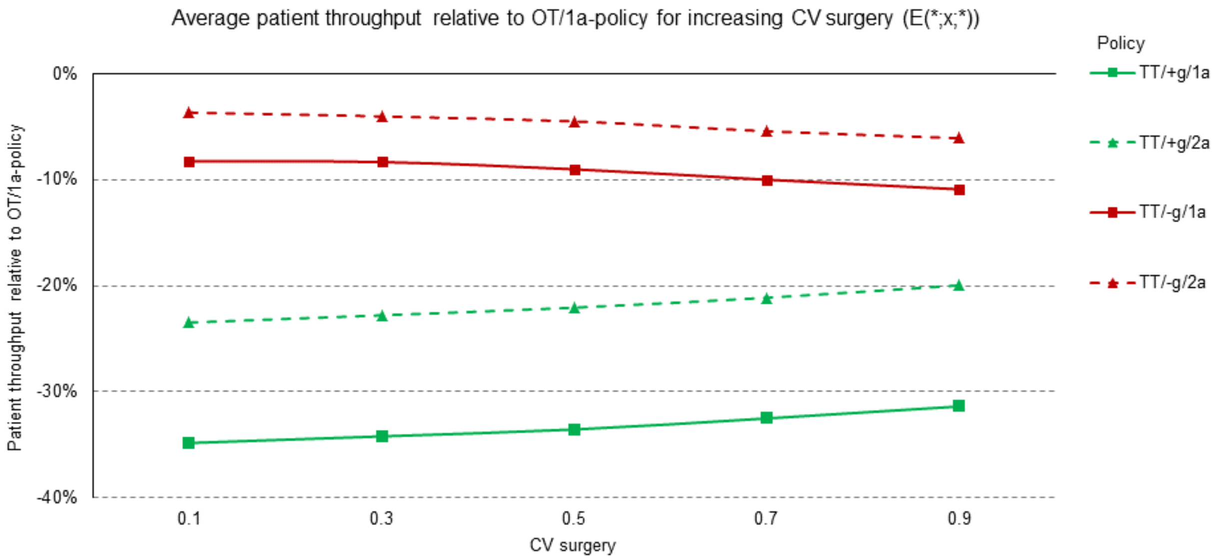

Figure 12: Effect of increasing CV surgery on the number of patients treated on two OR-days in regular OR time (960 minutes) in each TT-policy compared to OT/1a-policy (E(*;x;*))

Figure 13 shows the effect of an increasing CV anaesthesia on patient throughput in each TT-policy compared to the OT/1a-policy. The impact of the CV anaesthesia in each policy is also small. This can be explained by the relatively short duration of both anaesthesia phases. The TT/+g/1a-policy and TT/+g/2a-policy are slightly more sensitive to the CV anaesthesia than to the OT/1a-policy. This is because the unavailability of the anaesthetist during the prepare surgery, surgery and sign-out phase acts like a buffer to account for variability.

Contrary to our expectation, we conclude that both the CV surgery and CV anaesthesia hardly impact performance of the TT-policy compared to the OT-policy. This agrees with the conclusion of Hulshof et al. (2012).

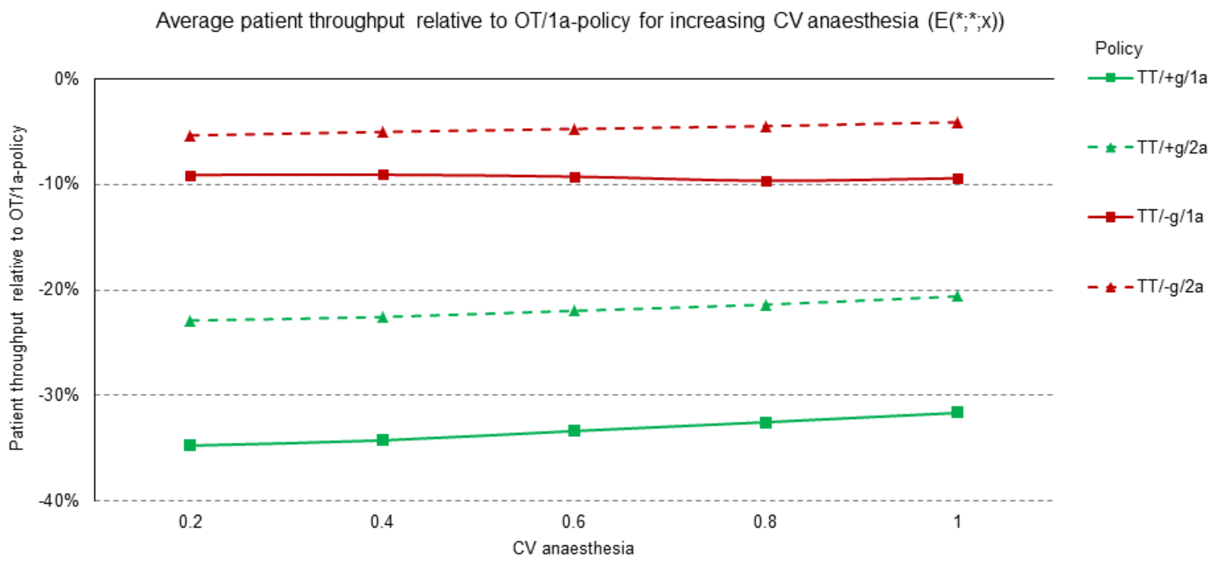

Figure 13: Effect of increasing CV anaesthesia on number of the patients treated on two OR-days in regular OR time (960 minutes) in each TT-policy compared to OT/1a-policy (E(*;*;x))

6.1.3 Significant increase in patient throughput in TT-policy

This section evaluates under which conditions patient throughput is significantly higher than the OT/1a-policy. As we expected, patient throughput in the TT-policy cannot increase when respecting the two-table anaesthesia policy because of the additional surgeon dependency. Using one anaesthetist in each OR may however result in an increasing patient throughput. Table 6 shows that patient throughput can only increase in the TT/-g/2a-policy compared to the OT/1a-policy for surgeries up to 20 minutes. Table 7 shows under which conditions patient throughput in the TT/-g/2a-policy is significantly higher. The table clearly shows that this policy shows best relative performance with surgeries up to 20 minutes with low variability.

Table 7: Condition under which the number of patients treated on two OR-days in regular OR time (960 minutes) is significantly higher in the TT/-g/2a-policy compared to the OT/1a-policy (α = 0.05)

Exp. surgery duration (min.)	CV surgery	CV anaesthesia	Average relative increase *(min/max)*
10	All	All	4.5% *(1.4%/7.3%)*
20	0.1	All	3.2% *(2.8%/3.9%)*
	0.3	All	2.3% *(1.9%/2.9%)*
	0.5	0.2, 0.6, 1.0	1.6% *(1.4%/1.7%)*

6.1.4 Surgeon productivity

This section evaluates the number of patients each surgeon treats (i.e. surgeon productivity) in the TT-policy and the OT/1a-policy. Each surgeon treats, on average, half of the patient throughput in the OT-policy. Figure 11 indicates that surgeon productivity in each TT-policy increases compared to the OT/1a-policy. Table 8 shows that surgeon productivity increases considerably when using a TT-policy. Not surprisingly, highest increase is obtained when relaxing the guidelines. Sensitivity of each policy compared to the OT/1a-policy to the expected surgery duration, CV surgery and CV anaesthesia is shown in Section 6.1.2. Hence, highest relative increase in surgeon productivity is obtained for surgeries of 10 minutes.

Table 8: Relative increase in the number of patients treated on two OR-days in regular OR time (960 minutes) in each TT-policy compared to the OT/1a-policy (E(*;*;*))

Policy	Average increase in rel. surgeon productivity *(min/max)*
TT/+g/1a	33.4% *(17.2% - 52.0%)*
TT/+g/2a	56.2% *(30.0% - 86.8%)*
TT/-g/1a	81.4% *(63.0% - 93.5%)*
TT/-g/2a	90.5% *(65.4% - 114.7%)*

The results indicate that the number of patients treated per surgeon in a TT-policy increases considerably compared to the OT/1a-policy, also under the current guidelines. Hence, the TT-policy may provide an alternative to the current situation when surgeon availability is scarce.

6.1.5 Indication cost efficiency

This section roughly evaluates the cost efficiency (i.e. average costs per surgery) of each policy. From the annual report of SDCC, the ratio of annual OR costs at SDCC to annual surgeon or anaesthetist costs (which are comparable) is approximately four. Table 9 roughly compares the average cost per surgery in regular OR time of each TT-policy to the OT/1a-policy. The table shows that the cost efficiency is unlikely to increase in the TT/+g/1a-policy and TT/+g/2a-policy. Cost efficiency may however increase slightly in the TT/-g/1a-policy and TT/-g/2a-policy for surgeries up to 40 and 20 minutes, respectively.

Table 9: Rough comparison of the average costs per surgery in regular OR time in each TT-policy to the OT/1a-policy (+ is performance increase between 5% and 20%; □ is performance between decrease up to 5% and increase up to 5%; - is decreased performance between 5% and 20%; -- is decreased performance of more than 20%)

Experiment	TT/+g/1a	TT/+g/2a	TT/-g/1a	TT/-g/2a
E(10;*;*)	-	-	+	□
E(20;*;*)	--	--	+	□
E(30;*;*)	--	--	+	□
E(40;*;*)	--	--	□	-
E(50;*;*)	--	--	□	-

Further analysis shows that cost efficiency in each policy decreases as the expected surgery duration increases, which is intuitive. In addition, cost efficiency decreases as the CV surgery and CV anaesthesia increase in the OT/1a-policy, TT/-g/1a-policy and TT/-g/2a-policy. In the TT/+g/1a-policy and TT/+g/2a-policy, cost efficiency increases as variability increases, similar to the effect on patient throughput. Hence, the TT/+g/1a-policy and TT/+g/2a-policy show best relative performance with high variability whereas the TT/-g/1a-policy and TT/-g/2a-policy show best relative performance with low variability.

When the ratio of annual OR costs to annual surgeon or anaesthetist costs decreases, the cost efficiency of the TT/+g/1a-policy and TT/-g/1a-policy compared to the OT/1a-policy increases. When the ratio increases, relative performance of the TT/+g/1a-policy and TT/-g/1a-policy decreases. Hence, both policies show best relative performance when the ratio of annual OR costs to annual surgeon or anaesthetist costs is low. The TT/+g/2a-policy and TT/-g/2a-policy use an equal amount of resources with similar costs and relative performance is therefore insensitive to the ratio of annual OR costs to annual surgeon or anaesthetist costs.

The results indicate that cost efficiency compared to the OT/1a-policy may increase in a TT-policy when relaxing the guidelines. Hence, when the surgeon is no longer required during the time-out and sign-out procedure, the TT-policy may provide an alternative to the current situation to improve cost efficiency. The cost model presented in Section 3.2 may support this statement.

6.1.6 Evaluating the use of one anaesthetist in each OR

Currently, each anaesthetist is responsible for anaesthesia in two ORs (see Section 2.2). We evaluate the use of an additional anaesthetist, i.e. one anaesthetist in each OR, to identify potential benefits with respect to patient throughput. This section compares the TT/+g/2a-policy and the TT/-g/2a-policy to the TT/+g/1a-policy and TT/-g/1a-policy, respectively. Intuitively, using one anaesthetist in each OR increases patient throughput. Table 10 indeed shows the increase in patient throughput. The table shows that highest increase in patient throughput is achieved in the TT/+g-policy, because the surgeon is always waiting for the anaesthetist in this policy. The table further shows that the CV surgery has negligible impact on the performance of an additional anaesthetist and the impact of the CV anaesthesia is small. Figure 14 shows the effect of an increasing expected surgery duration on patient throughput when using an additional anaesthetist. The figure shows that highest increase in patient throughput is achieved with surgeries of 10 minutes.

Roughly, cost efficiency in the TT/+g-policy increases slightly when using an additional anaesthetist. Cost efficiency in the TT/-g-policy, however, decreases slightly when using one anaesthetist in each OR. Hence, an additional anaesthetist may be used to improve cost efficiency in the TT/+g-policy. When other considerations (e.g. patient safety) lead to using one anaesthetist in each OR, these results show the side effect of an increasing patient throughput.

Table 10: Relative performance of the number of patients treated on two OR-days in regular OR time (960 minutes) when using an additional anaesthetist in the TT/+g-policy and TT/-g-policy (E(*;*;*))

Policy	Average rel. patient throughput *(min/max)*	Rel. performance when CV surgery increases	Rel. performance when CV anaesthesia increases
TT/+g	16.9% *(9.1% / 29.0%)*	Insensitive	Slight decrease
TT/-g	4.9% *(0.0% / 12.5%)*	Insensitive	Slight increase

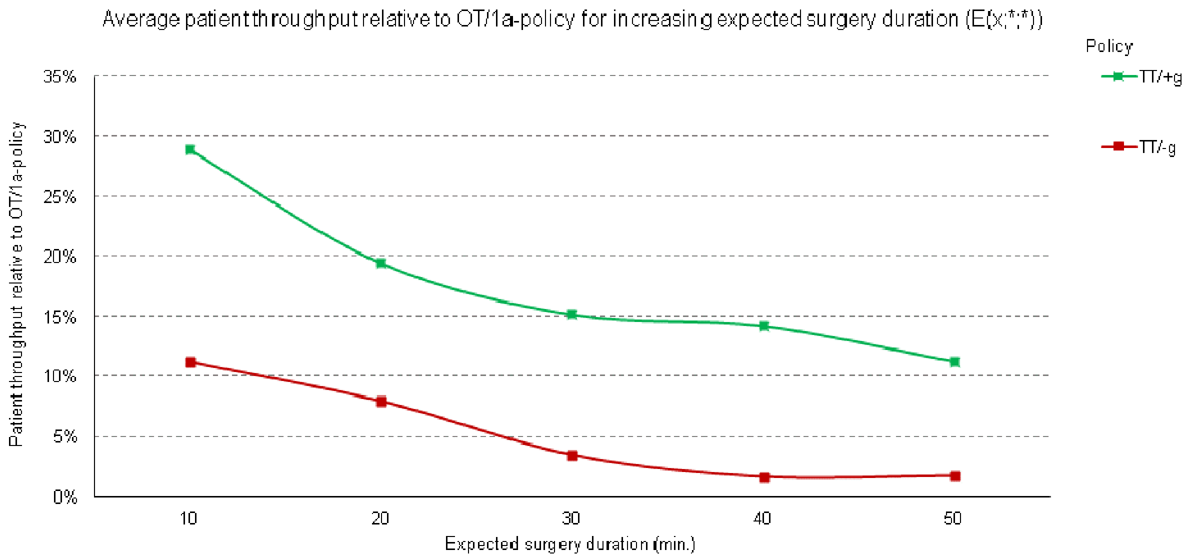

Figure 14: Effect of increasing expected surgery duration on the number of patients treated on two OR-days in regular OR time (960 minutes) when using an additional anaesthetist in the TT/+g-policy and TT/-g-policy (E(x;*;*)), for a fill rate of 1

6.2 Average time per surgery

This section evaluates the average time per surgery in each policy. We have defined average time per surgery as the total time required to finish all surgeries (including turnover) on a certain day divided by the number of surgeries, see Section 3.2. An increasing average time per surgery while patient throughput is consistent indicates an increasing amount of overtime to finish all surgeries. Table 11 shows the average time per surgery in each policy.

Table 11: Average time per surgery on two OR-days in each policy in hours (min/max)

Experiment	OT/1a	TT/+g/1a	TT/+g/2a	TT/-g/1a	TT/-g/2a
E(10;*;*)	0.93 *(0.89/0.96)*	1.26 *(1.25/1.27)*	1.01 *(1.00/1.03)*	0.97 *(0.94/1.01)*	0.88 *(0.86/0.89)*
E(20;*;*)	1.15 *(1.13/1.16)*	1.66 *(1.64/1.67)*	1.40 *(1.39/1.41)*	1.23 *(1.19/1.28)*	1.14 *(1.09/1.17)*
E(30;*;*)	1.30 *(1.28/1.32)*	1.98 *(1.95/1.99)*	1.72 *(1.70/1.73)*	1.43 *(1.31/1.53)*	1.38 *(1.30/1.44)*
E(40;*;*)	1.45 *(1.44/1.46)*	2.26 *(2.22/2.28)*	2.01 *(1.99/2.03)*	1.67 *(1.59/1.76)*	1.64 *(1.59/1.71)*
E(50;*;*)	1.61 *(1.59/1.63)*	2.57 *(2.53/2.60)*	2.32 *(2.29/2.35)*	1.95 *(1.90/2.03)*	1.93 *(1.90/1.98)*

Average time per surgery in the TT/+g/1a-policy and TT/+g/2a-policy is higher than in other policies because all operating room phases are performed consecutively. Hence, no patients can be treated simultaneously. In addition, the average time per surgery in the TT/-g/1a-policy is slightly higher and in the TT/-g/2a-policy slightly lower than the OT/1a-policy for surgeries up to 20 minutes. These results are in line with Section 6.1.1. The table also shows that the expected surgery duration impacts average time per surgery, which is intuitive. Further, from a multiple regression analysis (Appendix E) we conclude that the CV surgery and CV anaesthesia have negligible impact on the average time per surgery in the OT/1a-policy, TT/+g/1a-policy and TT/+g/2a-policy. The impact of the CV surgery is not significant in the TT/+g/1a-policy and TT/+g/2a-policy and the impact of the CV anaesthesia is not significant in the TT/+g/2a-policy The TT/-g/1a-policy and TT/-g/2a-policy, on the other hand, are more sensitive to the CV surgery: average time per surgery increases as the CV surgery increases. This is because the surgeon in this policy may not be available for a surgery right away, similar to the effect of the CV surgery to patient throughput. Both policies show best performance with surgeries up to 20 minutes with low variability.

These results are in line with Section 6.1. Hence, as the average time per surgery increases when patient throughput decreases and vice versa, we conclude that the amount of overtime possibly required is consistent when patient throughput is consistent.

6.3 Surgeon utilisation

This section evaluates surgeon utilisation in each policy. Note that utilisation only includes treating patients in an OR, see Section 3.2. In the OT/1a-policy, we consider the average utilisation rate of both surgeons. First, we evaluate the sensitivity of surgeon utilisation in each policy to the expected surgery duration, CV surgery and CV anaesthesia. Second, we compare the sensitivity of each TT-policy to the OT/1a-policy. Table 12 shows the average surgeon utilisation in each policy.

Table 12: Average surgeon utilisation in each policy (min/max)

Experiment	OT/1a	TT/+g/1a	TT/+g/2a	TT/-g/1a	TT/-g/2a
E(10;*;*)	39.5%	55.0%	68.7%	57.2%	62.9%
	(38.3%/40.9%)	*(54.5%/55.7%)*	*(66.8%/70.1%)*	*(55.0%/58.9%)*	*(61.3%/64.7%)*
E(20;*;*)	47.4%	61.6%	73.1%	72.5%	77.8%
	(46.8%/47.9%)	*(61.0%/62.5%)*	*(72.3%/73.9%)*	*(69.4%/75.5%)*	*(74.6%/81.5%)*
E(30;*;*)	55.1%	67.8%	78.2%	85.0%	87.7%
	(54.3%/56.0%)	*(67.3%/68.8%)*	*(77.6%/79.0%)*	*(79.0%/92.9%)*	*(83.2%/93.6%)*
E(40;*;*)	61.1%	72.4%	81.6%	91.1%	92.6%
	(60.2%/62.2%)	*(71.5%/73.6%)*	*(80.9%/82.7%)*	*(85.4%/96.5%)*	*(87.8%/96.8%)*
E(50;*;*)	65.3%	75.7%	84.1%	94.2%	95.2%
	(64.2%/66.4%)	*(74.9%/76.9%)*	*(83.4%/85.1%)*	*(89.4%/97.1%)*	*(91.2%/97.4%)*

Highest surgeon utilisation is achieved in the TT-policy since each surgeon is responsible for surgeries in two ORs and is therefore occupied for a larger part of time. In addition, surgeon utilisation in each policy increases as the expected surgery duration increases, which is intuitive. From a multiple regression analysis (see Appendix F) we conclude that surgeon utilisation in each policy is insensitive to the CV anaesthesia (the impact is not significant in the TT/+g/2a-policy). This can be explained by the relative short duration of both phases. Moreover, the CV surgery has negligible impact on surgeon utilisation in the OT/1a-policy, TT/+g/1a-policy and TT/+g/2a-policy. This is because the surgeon is always available for surgery right away. The TT/-g/1a-policy and TT/-g/2a-policy, on the other hand, show more sensitivity to the CV surgery: surgeon utilisation decreases as the CV surgery increases.

Now, we compare the sensitivity of each TT-policy to the OT/1a-policy. Figure 15 shows the effect of an increasing expected surgery duration on surgeon utilisation in each TT-policy compared to the OT/1a-policy. The figure shows that surgeon utilisation in the TT/+g/1a-policy and TT/+g/2a-policy decreases compared to the OT/1a-policy as the expected surgery duration increases, which agrees with Figure 11. Note however that surgeon utilisation increases considerably, regardless of the expected surgery duration. The TT/-g/1a-policy and TT/-g/2a-policy, on the other hand, show an increase in surgeon utilisation up to an expected surgery duration of 20 minutes and a slight decrease as the expected surgery duration further increases. The increasing utilisation is because patient throughput in both policies is comparable to the OT/1a-policy while the surgeon performs surgeries in two ORs. The decrease in surgeon utilisation is because relative patient throughput decreases considerably, see Figure 11. In Section 4.2.1, we hypothesised that the TT-policy shows best performance with surgeries up to 30 minutes. Figure 15 proves this claim.

Further analysis shows that the impact of the CV surgery and CV anaesthesia on surgeon utilisation in each policy compared to the OT/1a-policy shows similar patterns as the impact on patient throughput (see Figure 12 and Figure 13). Hence, the TT/+g/1a-policy and TT/+g/2a-policy show best relative performance for relatively high variability and the TT/-g/1a-policy and TT/-g/2a-policy show best relative performance with relatively low variability.

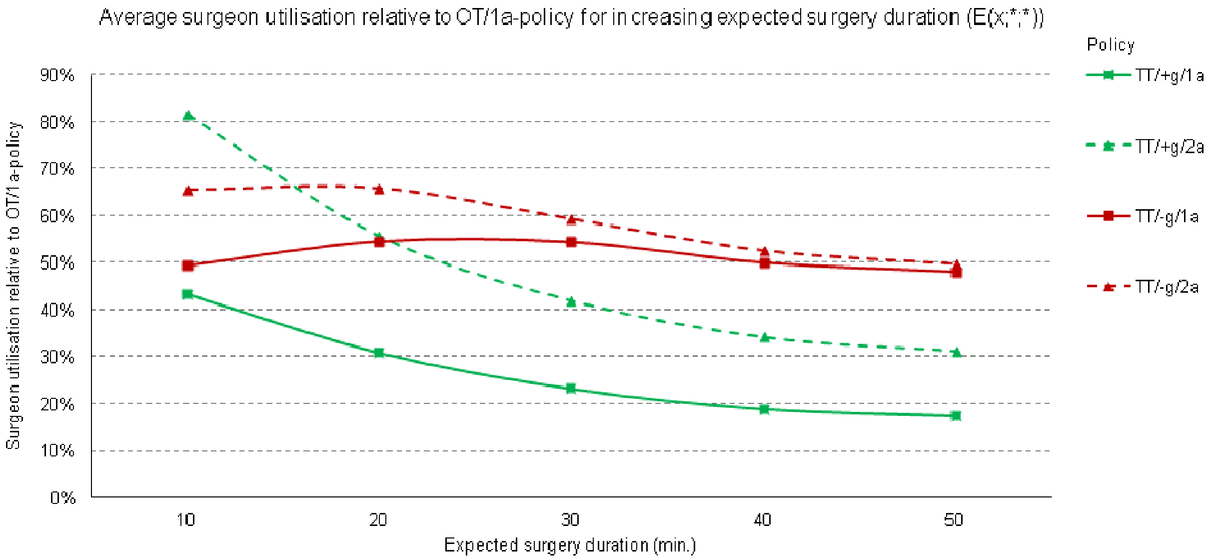

Figure 15: Effect of increasing expected surgery duration on surgeon utilisation in each policy compared to the OT/1a-policy (E(x;*;*)), for a fill rate of 1

Surgeon utilisation in practice is significantly higher since a surgeon visits patients on the recovery department, performs administrative tasks, etc. As a result, the time the surgeon is not utilised may be insufficient to perform these tasks. Hence, the TT-policy may be inappropriate to combine with these additional surgeon tasks.

6.4 Anaesthetist utilisation

This section evaluates anaesthetist utilisation in each policy. Note that utilisation only includes treating patients in an OR. In the TT/+g/2a-policy and TT/-g/2a-policy, we consider the average utilisation rate of both anaesthetists. Table 13 shows average anaesthetist utilisation in each policy.

Table 13: Average anaesthetist utilisation in each policy (min/max)

Experiment	OT/1a	TT/+g/1a	TT/+g/2a	TT/-g/1a	TT/-g/2a
E(10;*;*)	*76.1%* (72.0%/80.7%)	*55.0%* (54.3%/55.5%)	*35.0%* (34.0%/35.9%)	*72.5%* (68.7%/75.6%)	*40.4%* (39.4%/41.4%)
E(20;*;*)	*67.2%* (64.2%/69.4%)	*46.2%* (45.4%/46.8%)	*28.2%* (27.6%/28.8%)	*63.3%* (59.5%/66.1%)	*34.9%* (33.4%/36.6%)
E(30;*;*)	*58.8%* (55.4%/61.6%)	*38.7%* (37.7%/39.3%)	*23.1%* (22.4%/23.6%)	*54.3%* (49.7%/59.2%)	*29.0%* (27.4%/30.7%)
E(40;*;*)	*52.5%* (49.3%/54.6%)	*33.6%* (32.1%/34.6%)	*19.8%* (18.8%/20.6%)	*46.4%* (43.5%/48.5%)	*24.5%* (23.4%/25.3%)
E(50;*;*)	*47.2%* (44.5%/48.9%)	*29.5%* (28.1%/30.5%)	*17.2%* (16.2%/17.9%)	*39.8%* (37.8%/41.0%)	*20.9%* (19.9%/21.4%)

The table shows that anaesthetist utilisation decreases as the expected surgery duration increases, which is intuitive. The table further indicates that, for a given expected surgery duration, anaesthetist utilisation decreases when using a TT-policy because of the additional dependency of the surgeon. Moreover, using an additional anaesthetist decreases utilisation considerably. We further conclude that the average anaesthetist utilisation in the TT-policy compared to the OT/1a-policy decreases slightly as the expected surgery duration increases. Hence, from anaesthetist utilisation perspective, the TT-policy shows best performance with surgeries up to 10 minutes. From a multiple regression analysis (see Appendix G), we conclude that the CV surgery and CV anaesthesia have minor impact on anaesthetist utilisation in each policy.

Anaesthetist utilisation in practice is higher because the anaesthetist visits patients on the holding and/or recovery department, performs administrative tasks, etc. As a result, the time the anaesthetist is not utilised in the OT/1a-policy and TT/-g/1a-policy may be insufficient to perform these additional anaesthetist tasks.

6.5 Patient waiting time

This section evaluates patient waiting time in the intraoperative process in each policy. Total patient waiting time in the OR in our model does not describe reality as waiting time for the time-out procedure results from our release policy, which is arbitrary chosen (see Section 5.4). Therefore, we distinguish patient waiting time for the time-out procedure and (remaining) intra-phase patient waiting time to compare policies properly. Section 6.5.1 describes waiting time for the time-out procedure and Section 6.5.2 describes the intra-phase patient waiting time.

6.5.1 Patient waiting time resulting from release policy

This section evaluates patient waiting time resulting from our release policy. In this release policy a patient enters an OR as soon as the OR is available (i.e. immediately after the turnover phase has finished, see Section 5.4). Subsequently, a patient may incur waiting time for the time-out procedure. Table 14 shows the average patient waiting time resulting from this release policy.

Table 14: Average patient waiting time resulting from the release policy where a patients enters an OR as soon as it is available (E(*;*;*))

Policy	Average patient waiting time in minutes (min – max)
OT/1a-policy	3.5 (0.3 – 14.8)
TT/+g/1a-policy	45.7 (18.7 – 123.9)
TT/+g/2a-policy	30.6 (6.8 – 112.9)
TT/-g/1a-policy	2.5 (0.2 – 12.5)
TT/-g/2a-policy	0 (0 – 0)

Patient waiting time in the TT/+g/1a-policy and TT/+g/2a-policy is highest since the time-out procedure cannot start until the anaesthetic emergence phase and sign-out procedure in the opposite OR has finished, respectively (due to assumption 5 and 9 in Section 3.1). Patient waiting time in both policies is therefore strongly affected by the expected surgery duration. In the TT/-g/2a-policy, patients do not incur waiting time for the time-out procedure as all resources are available immediately. Concluding, especially when applying the TT/+g/1a-policy or TT/+g/2a-policy we recommend the use of a different release policy. Our release policy may be appropriate to use in the OT/1a-policy, TT/-g/1a-policy and TT/-g/2a-policy since OR crew waiting time in these policies is minimised while patient waiting time is limited.

6.5.2 Intra-phase patient waiting time

In our further analysis we exclude patient waiting time for the time-out procedure as this depends on the release policy. Hence, we consider intra-phase patient waiting time: waiting time incurred between the time-out procedure and anaesthetic emergence phase (i.e. intraoperative patient waiting time – patient waiting time due to release policy). Table 15 shows the average intra-phase patient waiting time in each policy.

Table 15: Average intra-phase patient waiting time in each policy in minutes (min/max)

Experiment	OT/1a	TT/+g/1a	TT/+g/2a	TT/-g/1a	TT/-g/2a
E(10;*;*)	2.6 (0.3/8.3)	0 (0/0)	0 (0/0)	5.4 (1.7/13.5)	3.3 (0.9/12.1)
E(20;*;*)	3.3 (0.3/13.3)	0 (0/0)	0 (0/0)	9.1 (3.9/26.5)	6.4 (0.7/25.0)
E(30;*;*)	2.7 (0.1/12.6)	0 (0/0)	0 (0/0)	11.9 (3.2/47.2)	10.9 (3.2/42.2)
E(40;*;*)	2.2 (0.1/8.9)	0 (0/0)	0 (0/0)	17.0 (4.7/64.5)	17.0 (3.4/65.6)
E(50;*;*)	2.0 (0.1/9.1)	0 (0/0)	0 (0/0)	23.9 (6.0/86.0)	24.3 (4.3/87.5)

Intra-phase patient waiting time in the TT/+g/1a-policy and TT/+g/2a-policy is zero because all recourses are available for each phase immediately. Average intra-phase patient waiting time is lowest in the OT/1a-policy and generally decreases when the expected surgery duration increases. This is because it is less likely that two patients require the anaesthetist, which is the only dependency, simultaneously. In addition, intra-phase patient waiting time in the TT/-g/1-policy and TT/-g/2a-policy grows exponentially for an increasing expected surgery duration. This is intuitive as the probability that a patient is ready to undergo surgery increases while the surgeon performs a surgery in the opposite OR. Both policies are also more sensitive to the CV surgery than the OT/1a-policy: intra-phase patient waiting time increases as the CV surgery increases. This is because the surgeon may not be available for a surgery right away, similar to the effect of the CV surgery to patient throughput and average time per surgery. The CV anaesthesia shows the opposite effect. Concluding, also from a patient waiting time perspective, the TT/-g/1a-policy and TT/-g/2a-policy show best performance with surgeries up to 10 minutes with low variability.

6.6 Sensitivity analysis

This section conducts a sensitivity analysis to evaluate the robustness of the results. To do so, we modify the number of patients scheduled and the probability distributions. Section 6.6.1 evaluates the sensitivity of the results when scheduling one and two patients less in each OR compared to our scheduling policy, which may be a more realistic representation of the number of patients scheduled in practice. As our model is currently generic, Section 6.6.2 evaluates the results for one particular type of surgery. Section 6.6.3 draws a conclusion.

6.6.1 Sensitivity of results when scheduling fewer patients

We filled the available OR time as much as possible based on the expected duration of the seven operating room phases of each patient (see Section 5.4). In practice, less patients may be scheduled, e.g. to prevent working in overtime or insufficient demand. Therefore, we evaluate scheduling one and two patients less in each OR (i.e. 8 and 7 patients in each OR for an expected surgery duration of 10 minutes, respectively). We conclude that when scheduling fewer patients patient throughput in each TT-policy shifts towards the OT/1a-policy because OR time is not used. Average patient throughput in the TT/+g/1a-policy is, on average, approximately 10% lower than the OT/1a-policy. Since this policy uses only one surgeon, cost efficiency may improve. In addition, patient throughput in the TT/-g/1a-policy and TT/-g/2a-policy is similar to the OT/1a-policy. Moreover, each TT-policy compared to the OT/1a-policy is less sensitive to the expected surgery duration. Sensitivity of each policy to the CV surgery and CV anaesthesia is similar. Results of the average time per surgery, surgeon utilisation, anaesthetist utilisation and patient waiting time are very similar. Hence, performance of the TT-policies relative to the OT/1a-policy increases when the available OR time is only partially filled. Cost efficiency may improve in the TT/+g/1a-policy, TT/-g/1a-policy and TT/-g/2a-policy. Therefore, when a specialty has two OR-days available while the OR time is only partially filled, the TT-policy may improve operating room performance.

6.6.2 Sensitivity of results when using one particular type of surgery

Our simulation model is generic as the probability distributions of the prepare surgery and surgery phase are independent of the surgery type. To evaluate the robustness of the results for surgery types in practice we use distributions from a surgery type potentially suitable in a TT-policy. We select arthroscopic knee surgeries, which is currently applied in a TT-policy in hospital ‘Refaja Ziekenhuis’ (see Section 4.1.2). From the data we obtain that the average surgery duration is 29 minutes and CV surgery 0.49. The duration can best be modelled as a 3-parameter lognormal distribution with threshold of 2.71, location of 3.37 and scale of 0.48. We used expert opinion from the head of the SDCC to model the duration of the prepare surgery phase: a triangular distribution with a minimum duration of 4 minutes, maximum duration of 7 minutes and expected duration of 5.5 minutes. The results are very similar. Patient throughput in each policy is slightly lower and average time per surgery slightly higher. Due to the shorter prepare surgery phase, surgeon utilisation increases slightly. The results suggest that different statistical distributions have small impact and the results are useful for specific types of surgeries. Further research should be used to determine whether the results are insensitive of different distributions.

6.6.3 Conclusion sensitivity analysis

We conclude that the results from our (generic) model are valid for specific types of surgeries, also when using (slightly) different statistical distributions. The number of patients scheduled, on the other hand, impacts patient throughput in each policy. When scheduling fewer patients than our scheduling policy (which may be common in practice, see Section 5.4), relative difference in patient throughput of each TT-policy to the OT/1a-policy decreases. Hence, when the available OR time is only partially filled, the TT/+g/1a-policy may provide an alternative to improve cost efficiency. When the objective is to maximise the increase in patient throughput in regular OR time, the TT/-g/2a-policy and filling the available OR time based on the expected duration of the seven operating room phases provides a good solution.

6.7 Evaluating overall performance of each TT-policy and the OT/1a-policy

This section evaluates the overall performance of each TT-policy and the OT/1a-policy. Table 16 shows the average performance of each TT-policy compared to the OT/1a-policy.

Surgeon productivity in the TT-policy increases considerably compared to the OT/1a-policy (on average, 33.4% and 56.2% in the TT/+g/1a-policy and TT/+g/2a-policy). As a result, surgeon utilisation also increases significantly (on average, 25.3% and 46.4%, respectively). Moreover, intra-phase patient waiting time decreases to 0 in both policies. Both policies show best relative performance with surgeries up to 20 minutes and high variability. The high variability is contrary to our expectation but is because the OT-policy is more sensitive to variability than the TT-policy. Hence, the unavailability of the surgeon between the time-out procedure and surgery phase acts like a buffer to account for variability. We hypothesised that current guidelines, which require that the surgeon is present during the time-out and sign-out procedure, restrict patient throughput in the TT-policy. The results indeed show that the OT/1a-policy is superior to the TT/+g/1a-policy and TT/+g/2a-policy with respect to patient throughput (decrease of at least 24.0% and 6.6%, respectively). Both policies are also unlikely to improve costs efficiency. Concluding, the TT-policy improves surgeon productivity and intra-phase patient waiting time significantly compared to the OT/1a-policy. Hence, the TT-policy can be used to improve operating room performance when surgeon availability is scarce.

We also hypothesised that the TT-policy offers most potential when relaxing the requirement that the surgeon is present during the time-out and sign-out procedure. The results indeed show that the TT-policy has an increased or similar patient throughput compared to the OT/1a-policy. Patient throughput is slightly lower (at least 3.3%) in the TT/-g/1a-policy and can increase up to

7.3% in the TT/-g/2a-policy. As both policies require only one surgeon, cost efficiency may improve for surgeries up to 30 and 20 minutes, respectively. The cost model presented in Section 3.2 can support this statement. Also, surgeon productivity increases with, on average, 81.4% and 90.5% in the TT/-g/1a-policy and TT/-g/2a-policy and average surgeon utilisation increases 49.0% and 55.9%, respectively. Both policies show best relative performance with surgeries up to 20 minutes and low variability. Subsequently, the TT-policy can improve operating room performance compared to the OT/1a-policy when relaxing requirements that the surgeon is present during the time-out and sign-out procedure. Highest increase is achieved with surgeries of 10 minutes and low variability. The results also show that the guidelines restrict patient throughput in the TT-policy.

In Section 4.2, we hypothesised that the expected surgery duration and variability impact performance of the TT-policy. The results show that expected surgery duration has most impact. Performance of the TT-policy compared to the OT/1a-policy decreases as the expected surgery duration increases, which confirms our hypothesis that the TT-policy shows best performance with surgeries up to 20 minutes. The TT/+g/1a-policy and TT/+g/2a-policy are slightly less sensitivity to the CV surgery than the OT/1a-policy but patient throughput in both policies decreases considerably. The TT/-g/1a-policy and TT/-g/2a-policy, on the other hand, are slightly more sensitive to the CV surgery, which corresponds to our hypothesis that the TT-policy shows best performance with relatively low variability. Contrary to our expectations, the CV anaesthesia has minor impact on the performance of each policy. This can be explained by the relative short duration of both phases.

We conclude that the choice for a policy involves a trade-off between surgeon utilisation and anaesthetist utilisation. The results indicate that one surgeon in each OR is preferable with relatively long surgeries whereas one anaesthetist in each OR is favourable with relatively short surgeries. This trade-off may be used to determine the optimal operating room policy for both the surgeon and anaesthetist. The choice for a policy may further depend on the (un)availability of each resource, profit per surgery, capability of OR staff and patients, and available OR time.

Table 16: Average performance of each TT-policy compared to the OT/1a-policy (++ is increased performance of more than 20%; + is increased performance between 5% and 20%; □ is performance between decrease up to 5% and increase up to 5%; - is decreased performance between 5% and 20%; -- is decreased performance of more than 20%)

		TT/+g/1a-policy	TT/+g/2a-policy	TT/-g/1a-policy	TT/-g/2a-policy
E(10;*;*)[3]	Patient throughput	--	-	-	□
	Surgeon productivity	++	++	++	++
	Cost efficiency (indication)	-	-	+	□
	Surgeon utilisation	++	++	++	++
	Intra-phase patient waiting time	++	++	--	--
E(20;*;*)	Patient throughput	--	-	-	□
	Surgeon productivity	++	++	++	++
	Cost efficiency (indication)	--	--	+	□
	Surgeon utilisation	++	++	++	++
	Intra-phase patient waiting time	++	++	--	--
E(30;*;*)	Patient throughput	--	--	-	□
	Surgeon productivity	++	++	++	++
	Cost efficiency (indication)	--	--	+	□
	Surgeon utilisation	++	++	++	++
	Intra-phase patient waiting time	++	++	--	--
E(40;*;*)	Patient throughput	--	-	-	-
	Surgeon productivity	++	++	++	++
	Cost efficiency (indication)	--	--	□	-
	Surgeon utilisation	++	++	++	++
	Intra-phase patient waiting time	++	++	--	--
E(50;*;*)	Patient throughput	--	--	-	-
	Surgeon productivity	++	++	++	++
	Cost efficiency (indication)	--	--	□	-
	Surgeon utilisation	++	++	++	++
	Intra-phase patient waiting time	++	++	--	--

[3] See Table 5 for explanation of the notation.

7. Implementing the TT-policy

This chapter describes practical issues related to the implementation of the TT-policy. Section 7.1 describes issues in the organisation of the TT-policy. Section 7.2 describes issues related to OR staff. Section 7.3 describes resources that may restrict the use of this policy.

7.1 Organisation

This section describes important implementation issues with respect to the organisation of the TT-policy. First, from an efficiency perspective, using one type of surgery (e.g. arthroscopic knee surgeries) offers most benefits. Performing identical or very similar surgeries increases the quality and speed, and reduces the probability of making mistakes. Also, one type of surgery can lead to surgeon specialisation. As a result, the expected surgery duration and variability may decrease, subsequently achieving even better results. Including different types of surgeries, on the other hand, may require adapting the operating table, subsequently losing productive time. Obviously, feasibility on this point depends on patient demand. In addition, the TT-policy is most appropriate for surgeries of one specialty that require only one surgeon. Including surgeries that require two or more specialties (and/or surgeons) induces an addition dependency, subsequently decreasing efficiency.

Second, the results show that the TT-policy shows best performance with surgeries up to 20 minutes with low variability. This policy is therefore most useful with outpatient or day care patients. Selection of patients can also contribute to the predictability of the surgical procedure. Healthy patients (ASA classification 1 and 2) offer most predictable surgeries. In addition, excluding children, disabled patients or (drug) addicts from the TT-policy programme may further increase the predictability of surgeries. Since most predictable surgeries are used in the TT-policy, surgeries with higher variability are performed on one or more different OR-days. Hence, operating room performance on these OR-days may decrease.

Third, the order of surgeries is an important organisational issue. Most reasonable is a pre-determined order of patients or a pre-determined order in each OR. The former requires more flexibility as the next patient in an OR may be unknown until the OR is available and the latter may increase the probability of making mistakes because the order of patients can change. Further research can focus on the optimal order of surgeries.

Fourth, the surgeon is (also) a dependent resource in the TT-policy. The first patient in OR 2 can only undergo surgery when surgery of the first patient in OR 1 has finished. Therefore, to minimise OR staff waiting time, it may be more efficient to shift opening hours of OR 2 to e.g. 8:30 AM to 4:30 PM.

Fifth, the time patients are admitted to an OR (i.e. release policy) affects performance of the TT-policy. This time can depend on the availability of staff members for the time-out procedure, be determined by a pre-determined schedule or as soon as the OR is available. The first option can reduce patient and OR staff waiting time but requires close communication (see point five in Section 7.2). The second option may result in OR staff waiting time. The third option can induce significant patient waiting time (see Section 6.5.2). Further research can determine the optimal release policy.

Sixth, a briefing at the start of each day can instruct all OR staff members. In this briefing, staff members can discuss the surgery schedule, and order and details of patients. This time can also be used to prepare materials, instrument sets, etc.

7.2 OR staff

This section describes important implementation issues with respect to OR staff in the TT-policy. First, the surgeon plays a key role in this policy. To apply the TT-policy successfully, the surgeon should have a lot of experience with the type(s) of surgery and have a focus for efficiency. This also applies to the anaesthetist(s).

Second, surgery assistants also play an important role in the TT-policy. Each surgery assistant should be able to perform the prepare surgery phase independently, i.e. without the aid of the surgeon. In addition, the time the surgeon is required is further minimised when the surgery assistant (or a perioperative nurse) performs “opening” and “closing”. Therefore, surgery assistants are preferably Physician Assistants (PA). Alternatively, surgeons in training can be used in this policy but training these surgeons during the programme limits the efficiency.

Third, the surgeon and anaesthetist preferably use the same ORs when both use a two-table policy. Applying the two-table anaesthesia policy with one OR included and one OR excluded from the TT-policy would induce an additional dependency.

Fourth, to enhance efficiency in the TT-policy, staff members with an efficiency driven attitude (so-called factory focus) can be selected. Forming dedicated teams can increase efficiency and create an effective co-operation and learning curve. As an example of an efficiency drive attitude, the surgeon preferably performs administrative handlings after the surgery programme (instead of current practice where the surgeon performs these activities immediately after each surgery).

Fifth, close communication between both ORs is important in the TT-policy to determine when each operating room phase can start and resources are required. Also, when “opening” is performed by a staff member different than the surgeon, communication is required about the expected time the surgeon is available in the OR to determine when to start this activity.

7.3 Restrictive resources

This section describes resources that can restrict the use of the TT-policy. First, performing identical or very similar surgeries requires multiple instrument sets. When the current number of instrument sets are insufficient (e.g. only two sets are available for arthroscopic surgeries at SDCC), more sets may be purchased. Also, adapting the cycle time or capacity of the cleaning department may achieve this objective.

Second, the capacity of the recovery department can restrict the number of patients that can be treated. No patients may be admitted to an OR when all beds at the recovery department are occupied, subsequently resulting in unused OR time. In addition, the number of patients that visit the recovery department when using the TT-policy may increase compared to the current situation. Hence, to apply the TT-policy efficiently, the recovery department should have sufficient capacity to admit patients as soon as requested.

Third, capacity of the holding department can also restrict the number of patients that can be treated. In general, the TT-policy leads to a spread of patients at the holding department compared to the OT-policy. However, when patient throughput increases, capacity may be insufficient. Insufficient capacity at the holding department can result in unused OR time when an OR (and crew) is available while no patient is prepared to enter the OR. Hence, to apply the TT-policy efficiently, patient should be prepared at the holding department before an OR is available.

Capacity of departments outside the OR department can also restrict the number of patients that can be treated, e.g. an outpatient department for pre-surgery consultation can restrict the number of patients that can be scheduled. We do not address these departments separately. Further research may determine the impact of the TT-policy on the healthcare chain.

8. Conclusions and recommendations

This chapter presents the conclusions of our research. Section 8.1 draws conclusions, Section 8.2 describes recommendations and Section 8.3 discusses the results.

8.1 Conclusions

In this thesis we evaluated the TT-policy and OT/1a-policy (current situation). The TT-policy may improve operating room performance by using surgeon capacity more effectively. We defined our research objective as follows:

The aim of this research is to determine conditions under which it is more efficient to apply the TT-policy rather than the OT-policy.

We have used simulation modelling to evaluate both policies. Our main performance indicators are patient throughput, surgeon productivity and surgeon utilisation. We also roughly indicate the cost efficiency of both policies. To determine appropriate conditions, we vary the expected surgery duration, and variability in surgery and anaesthesia duration (measured by CV surgery and CV anaesthesia, respectively). We have evaluated surgeries up to 50 minutes because experience of hospitals 'Refaja ziekenhuis' and 'ZGT' shows that the TT-policy may be particularly useful with surgeries up to 30 minutes.

The TT/+g/1a-policy results in an increase in surgeon productivity between 17.2% and 52.0% compared to the OT-policy. The TT/+g/1a-policy shows best relative performance with surgeries up to 20 minutes and high variability. The high variability is contrary to our expectation but is because the OT-policy is more sensitive to variability than the TT-policy. Due to the increasing surgeon productivity, surgeon utilisation also increases significantly and intra-phase patient waiting time is zero. Patient throughput, on the other hand, is considerably lower than the OT/1a-policy (at least 24.0%). This is caused by the additional surgeon dependency and guidelines, which require that the surgeon is present during the time-out and sign-out procedure. For patient safety, we assume that the surgeon will not switch to another patient after a time-out procedure in the TT-policy, although he is not required between the time-out procedure and surgery phase. The allocation of one anaesthetist to each OR (TT/+g/2a-policy) further increases surgeon productivity and surgeon utilisation. The OT/1a-policy is however superior with respect to patient throughput. Cost efficiency in the TT/+g/1a-policy and the TT/+g/2a-policy decreases significantly compared to the OT/1a-policy. Concluding, surgeon productivity increases considerably in the TT-policy. This policy can therefore be used when surgeon availability is scarce.

We also evaluated the TT-policy when relaxing the requirement that the surgeon is present during the time-out and sign-out procedure (TT/-g/1-policy). In this policy, surgeon productivity increases between 63.0% and 93.5% compared to the OT/1a-policy. As a result, surgeon utilisation also increases considerably. Patient throughput in the TT/-g/1a-policy is only slightly lower (on average, 9.3%) but cost efficiency in this policy may improve with surgeries up to 40 minutes. The TT/-g/1a-policy shows best relative performance with surgeries up to 20 minutes and low variability. Allocating one anaesthetist to each OR (TT/-g/2a-policy) further increases surgeon productivity and surgeon utilisation. In addition, patient throughput in the TT/-g/2a-policy can increase up to 7.3% compared to the OT/1a-policy with surgeries up to 20 minutes and low variability. Intra-phase patient waiting time can increase considerably, especially with surgeries of more than 30 minutes. Concluding, the TT-policy can improve operating room performance compared to the OT/1a-policy when the surgeon is not required during the time-out and sign-out procedure. Table 17 summarises the results of each TT-policy compared to the OT/1a-policy.

Table 17: Results of each TT-policy compared to the OT/1a-policy (min/max, - indicates increased performance)

Performance indicator	TT/+g/1a	TT/+g/2a	TT/-g/1a	TT/-g/2a
Surgeon productivity	+17.2%/+52.0%	+30.0%/+86.8%	+63.0%/+93.5%	+65.4%/+114.7%
Surgeon utilisation	+15.0%/+44.5%	+27.7%/+74.8%	+38.4%/+65.9%	+41.2%/+70.0%
Patient throughput	-24.0%/-41.4%	-6.6%/-35.0%	-3.3%/-18.5%	+7.3%/-17.3%
Cost efficiency (indication)	-12.8%/-46.3%	-7.1%/-53.8%	-11.4%/+5.1%	-6.8%/+20.9%

8.2 Recommendations

From the conclusions, we recommend to use the TT/+g-policy when surgeon availability is scarce. When other resources are sufficiently available, this policy increases the number of patients that can be treated compared to the OT/1a-policy with surgeries up to 50 minutes, subsequently increasing revenues. To maximise patient throughput, one anaesthetist should be used in each OR.

We further recommend to consider alternative task allocations during the time-out and sign-out procedure so that efficiency gains of the TT-policy can be achieved while patient safety is ensured. Possibly, sufficient trained and experienced surgery assistants can perform the time-out and sign-out procedures independently. Another option may be that surgery assistants perform both procedures and the surgeon can be consulted in case of difficulties.

8.3 Discussion

This section discusses our research. First, an important note is that the TT-policy may be inappropriate to combine with scheduling the number of patients based on the expected duration of the seven operating room phases (see Section 5.4) and tasks outside an OR during an OR-day. These surgeon or anaesthetist tasks include visiting patients on the holding and/or recovery department, and performing administrative tasks. Section 6.3 and 6.4 indicate that time the surgeon and/or anaesthetist are not utilised in the OR may be inappropriate to combine with these tasks outside the OR. Possibly, a different resource can perform these tasks.

Second, in practice, a surgery assistant may perform the time-out and sign-out procedure and/or (part of the) surgery phase under supervision of a surgeon. A surgeon can supervise in one or multiple ORs. In this research we focus on general surgery policies that do not include supervision. However, results for such policies may be derived from our analysis. The simulation model we constructed can be adapted to evaluate different policies, e.g. including supervision.

Third, we evaluated the TT-policy and OT-policy for one type of surgery (e.g. arthroscopic knee surgeries). When demand for one surgery type is insufficient, multiple types may be included to fill an entire TT-policy programme. Further research should focus on the impact of including several types of surgeries in a TT-policy.

Fourth, we evaluated both policies when applying general anaesthesia. This is the only anaesthesia technique applied on a sufficiently large scale to use in a TT-policy at SDCC. Applying regional anaesthesia results in a slightly different order of the seven operating room phases. These results may therefore be (slightly) different. Further research can evaluate both policies when using regional anaesthesia.

Fifth, we created a generic model to evaluate the OT-policy and TT-policy. The results for a specific type of surgery can therefore be slightly different. To obtain proper results, the analysis should be repeated with specific statistical distributions. However, our sensitivity analysis indicates that the results may be very similar.

Sixth, the software of our simulation model is not capable of using one queue of patients for both ORs and using a fixed sequence of surgeries. Therefore, we have used one queue of patients for each OR. Thus, patients undergo surgery in a fixed sequence in each OR. In practice, patients may form one queue (see point three in Section 7.1). As both ORs are approximately equally occupied, we expect that the results are only slightly different.

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Appendix A: Search strategy

We have searched for literature about the TT-policy and in particular factors that potentially affect efficiency of this policy. To do so, we used three search engines: Scopus, Google Scholar and PubMed. In each engine we applied many varying (wide and narrow) keywords to identify related articles. In this appendix we describe our search strategy and give a summary of these keywords. We have considered literature by sorting results of our keywords on relevance. As the resulting literature was unsatisfying, we also considered results by date. We selected articles with a title or summary related to a TT-policy or similar applications aiming to improve efficiency. In particular, we tried to find literature about comparable applications in use by anaesthetists and/or dentists. Unfortunately, this resulted in very little useful literature. Further, we approached various professionals related with this policy such as surgeons, anaesthetists and OR planners. They could not refer to any (academic) literature. Forward and backward search of articles related to the policy (among Hulshof et al. (2012)) did not result in any useful literature either.

Most of the keywords we have used in each search engine are as follows:

Pubmed

- Bottleneck
- Bottleneck management
- Two table anesthesia
- Multi table anesthesia
- Flexible table anesthesia
- Flexible anesthesia
- Anesthetist two table
- Anesthetist multiple tables
- Anesthetist two operating rooms
- Anesthetist multiple operating rooms
- Surgeon multiple tables
- Surgeon two tables
- Multiple table operating room
- Two table operating room
- Two table surgery
- Multi table surgery
- Two table operating
- Multi table operating

Google Scholar

- Assembly line surgery
- Production line surgery
- Assembly line anesthesia
- Production line anesthesia
- Cost-effective surgery
- Multi chair concept
- Multi chair dentist
- Multi table surgery

- Bottleneck management production
- Movable bottleneck
- Movable bottleneck management
- Aravind Eye Care system
- Aravind model
- Aravind assembly line
- Aravind assembly surgery
- Single minute exchange of die
- Single minute exchange of die bottleneck resource
- Scarce resource
- Maximize utilisation specialized resource
- Maximize utilisation bottleneck resource
- Highly specialized resource
- Specialized resource
- Conditions optimal use movable bottleneck
- Optimal use movable bottleneck
- Conditions movable bottleneck
- Theory of Constraints bottleneck
- Theory of Constraints bottleneck management
- Parallel setup
- Parallel setup with sequence-independent setup times
- Analysis setup time reduction
- Analysis single minute exchange of die
- Formal analysis setup time reduction
- Conditions setup reduction
- Increase effective production capacity
- Increase effective working time

Scopus

- Anesthesia double table system
- Anesthesia two operating rooms
- Anesthesia multiple operating rooms
- Anesthetist two operating rooms
- Anesthetist multiple operating rooms
- Scarce resources
- Optimal use of scarce resources
- Specialized resource
- Maximum use specialized resource
- Optimize utilisation surgeon
- Maximize surgeon utilisation
- Maximize surgery time utilisation
- Maximize use surgeon's time
- Bottleneck management
- Assembly line surgery
- Production line surgery
- Scare production resource
- Movable bottleneck

- Multi chair dentist
- Two station dentist
- Dentist efficiency
- Dentist multiple stations
- Dentist multiple chairs
- Dentist parallel processing
- Parallel processing bottleneck resource
- Single minute exchange of die
- Single minute exchange of die to increase productivity

Appendix B: Evaluating the OT/2a-policy

This section briefly compares the OT/2a-policy to the OT/1a-policy. The former policy is frequently proposed in practice to improve operating room performance. Table 18 shows the results of the OT/2a-policy.

Table 18: Average results of the OT/2a-policy (min/max)

Experiment[4]	Patient throughput (960 min.)	Average time per surgery (hours)	Surgeon utilisation	Anaesthetist utilisation	Intra-phase patient waiting time
E(10;*;*)	17.8 *(17.7/18.0)*	0.82 *(0.82/0.83)*	44.2% *(43.7%/44.7%)*	43.1% *(42.4%/43.6%)*	0 *(0/0)*
E(20;*;*)	13.9 *(13.7/14.0)*	1.03 *(1.02/1.04)*	52.4% *(51.8%/53.2%)*	38.4% *(37.5%/39.1%)*	0 *(0/0)*
E(30;*;*)	11.8 *(11.5/12.0)*	1.20 *(1.19/1.21)*	59.5% *(58.8%/60.4%)*	33.2% *(32.1%/34.0%)*	0 *(0/0)*
E(40;*;*)	9.9 *(9.7/10.0)*	1.36 (1.33/1.37)	65.0% *(63.8%/66.1%)*	29.5% *(28.0%/30.6%)*	0 *(0/0)*
E(50;*;*)	9.5 *(9.2/10.0)*	1.52 *(1.50/1.53)*	68.7% *(67.6%/69.9%)*	26.3% *(24.8%/27.4%)*	0 *(0/0)*

Table 18 indicates that patient throughput in the OT/2a-policy can increase significantly compared to the OT/1a-policy (see below). This result is intuitive because all resources are available immediately. Subsequently, patient throughput is maximised and patient waiting time is zero. Also, surgeon productivity increases slightly for each surgery duration and the average time per surgery is slightly lower, which agrees with the increasing patient throughput. Moreover, as the surgeon does not have to wait for the anaesthetist, surgeon utilisation is slightly higher. Anaesthetist utilisation, on the other hand, decreases considerable due to the additional anaesthetist. Roughly, cost efficiency of the OT/2a-policy compared to the OT/1a-policy slightly decreases for each surgery duration. Hence, from a patient throughput and surgeon productivity perspective, the OT/2a-policy may provide an alternative to the OT/1a-policy. In other situations, however, this policy does not improve operating room performance. When other considerations (e.g. patient safety) lead to using one anaesthetist in each OR, these results show the side effect of an increasing patient throughput.

The OT/2a-policy compared to the OT/1a-policy generally performs best for surgeries up to 30 minutes, low CV surgery and high CV anaesthesia. Hence, an additional anaesthetist is most beneficial for surgeries up to 20 minutes with low variability. Table 18 indicates that patient throughput can increase significantly in the OT/2a-policy. Table 19 shows under which conditions patient throughput in the OT/2a-policy is significantly higher than the OT/1a-policy.

[4] See Table 5 for explanation of the notation.

Table 19: Conditions under which patient throughput in the OT/2a-policy is significantly higher than the OT/1a-policy ($\alpha = 0.05$)

Expected surgery duration (min.)	CV surgery	CV anaesthesia	Average relative increase (min/max)
10	All	All	7.3% (3.3%/10.2%)
20	All	All	5.9% (4.3%/7.5%)
30	All	All	3.7% (1.1%/5.1%)
40	0.1	0.6-1.0	0.9% (0.6%/1.2%)
	0.3-0.9	All	1.4% (0.5%/2.2%)
50	All	All	4.9% (2.7%/8.5%)

Appendix C: Results simulation study

Expected surgery duration: 10 minutes

Table 20: Average results of each policy with expected surgery duration = 10 minutes and CV surgery = 0.1 (E(10;0.1;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	16.7	39.8%	2.3
TT/+g/1a	12.0	77.6%	0.0
TT/+g/2a	15.2	84.6%	0.0
TT/-g/1a	15.8	78.8%	5.2
TT/-g/2a	17.5	81.9%	2.9

Table 21: Average results of each policy with expected surgery duration = 10 minutes and CV surgery = 0.5 (E(10;0.5;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	16.6	39.5%	2.6
TT/+g/1a	12.0	77.5%	0.0
TT/+g/2a	15.2	84.4%	0.0
TT/-g/1a	15.8	78.6%	5.2
TT/-g/2a	17.4	81.5%	3.3

Table 22: Average results of each policy with expected surgery duration = 10 minutes and CV surgery = 0.9 (E(10;0.9;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	16.6	39.2%	2.9
TT/+g/1a	12.1	77.4%	0.0
TT/+g/2a	15.1	84.0%	0.0
TT/-g/1a	15.7	78.3%	5.9
TT/-g/2a	17.2	80.9%	3.9

Expected surgery duration: 30 minutes

Table 23: Average results of each policy with expected surgery duration = 30 minutes and CV surgery = 0.1 (E(30;0.1;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	11.6	55.6%	2.5
TT/+g/1a	7.4	84.0%	0.0
TT/+g/2a	8.5	89.2%	0.0
TT/-g/1a	11.0	94.8%	8.4
TT/-g/2a	11.3	95.6%	8.0

Table 24: Average results of each policy with expected surgery duration = 30 minutes and CV surgery = 0.5 (E(30;0.5;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	11.4	55.1%	2.8
TT/+g/1a	7.5	83.9%	0.0
TT/+g/2a	8.6	89.1%	0.0
TT/-g/1a	10.5	92.7%	11.9
TT/-g/2a	10.9	94.0%	10.6

Table 25: Average results of each policy with expected surgery duration = 30 minutes and CV surgery = 0.9 (E(30;0.9;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	11.2	54.6%	2.6
TT/+g/1a	7.6	83.8%	0.0
TT/+g/2a	8.7	88.9%	0.0
TT/-g/1a	10.0	90.0%	15.5
TT/-g/2a	10.4	91.8%	14.3

Expected surgery duration: 50 minutes

Table 26: Average results of each policy with expected surgery duration = 50 minutes and CV surgery = 0.1 (E(50;0.1;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	9.1	65.8%	1.9
TT/+g/1a	5.4	88.1%	0.0
TT/+g/2a	6.0	92.2%	0.0
TT/-g/1a	7.5	98.3%	21.7
TT/-g/2a	7.7	98.6%	22.4

Table 27: Average results of each policy with expected surgery duration = 50 minutes and CV surgery = 0.5 (E(50;0.5;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	9.1	65.5%	2.0
TT/+g/1a	5.6	87.9%	0.0
TT/+g/2a	6.1	92.1%	0.0
TT/-g/1a	7.5	97.6%	22.8
TT/-g/2a	7.6	98.0%	23.4

Table 28: Average results of each policy with expected surgery duration = 50 minutes and CV surgery = 0.9 (E(50;0.9;*))

Policy	Patient throughput	Surgeon utilisation	Patient waiting time (min.)
OT/1a	8.9	64.5%	2.0
TT/+g/1a	5.7	87.6%	0.0
TT/+g/2a	6.3	91.8%	0.0
TT/-g/1a	7.3	94.9%	27.8
TT/-g/2a	7.5	95.8%	27.7

Appendix D: Results multiple regression analysis patient throughput

Summary output OT/1a-policy

Regression Statistics	
Multiple R	0,920168757
R Square	0,846710542
Adjusted R Square	0,846667244
Standard Error	1,116644298
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	73150,58306	24383,52769	19555,40579	0
Residual	10621	13243,26635	1,246894488		
Total	10624	86393,84941			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	17,98268235	0,039246419	458,1993131	0	17,90575202	18,05961269	17,90575202	18,05961269
Expected surgery duration	-0,185181176	0,000766012	-241,7472005	0	-0,186682703	-0,18367965	-0,186682703	-0,18367965
CV surgery	-0,334117647	0,038300583	-8,723565468	3,09844E-18	-0,409193967	-0,259041327	-0,409193967	-0,259041327
CV anaesthesia	-0,466588235	0,038300583	-12,18227488	6,50223E-34	-0,541664555	-0,391511916	-0,541664555	-0,391511916

Summary output TT/+g/1a-policy

Regression Statistics	
Multiple R	0,893905622
R Square	0,799067261
Adjusted R Square	0,799010506
Standard Error	1,105940518
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	51660,85407	17220,28469	14079,16142	0
Residual	10621	12990,59214	1,223104429		
Total	10624	64651,44621			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	12,51868235	0,038870216	322,0636153	0	12,44248945	12,59487526	12,44248945	12,59487526
Expected surgery duration	-0,155797647	0,000758669	-205,3565654	0	-0,15728478	-0,154310514	-0,15728478	-0,154310514
CV surgery	0,232941176	0,037933447	6,14078593	8,50514E-10	0,158584513	0,30729784	0,158584513	0,30729784
CV anaesthesia	0,202352941	0,037933447	5,334420101	9,78205E-08	0,127996278	0,276709604	0,127996278	0,276709604

Summary output TT/+g/2a-policy

Regression Statistics	
Multiple R	0,906602467
R Square	0,821928034
Adjusted R Square	0,821877736
Standard Error	1,41781551
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	98546,92899	32848,97633	16341,14164	0
Residual	10621	21350,34292	2,010200821		
Total	10624	119897,2719			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	15,94381176	0,049831609	319,9537824	0	15,84613247	16,04149105	15,84613247	16,04149105
Expected surgery duration	-0,215312941	0,000972613	-221,3756644	0	-0,217219446	-0,213406437	-0,217219446	-0,213406437
CV surgery	0,194352941	0,048630671	3,996509569	6,47177E-05	0,099027715	0,289678168	0,099027715	0,289678168
CV anaesthesia	-0,025176471	0,048630671	-0,517707656	0,604673038	-0,120501697	0,070148756	-0,120501697	0,070148756

Summary output TT/-g/1a-policy

Regression Statistics	
Multiple R	0,907340793
R Square	0,823267314
Adjusted R Square	0,823217395
Standard Error	1,32402996
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	86733,13209	28911,04403	16491,80346	0
Residual	10621	18619,20071	1,753055334		
Total	10624	105352,3328			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	17,64032941	0,046535352	379,0737328	0	17,5491114	17,73154742	17,5491114	17,73154742
Expected surgery duration	-0,201317647	0,000908277	-221,6478387	0	-0,20309804	-0,199537254	-0,20309804	-0,199537254
CV surgery	-0,690823529	0,045413853	-15,21173572	1,03494E-51	-0,77984319	-0,601803869	-0,77984319	-0,601803869
CV anaesthesia	-0,489647059	0,045413853	-10,78188762	5,77983E-27	-0,57866672	-0,400627398	-0,57866672	-0,400627398

Summary output TT/-g/2a-policy

Regression Statistics	
Multiple R	0,931260658
R Square	0,867246413
Adjusted R Square	0,867208915
Standard Error	1,325591692
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	121921,7544	40640,58482	23128,12371	0
Residual	10621	18663,1504	1,757193334		
Total	10624	140584,9048			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	19,25997647	0,046590241	413,3907856	0	19,16865087	19,35130207	19,16865087	19,35130207
Expected surgery duration	-0,239077647	0,000909348	-262,9109453	0	-0,24086014	-0,237295154	-0,24086014	-0,237295154
CV surgery	-0,695294118	0,04546742	-15,29213927	3,10119E-52	-0,78441878	-0,606169456	-0,78441878	-0,606169456
CV anaesthesia	-0,242117647	0,04546742	-5,325079968	1,02969E-07	-0,331242309	-0,152992985	-0,331242309	-0,152992985

Appendix E: Results multiple regression analysis average time per surgery

Summary output OT/1a-policy

Regression Statistics	
Multiple R	0,896471634
R Square	0,80366139
Adjusted R Square	0,803605932
Standard Error	0,115846839
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	583,4466886	194,4822295	14491,44012	0
Residual	10621	142,539026	0,01342049		
Total	10624	725,9857146			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,776325647	0,00407164	190,6665719	0	0,76834447	0,784306824	0,76834447	0,784306824
Expected surgery duration	0,016561459	7,94703E-05	208,3981539	0	0,016405682	0,016717235	0,016405682	0,016717235
CV surgery	-0,004682353	0,003973514	-1,178391009	0,238667161	-0,012471185	0,003106479	-0,012471185	0,003106479
CV anaesthesia	0,026098824	0,003973514	6,568197523	5,33092E-11	0,018309992	0,033887655	0,018309992	0,033887655

Summary output TT/+g/1a-policy

Regression Statistics	
Multiple R	0,903623874
R Square	0,816536106
Adjusted R Square	0,816484285
Standard Error	0,216608793
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2217,902049	739,300683	15756,83332	0
Residual	10621	498,3306223	0,046919369		
Total	10624	2716,232671			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	1,002874118	0,007613095	131,7301399	0	0,987951024	1,017797211	0,987951024	1,017797211
Expected surgery duration	0,032299576	0,000148592	217,3703034	0	0,032008308	0,032590845	0,032008308	0,032590845
CV surgery	-0,012228235	0,00742962	-1,645876205	0,099818837	-0,026791683	0,002335213	-0,026791683	0,002335213
CV anaesthesia	-0,031470588	0,00742962	-4,235827253	2,29632E-05	-0,046034036	-0,01690714	-0,046034036	-0,01690714

Summary output TT/+g/2a-policy

Regression Statistics	
Multiple R	0,90948363
R Square	0,827160473
Adjusted R Square	0,827111653
Standard Error	0,209377088
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2228,283383	742,7611277	16943,02135	0
Residual	10621	465,6115209	0,043838765		
Total	10624	2693,894904			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,731187059	0,007358924	99,36058851	0	0,716762188	0,745611929	0,716762188	0,745611929
Expected surgery duration	0,032381412	0,000143631	225,4478469	0	0,032099867	0,032662956	0,032099867	0,032662956
CV surgery	-0,006162353	0,007181575	-0,858078216	0,390868638	-0,020239585	0,007914879	-0,020239585	0,007914879
CV anaesthesia	-0,009072941	0,007181575	-1,263363727	0,206486225	-0,023150173	0,005004291	-0,023150173	0,005004291

Summary output TT/-g/1a-policy

Regression Statistics	
Multiple R	0,865992104
R Square	0,749942324
Adjusted R Square	0,749871693
Standard Error	0,19611456
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1225,103438	408,3678126	10617,73369	0
Residual	10621	408,4934379	0,038460921		
Total	10624	1633,596876			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,647099059	0,00689279	93,88057561	0	0,6335879	0,660610218	0,6335879	0,660610218
Expected surgery duration	0,023879388	0,000134533	177,4977392	0	0,023615677	0,024143099	0,023615677	0,024143099
CV surgery	0,114750588	0,006726674	17,05903835	2,14981E-64	0,101565047	0,127936129	0,101565047	0,127936129
CV anaesthesia	0,050670588	0,006726674	7,532784985	5,37074E-14	0,037485047	0,063856129	0,037485047	0,063856129

Summary output TT/-g/2a-policy

Regression Statistics	
Multiple R	0,885276765
R Square	0,783714951
Adjusted R Square	0,783653859
Standard Error	0,193444918
Observations	10625

ANOVA

	df	SS	MS	F	Significance F
Regression	3	1440,163148	480,0543825	12828,4973	0
Residual	10621	397,4477664	0,037420936		
Total	10624	1837,610914			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	0,559287059	0,00679896	82,26067292	0	0,545959823	0,572614295	0,545959823	0,572614295
Expected surgery duration	0,025970776	0,000132702	195,7073226	0	0,025710655	0,026230897	0,025710655	0,026230897
CV surgery	0,088795294	0,006635106	13,38264899	1,6249E-40	0,075789243	0,101801345	0,075789243	0,101801345
CV anaesthesia	0,014896471	0,006635106	2,245099124	0,02478226	0,00189042	0,027902521	0,00189042	0,027902521

Appendix F: Results multiple regression analysis surgeon utilisation

Summary output OT/1a-policy

Regression Statistics	
Multiple R	0,914773275
R Square	0,836810145
Adjusted R Square	0,836764051
Standard Error	0,040870509
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	90,97441507	30,32480502	18154,23423	0
Residual	10621	17,74130212	0,001670398		
Total	10624	108,7157172			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,350656596	0,001436466	244,1106821	0	0,347840854	0,353472337	0,347840854	0,353472337
Expected surgery duration	0,006537462	2,80369E-05	233,1731822	0	0,006482504	0,00659242	0,006482504	0,00659242
CV surgery	-0,011915388	0,001401847	-8,499778406	2,1539E-17	-0,01466327	-0,009167505	-0,01466327	-0,009167505
CV anaesthesia	-0,006381645	0,001401847	-4,552312181	5,36493E-06	-0,009129527	-0,003633762	-0,009129527	-0,003633762

Summary output TT/+g/1a-policy

Regression Statistics	
Multiple R	0,885842824
R Square	0,784717508
Adjusted R Square	0,7846567
Standard Error	0,038824657
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	58,35596992	19,45198997	12904,72591	0
Residual	10621	16,00960663	0,001507354		
Total	10624	74,36557655			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,504982858	0,001364561	370,0699515	0	0,502308064	0,507657652	0,502308064	0,507657652
Expected surgery duration	0,005233059	2,66335E-05	196,4841135	0	0,005180852	0,005285265	0,005180852	0,005285265
CV surgery	-0,007614237	0,001331675	-5,717790426	1,1083E-08	-0,010224569	-0,005003905	-0,010224569	-0,005003905
CV anaesthesia	0,011569314	0,001331675	8,687792685	4,23802E-18	0,008958982	0,014179646	0,008958982	0,014179646

Summary output TT/+g/2a-policy

Regression Statistics	
Multiple R	0,831607635
R Square	0,691571259
Adjusted R Square	0,69148414
Standard Error	0,037285406
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	33,10741347	11,03580449	7938,277001	0
Residual	10621	14,76532999	0,001390201		
Total	10624	47,87274347			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,658441368	0,001310461	502,4502279	0	0,655872619	0,661010117	0,655872619	0,661010117
Expected surgery duration	0,003941418	2,55776E-05	154,0966206	0	0,003891281	0,003991555	0,003891281	0,003991555
CV surgery	-0,01062697	0,001278879	-8,309598201	1,07726E-16	-0,013133812	-0,008120127	-0,013133812	-0,008120127
CV anaesthesia	-0,000146352	0,001278879	-0,114437483	0,908893165	-0,002653194	0,002360491	-0,002653194	0,002360491

Summary output TT/-g/1a-policy

Regression Statistics	
Multiple R	0,911396587
R Square	0,83064374
Adjusted R Square	0,830595903
Standard Error	0,060129174
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	188,3429757	62,7809919	17364,31656	0
Residual	10621	38,40041228	0,003615518		
Total	10624	226,743388			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,578485604	0,002113345	273,7298312	0	0,574343051	0,582628156	0,574343051	0,582628156
Expected surgery duration	0,009263154	4,12483E-05	224,5707216	0	0,0091823	0,009344009	0,0091823	0,009344009
CV surgery	-0,079304884	0,002062414	-38,45246244	5,5272E-303	-0,083347601	-0,075262167	-0,083347601	-0,075262167
CV anaesthesia	-0,027850133	0,002062414	-13,50365986	3,25349E-41	-0,03189285	-0,023807415	-0,03189285	-0,023807415

Summary output TT/-g/2a-policy

Regression Statistics	
Multiple R	0,904612546
R Square	0,818323859
Adjusted R Square	0,818272543
Standard Error	0,053813339
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	138,5391754	46,17972514	15946,72376	0
Residual	10621	30,75709269	0,002895875		
Total	10624	169,2962681			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,640470427	0,001891364	338,6288522	0	0,636762999	0,644177855	0,636762999	0,644177855
Expected surgery duration	0,007943532	3,69156E-05	215,1806283	0	0,00787117	0,008015893	0,00787117	0,008015893
CV surgery	-0,069847498	0,001845782	-37,84167733	4,4476E-294	-0,073465577	-0,066229419	-0,073465577	-0,066229419
CV anaesthesia	-0,018956456	0,001845782	-10,2701476	1,25213E-24	-0,022574536	-0,015338377	-0,022574536	-0,015338377

Appendix G: Results multiple regression analysis anaesthetist utilisation

Summary output OT/1a-policy

Regression Statistics	
Multiple R	0,87271552
R Square	0,76163238
Adjusted R Square	0,76156505
Standard Error	0,057906895
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	113,7952408	37,93174692	11312,07543	0
Residual	10621	35,61442696	0,003353208		
Total	10624	149,4096677			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,861342809	0,002035239	423,2145297	0	0,857353358	0,865332259	0,857353358	0,865332259
Expected surgery duration	-0,007232768	3,97238E-05	-182,0764226	0	-0,007310634	-0,007154902	-0,007310634	-0,007154902
CV surgery	-0,018296049	0,00198619	-9,211630553	3,81698E-20	-0,022189354	-0,014402745	-0,022189354	-0,014402745
CV anaesthesia	-0,0525327	0,00198619	-26,44897884	2,4042E-149	-0,056426005	-0,048639395	-0,056426005	-0,048639395

Summary output TT/+g/1a-policy

Regression Statistics	
Multiple R	0,90730865
R Square	0,823208987
Adjusted R Square	0,823159051
Standard Error	0,041792651
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	86,3803902	28,7934634	16485,1944	0
Residual	10621	18,55091104	0,001746626		
Total	10624	104,9313012			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,599819999	0,001468876	408,3530827	0	0,596940727	0,602699271	0,596940727	0,602699271
Expected surgery duration	-0,006368254	2,86695E-05	-222,1262701	0	-0,006424452	-0,006312056	-0,006424452	-0,006312056
CV surgery	0,009238988	0,001433476	6,445163555	1,20483E-10	0,006429106	0,01204887	0,006429106	0,01204887
CV anaesthesia	-0,012328162	0,001433476	-8,60018645	9,07827E-18	-0,015138043	-0,00951828	-0,015138043	-0,00951828

Summary output TT/+g/2a-policy

Regression Statistics	
Multiple R	0,896562715
R Square	0,803824702
Adjusted R Square	0,803769291
Standard Error	0,030836005
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	41,38077718	13,79359239	14506,45121	0
Residual	10621	10,09907541	0,000950859		
Total	10624	51,47985259			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,383095668	0,001083785	353,4792713	0	0,380971245	0,38522009	0,380971245	0,38522009
Expected surgery duration	-0,004404865	2,11533E-05	-208,2351252	0	-0,00444633	-0,004363401	-0,00444633	-0,004363401
CV surgery	0,005874332	0,001057666	5,554050751	2,85843E-08	0,003801108	0,007947556	0,003801108	0,007947556
CV anaesthesia	-0,011902332	0,001057666	-11,25339109	3,26016E-29	-0,013975556	-0,009829108	-0,013975556	-0,009829108

Summary output TT/-g/1a-policy

Regression Statistics	
Multiple R	0,88491146
R Square	0,783068292
Adjusted R Square	0,783007017
Standard Error	0,061826649
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	146,5525663	48,85085544	12779,70286	0
Residual	10621	40,5991392	0,003822535		
Total	10624	187,1517055			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,841151666	0,002173006	387,0913033	0	0,836892167	0,845411164	0,836892167	0,845411164
Expected surgery duration	-0,008231466	4,24127E-05	-194,0800748	0	-0,008314603	-0,008148329	-0,008314603	-0,008148329
CV surgery	-0,024479321	0,002120637	-11,54338332	1,21423E-30	-0,028636166	-0,020322476	-0,028636166	-0,020322476
CV anaesthesia	-0,0492236	0,002120637	-23,21170943	2,6401E-116	-0,053380445	-0,045066755	-0,053380445	-0,045066755

Summary output TT/-g/2a-policy

Regression Statistics	
Multiple R	0,886332374
R Square	0,785585077
Adjusted R Square	0,785524513
Standard Error	0,036588061
Observations	10625

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	52,09336547	17,36445516	12971,26614	0
Residual	10621	14,21818628	0,001338686		
Total	10624	66,31155175			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,462977918	0,001285951	360,0275171	0	0,460457212	0,465498624	0,460457212	0,465498624
Expected surgery duration	-0,004934144	2,50992E-05	-196,5856789	0	-0,004983343	-0,004884945	-0,004983343	-0,004884945
CV surgery	-0,009164235	0,00125496	-7,30241138	3,02906E-13	-0,011624192	-0,006704278	-0,011624192	-0,006704278
CV anaesthesia	-0,018381805	0,00125496	-14,64732185	4,1225E-48	-0,020841762	-0,015921848	-0,020841762	-0,015921848