IMPROVEMENT IN OPERATING THEATRE EFFICIENCY THROUGH BETTER MEASUREMENT AND SCHEDULING

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Declaration of originality

I, the undersigned hereby declare the following, that:

- This is my own unaided work unless specifically referenced as such in the text
- That no work submitted here has previously been published
- That all the information gained herein was whilst in formal employ of the university of the Witwatersrand

________________ 27.12.2012

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Abstract

An operating theatre complex at a South African private hospital investigated to understand the reasons for poor operational performance. Initial qualitative enquiry found that major issues include a lack of scheduling, planning and control by support functions, poor adherence to schedules by surgeons and interpersonal politics between the two groups. A pilot study identified poor utilisation of the assets and it was suspected that the overall efficiency of the theatre complex was poor. The complex was measured against a framework to gauge its efficiency, which was defined in terms of eight key metrics. These are the financial contribution per theatre, staff costs in excess of budget, turnover times, errors in procedure duration forecasts, tardiness, recovery delays, procedure cancellation rates and extended turnovers. Measured against these criteria, the complex recorded an overall score of 5/12. Modifications to the management strategy were made; list durations were shortened from six to four hours and as a result the number of lists increased from two to three per day. These changes were simulated in Rockwell Arena® with a data driven model. The simulated states showed significant improvement in overall theatre utilisation and efficiency, moving from a current state utilisation of 47 % to a theoretical level of 85 % whilst the efficiency score rose from 5/12 to 11/12. This change is significant and meets established international best practice benchmarks.

To Carol, my Muse and Best Friend

Acknowledgements

To all of those who gave me valuable support during this time, I want to extend my deepest thanks:

Especially I would like to extend my thanks to Ms. Bernadette Sunjka, my supervisor in this project. Her guidance, extraordinary patience and support are deeply appreciated.

Respite from the humdrum and bustle of campus life at the aptly named oasis, my spot – my very own (0,0,0,0) and the Melville Menopausal Writing Collective – without all these places spaces and frames of mind, this MSc. would never have seen the dull glow of a slither-moon lit night.

Every member of the nursing staff and the surgeons who have supported my work with enthusiasm and curiosity – your support and enthusiasm is appreciated

Support from the medical industry, both private and public, has made this project narrowly, and a revolution in the treatment of healthcare systems broadly, possible.

And finally, to my Muse, my darling wife Carol, whose support, love and challenges have driven this work to completion, and whose sleep deprived state served as the inspiration to say "there has to be a better way to deliver medicine"

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Nomenclature

CSSD	Central Sterile Supply Department
DO	Direct Observation
IE	Industrial Engineering or Industrial Engineer
List	the time assigned to a surgeon during which he may perform surgery
NVA	Non Value Adding activities
PACU	Post Anaesthesia Care Unit
PO	Participant Observation
VA	Value Adding activities
VBA	Visual Basic for Applications

Chapter 1: Introduction.

Chapter One contextualises the research, and shows its relevance. It highlights the origin of the research interest, illustrates aspects which are to be researched and states the major questions of this research.

1.1. A Personal Narrative

During 2007 I became familiar with the way in which healthcare is run in South Africa. I was particularly taken aback by the extreme workload which South African doctors experience whilst in training to become medical specialists. It was not uncommon for doctors to work 300 hours per month. Additionally, heavy workloads, shortages of staff, equipment and consumables were a day to day occurrence and morale was very low, whilst staff turnover was very high. During this time, I recognised the potential for industrial engineering techniques to improve healthcare delivery. Basic ideas such as supply chain management, the elimination of waste, appropriate scheduling and human resource management were seemingly lacking from the industry.

Industrial engineering in health systems is globally well practiced yet insubstantial in South Africa. At a symposium at the end of 2007, Prof Koot Pieterse[1] spoke about five unexplored fields in South African industrial engineering; highlighting healthcare as one of them. This inspired me to begin my academic work in this field. I believe that with good industrial engineering, the state of healthcare in South Africa as well as lives of medical professionals and patients could be improved.

[11] Nelson Mandela Metropolitan University

In selecting a project, I looked at several problems facing healthcare delivery, such as document management, flow processes in small medical practices; staff shift structures and emergency department optimisation. Ultimately I took the decision to focus on an operating theatre complex, looking in particular at the effective utilisation of this space.

This project presented me with an interesting paradoxical situation. On the one hand were the claims that surgeons lacked theatre time and needed more resources to perform their surgeries. On the other hand were observations which I made early on, that the theatres were in fact significantly underutilised. This became a great mystery to solve. There were hours missing and no one knew where they were. There was data refuting people's claims of overwork and there was a need to understand and navigate an immensely complicated political and, at times, adversarial interpersonal network.

I believe that the work presented here has fundamental value to the practicing of medicine in South Africa. I further contend that the scientific methods of industrial engineering proposed for managing theatres narrowly and healthcare broadly are the precursors for a step change in healthcare provision efficiency and quality. I believe that the cost of healthcare, private and public, can be reduced if the broad principles described in this research, and the scientific rigour with which this enquiry was conducted are adopted as basic operating principles within the industry.

1.2. Background

This research arose out of a partnership with a private healthcare provider. For reasons of confidentiality, the healthcare company as well as the hospital in question will not be identified in this report. The company allowed the researcher access to the operating theatre, but did not support the work financially or with resources.

Surgeons at the hospital felt that they lacked theatre time and the hospital was not providing sufficient resources. In response, the hospital manager requested that the theatres be investigated, looking at two principal aspects. The first aspect was to investigate whether doctors have sufficient operating time. The second aspect depended on the first. If surgeons had inadequate resources, the study was to propose a capitalisation plan to expand the resources available. If however resource utilisation was inefficient, the research was to highlight how the utilisation and, therefore, patient volumes and earnings could be improved.

1.3. Rationale for this research

This work was requested by the hospital manager and as such represents an organisational need identified by him in consultation with his corps of surgeons who feel that they have inadequate theatre time. Narrowly this is adequate Justification for conducting this research.

More broadly, this research also tries to show the usefulness of industrial engineering in the healthcare setting in South Africa by improving efficiency, earnings and agility. this may be particularly important in view of the future implementation of a National Health Insurance (NHI) scheme to South Africa.

1.4. Contextualisation of hospital operations

This section introduces an operating theatre environment to the reader who may be unfamiliar with this space. It provides understanding and context for this research.

The terms "operations" and "surgery" remain discreet in this report. "*Surgery*" means the performing of a surgical procedure on a patient, whereas "*Operation*(s)[2]" refers to the practices, behaviours, processes and systems which define a particular environment.

Surgery takes place in an "*Operating Room*" (*OR*) or an "*Operating Theatre*" (*OT*) (see Figure 1). This report will use "OT", however the norm in the USA is "OR" [1]. These rooms are equipped with an operating table; the space where an anaesthetised patient lies. The room is fitted with large lights, several high tech systems for anaesthetics, x-rays and other diagnostic tools [2]. The room is further outfitted with piped gases, notably Oxygen and Nitrous Oxide and other services such as water and vacuum (suction). Theatres, due to their high specification of fittings, consume overhead costs at roughly R 120 – R 160 per minute.

Some hospitals unnecessarily reserve one theatre for a particular speciality. Mobile equipment and a common base-level of fixtures makes theatres able to adapt and be used for multiple specialities. Several studies [3] [4] have shown that multi-purpose approaches to theatres are effective and raise utilisation. The only real constraint to implementing such a system is surgeon *preference* for a particular theatre.

Most hospitals have more than one OT, which are typically clustered together into a "*Theatre Complex*" or "*Theatre Suite*", which has three major shared facilities [2]. These facilities are

[2]This is the case, unless if used in conjunction with other words to form familiar phrases such as "operating theatre" or post-operative care" etc.

the waiting area for patients queued for surgery, a *recovery unit* – or post anaesthesia care unit (*PACU*) and a Central Sterile Supply Department or CSSD-unit which cleans and sterilizes surgical instruments and equipment.

Figure 1: Layout of a typical operating theatre [5]

A *theatre matron* is in charge of the theatre complex, scheduling resources and staff, instruments and equipment and ensuring that appropriate standards related to hygiene, infection control and professional conduct are adhered to [1].

The matron supervises a variety of levels of nurses, theatre sisters and other staff.
The most senior nurses are called “*scrub-sisters*”. Scrub-sisters are registered nurses and are required to directly assist in surgery. They are further assisted by other nurses who support the surgery function, but do not participate directly, as a scrub-sister does [2].
The *cleaning-staff* is responsible for restoring a used OT to acceptable levels of cleanliness and hygiene, to ensure suitable infection control.

A *surgeon* is a medical specialist qualified to perform surgery, which typically requires the skin to be cut. Surgery consists almost exclusively of invasive procedures. [2]

A surgeon is assisted by an *anaesthetist*. An anaesthetist is also a medical specialist, who is qualified to administer and monitor anaesthesia. *Anaesthesia* is the administration of a variety of substances which control the vital signs and induce a sedated state. This enables the surgeon to perform procedures without the patient moving around, being aware of the surgery taking place or momentarily, experiencing pain [1].

The National Health Act [6] prohibits hospitals from employing doctors[3]. This means that by law, all practising clinicians are sole traders and free agents in their own name and therefore legally liable in their personal capacities.

The following structure has been put in place to accommodate the law in South Africa: Hospitals rent out doctor's rooms to generate income. In addition they make operating rooms available for surgeons to use. This space is made available to surgeons on the basis of a regular weekly allocation.

Typically a list is six hours in duration and during this time, the theatre is at the surgeon's disposal to perform as many or as few procedures as they can or wish to perform. The hospital generates revenue by billing the patient per minute spent in the theatre. No transaction exists between the surgeon and the hospital for the use of the theatre. Therefore underutilised theatre time is a liability to the hospital, but not to the surgeon.

[3] This is an impediment to efficiency, quality and control by hospitals, and a constraint for the introduction of new systems. Critically evaluating this may have significant value.

To perform surgery, the operations of the theatre complex need to be comprehensive. The surgeon's office communicates a list of patients which are scheduled for surgery on a particular operating-day. The theatre matron enters the patient details into the schedule, which is a wall mounted sheet of paper. The patient arrives, waits in the waiting area, whilst the theatre is prepared for surgery, which includes cleaning and the laying out of instruments and equipment. The patient is "clocked in", pushed into the theatre, where the anaesthetist begins inducing[4] the patient. The surgeon scrubs [5] and performs the surgery, assisted by his scrub-sister. The surgeon "closes up", the patient is wheeled out and "clocked out". The patient is now sent to the shared recovery area. Instruments are sent for cleaning and re-sterilisation.

1.5. Key elements of this research

This report highlights aspects of a study investigating the challenges facing a private operating theatre complex. It proposes simple remedies based on industrial engineering principles which may improve the efficiency of this unit.

To assess the impact of the remedies, we need to explore the meaning of "efficiency". In this particular study, "efficiency" will be defined using a theoretical framework [7] that focuses on eight key metrics as outlined in section 2.4.

[4] Anaesthetising

[5] The act of "scrubbing" is a process during which a surgeon washes hands, arms and other exposed parts of their body. The surgeon then dons surgical gowns, gloves, a mask and a cap. Once this is done, the now-sterile surgeon enters the operating theatre. The full process of scrubbing for surgery may take as long as 10 minutes. The scrubbing rooms adjoin the theatre directly, and often act as the chief entry way into the theatre for staff. It is therefore easy to evaluate whether a surgeon is present, scrubbing, or absent and still in need of performing this relatively lengthy procedure.

To improve the operating theatre efficiency, three components will be considered, cost, time and resources. Managing these components to work in a complementary fashion enables the goal of hospital profitability.

Cost refers to the hospital's ability to earn, and its need to spend, money. Maximising earning potential and minimising spend leads to a cost optimal situation [8]. Cost management needs to be paired with time management, ensuring that of the available billable time, a maximum is revenue earning. An idle theatre is a liability [9]. "Resources" includes staff, surgical machinery, surgical instruments, consumables, information and other aspects.

Cost, time and resources may be optimised by improved scheduling [10], by ensuring that the correct patient is in the correct theatre at the correct time, together with all the resources required to start and perform the surgery on time [9]. As a consequence, the goals of this research are as follows:

1.6. Objectives

The objectives of this research are to:

- Understand the theatre complex operations
- Analyse the resource utilisation within the theatre complex.
- Evaluate the opportunities to improve the situation in the theatre complex using industrial engineering analysis and tools
- Use simulation as a low risk verification tool in the healthcare context.

1.7. Research questions

Arising out of the problematique (section 1.2) and the objectives above, the following research questions were defined.

Q1: How efficiently is the theatre complex running?

Q2: Why are there impediments to the efficient running of the theatre complex at the test site?

Q3: How can the efficiency of the theatre complex be modified using scheduling methods?

1.8. Limitations and Assumptions

Assumptions

- It is assumed that the structural and other issues experienced in the pilot site are similar to sites of equivalent size and complexity within the private sector.
- It is assumed that billing data is accurate to acceptable levels after validation and verification

Limitations

- This research will not investigate quality issues related to surgery.
- This research focuses only on scheduled "working hours" the period between 07:00 and 19:00 on weekdays, and excludes public holidays.
- This work excludes emergency surgery that takes place during excluded hours.

- This study only investigated private healthcare and public healthcare is explicitly excluded. [6]
- This study only investigated nine major theatres and one minor theatre. The catheterisation laboratories and labour theatres have been excluded.

1.9. Report Layout

The remainder of this report is structured as follows:

Chapter Two presents a literature review which aims to:

- Introduce the reader to the healthcare system in South Africa.
- Show collaborations between healthcare and industrial engineers from literature
- Explore best practice in terms of operating theatre utilisation
- Define efficiency and develop a framework to measure this in operating theatres
- Explore threats to the private healthcare industry, chiefly National Health Insurance

Chapter Three presents the reader with a description of the methodology and the method for this study.

The methodology explored includes:

- Qualitative research methods relevant to this research, including interviews and observation techniques
- Single case study research methods
- The quantitative aspects used for this research
- The usefulness and application of simulation in research in healthcare

[6] It is nevertheless believed that the results of this study may be applicable to all sectors of the healthcare industry.

The chapter goes on to outline the particular method employed by showing:

- The observations performed in the theatre
- An initial study to evaluate doctors' claims of insufficient operating time
- Data collection method
- The data processing method
- The simulation algorithm

Chapter Four presents the results and the analysis, showing:

- An understanding of the operating theatre environment, including time behaviour
- The evaluation of the current state
- The simulated future states
- The improvements that can be made
- The extent to which the operating theatre in question was operating inefficiently and ineffectively

This chapter concludes with a discussion of the results

Chapter Five is the summation of this research and presents the major findings, the recommendations for implementation and future work.

Chapter 2: Literature Review:

2. Introduction

This chapter explores the South African healthcare system, differentiating between private and public healthcare and their funding mechanisms. This shows that a financial risk exists on private operators due to poor efficiency. This chapter further investigates the contribution which industrial engineering has made in healthcare and will show the synergies created by the different needs and skill sets of engineering and medical professionals. The use of industrial engineering techniques in the healthcare sector will be justified, drawing inspiration from international precedent and the need for operational improvement in South Africa.

Operating theatre utilisation will be introduced focusing on benchmarks derived from published work. The notion of efficiency in managing operating theatres will be introduced at the hand of a model consisting of eight key performance metrics. This model will be adapted for the test site by generalising these metrics. This will be the evaluation model used to assess theatre efficiency in the remainder of this report.

2.1.1. South African healthcare system, an overview

South Africa's healthcare system is divided into two sectors, the public, government run, tax funded sector and the corporate, medical insurance funded model known as "private healthcare". A public – private split is not a particularity of South African health care, but exists in many developing and developed nations. [11]

Annual overall expenditure on medical care in South Africa is at least R 250 bn. Whilst the private medical industry accounts for less than 20 % in terms of patient numbers (see Figure 2) it accounts for 45% of medical expenditure. Thus the average per capita expenditure in private healthcare is R 13 780.49 per annum whilst the per capita expenditure in public healthcare is less than a quarter of this at R 3 278.22.

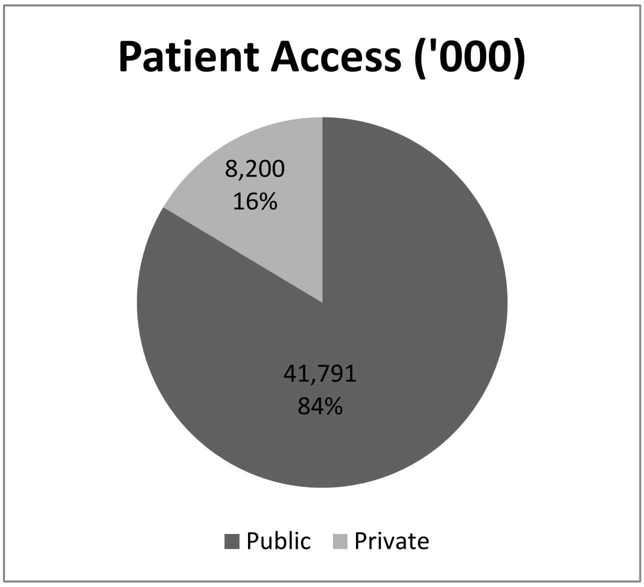

Figure 2: Patient access to modes of care [12] [13] [14] [15]

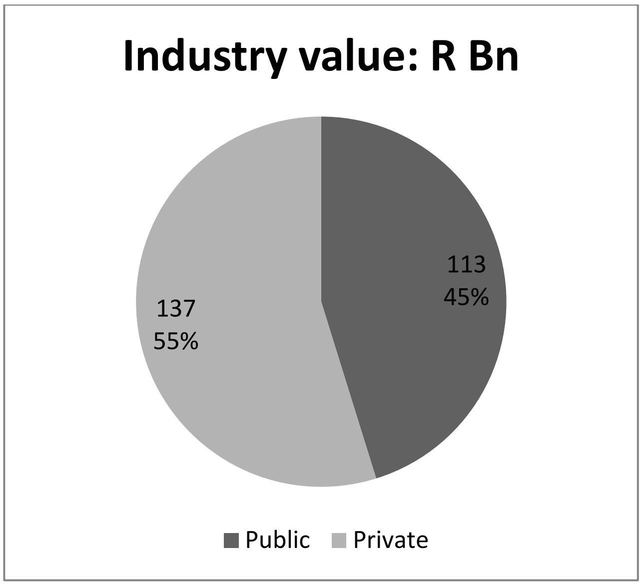

Figure 3: Industry value in billions [12] [13] [14] [15]

2.1.2. The public healthcare framework in South Africa

Government directly funds public hospitals. The constitution of South Africa [16] defines access to healthcare as a basic right. Through the National Health Act [6] the state, with the health department as its agent [6] is compelled to pay for the construction and equipping of hospitals, the maintenance of facilities, equipment and the day to day running of hospitals. The health department receives an allocation of tax revenue from the annual national budget [17]. Government via provincial health departments also pays the salaries of doctors and other staff, the procurement of services, resources and other costs associated with the running of hospitals [6]. Patients are required to pay token amounts towards their treatment, for the tariff schedule, see Appendix 1. In a personal communication between the researcher and the clinical director of a large tertiary hospital [18] it emerged that the costs associated with debt collection exceeds the amounts collected. Thus the net effect of charging for services impoverishes public hospitals[7].

Public healthcare is reliant in full on the tax funded national purse [17], to provide for its cash flows as it has no sustainable independent revenue streams. The fiscal allocation to the public health sector from the treasury for the 2011-2012 tax year was R 112.6bn [15], or 9.6% of the national budget. These funds are further distributed by the national Department of Health to provincial health departments which make the frontline disbursements.

National Health Insurance.

At the national conference of the "African National Congress" (ANC) in Polokwane, in December 2007, the party leadership agreed in principle to introduce a system of National Health Insurance (NHI) to South Africa [19]. The resolution particularly focused on strengthening the public healthcare system and resolving to make funds available for capital expansions deemed necessary [20].

Currently no clarity exists regarding cost or funding models for the NHI, however it has been suggested that full scale implementation of the NHI would be enormously costly[8], and might require the raising of taxes, either through raised personal- or sales- taxes, or both [21].

[7] Fees are charged, because it is believed that paying (token) fees for healthcare, elevates the commodity of what hospitals offer and encourages patients to take their treatment more seriously than if it were free [18].
[8] Econex [154] states that the cost of NHI, subject to various scenarios will cost between R 187 billion for a bare-bones scheme up to a comprehensive scheme at R443 Billion (which is two thirds of budgeted tax revenues (all figures in 2009 Rand)

2.1.3. <u>The private healthcare framework in South Africa</u>

By contrast with the public sector, private healthcare is a commercial, profit-driven venture. As mandated by the national health act, the health minister decrees whether or not a hospital may be operated for profit [6]. South Africa has three private hospital groups that are listed on the Johannesburg Securities Exchange (JSE) [9] [22] [23]. Together these three private hospital groups accounted for a turnover of R47.4 bn during 2010, with an aggregated profit of R4.5bn [24] [25] [26].

Private medicine funding: medical schemes

In private healthcare, the principle of Pecuniam Utilitor i.e. “the user pays”, applies. Often the user pays through a medical-aid as an intermediary. Nevertheless the aggregated funds that enter the private healthcare industry do so out of the pockets of the users.

As medical costs may be unaffordable for individuals, the medical schemes act [27] permits the establishment of so called “Medical Aids” – medical insurers that for a monthly premium act as guarantors for the medical expenses of their policy holders. The terms and conditions of the contracts of cover by these medical aids typically define the extent of cover for debts incurred by their customers. As is typical in insurance companies, schemes are designed on the basis of risk profiles however the minimum service levels are set by the minister of health, and are outlined in regulations published as an addendum to the act [28].

The rules of medical scheme are established with the intention to “make the house win”. Even though many patients will fall severely ill, and will cost the insurer in excess of their premiums, a far greater proportion of the insured will have only minor medical expenses. The

[9] Netcare Ltd. Life Healthcare and Mediclinic.

surplus from those who underspend is used to fund the medical needs of those who overspend. During 2010, the aggregated payments of premiums to all registered medical schemes in South Africa amounted to R 137 bn [14]. Currently the industry average is that 88% of risk contributions are disbursed for patient costs [14].

2.2. Industrial Engineering and Healthcare

2.2.1. Synergy between the disciplines

Medicine and Engineering are specialised disciplines, with highly educated practitioners. They work closely with risk and are potentially subject to litigation or other serious repercussions from errors. The skills that the two professions possess diverge and combining these provides opportunities for collaborative work.

Industrial engineering is a derivative discipline that integrates human aspects with the hard systems inherent to complex organisations [29]. Medicine by comparison is largely procedural, systematic and standardised [9].

Industrial engineering in healthcare has become a significant research thrust at many universities in the USA and in Europe. The American Institute of Industrial Engineering (IIE) publishes a specialist transactions journal which deals exclusively with "Healthcare Engineering". Lancet [11] [30], the world's oldest academic journal, and the preeminent journal of medicine, now publishes papers related to health systems and management, which is essentially industrial engineering.

2.2.2. Effective collaborations

Partnerships between industrial engineers and healthcare providers show the breadth of the opportunity presented by this synergy. This section presents examples of published work addressing the usefulness of simulation, the lean philosophy in healthcare, scheduling and managing queue length in hospitals.

Queue Management

Patient waiting time is a measure of patient satisfaction, but also of the quality of care, as extended waiting periods could delay treatment which may reduce efficacy [31]. Hartmann and Mandavha [32] found that simple industrial engineering techniques could reduce patient waiting time at a public hospital in South Africa from 6:48 to 3:30. This was achieved through two simple changes: a layout change (which reduced patient and doctor movement from 800 to 250 metres per case) and an improved shift structure (which aligned peak staffing levels with peak patient volumes).

A similar study in the UK, investigated patient satisfaction related to extended waiting times and mechanisms to improve both perception and reality [31]. Later research focused on patient flow in a hospital in the USA, using simulation as a proofing tool [33]. Both authors found that the use of industrial engineering techniques for queue management improved perception and reality of queuing time.

The use of simulation as a low risk proofing tool in the healthcare sector has been tested by numerous studies. Eldabi [34] states that the “convoluted nature of health care systems requires managers to use sophisticated decision support tools”, a need that is well satisfied using simulation. Simulation can be effectively used to, amongst others, forecast demand, practice pattern analysis, size facilities and set staffing levels [35].

Simulation

Recent simulation studies have looked at sizing theatre complexes using simulation techniques [36], [37]. Van Berkel [37] predicted the rate at which the time spent waiting for surgery would increase (due to growth of the patient base). Simulated growth resulted in wait time increasing from 40 days in 2003 (for elective surgery) to 140 days in 2009. A Simulated capital expansion model proposed that this is reversible by adding three hospital beds and one surgical slot per week.

Without simulation methods, the accuracy of decision making for hospitals may have been curtailed. Underestimating future demand, could have led to no, or a too small, capital expansion project. Similarly unscientific optimistic forecasts of future needs might have resulted in an excessive and costly building programme. Simulation aided in finding the right level of expansion and minimised waste [36]. Both studies identified the complexity of modelling thousands of different procedures as a constraint and opted to use undifferentiated historical data, using a statistical model to describe all procedure durations under one model. This approach is useful, however ignores the complexities inherent to the different behaviours and frequencies of distinct procedures. This study will attempt to maintain the thoroughness of differentiated procedures using data driven simulations [38].

Elimination of waste and Lean

The lean philosophy identifies “seven wastes” [39]. Reducing waste has been the focus of many research studies, and some interesting ones are presented:

An American dental practice has pioneered the use of lean principles in dentistry. Major causes of waste were identified and these were overcome [40]. The layout was rearranged to benefit from improved flow between dentistry and dental hygiene. Realising that many patients need more than one procedure and are therefore scheduled for treatment in separate sessions – focus was placed on the value adding function in dentistry. It was identified that only one of nine actions in a treatment is value adding. Gaining maximal value therefore meant minimising the others. This was achieved by performing multiple treatments in one appointment. Unnecessary ring-fencing of dental-hygiene and dentistry was stopped raising the usefulness of previously dedicated and often duplicated resources such as cubicles and dental instruments [40].

As a result of implemented lean principles, this practice increased the number of available hours per week by 82 % and reduced the time per patient for completed treatment from 99 days to 38 days. The practice was able to reduce the number of hygienists from three to two, and the number of assistants decreased from five to four[10], whilst the number of dentists remained unchanged at three. The number of cubicles required was also reduced from ten to six, which translated into a smaller footprint and consequently savings in rental [40].

Kim [41] identifies further examples of the beneficial effect of striving for waste reduction. He mentions work performed in Montana, where lean principles assisted in reducing the time taken to return laboratory results from five days to two days and where the removal of unnecessary steps led to treatment delay being reduced from four hours to twelve minutes. He also mentions work performed in Minnesota, where radiology capacity was increased by

[10] Bahri [40] makes the point that neither was dismissed, but that staff who resigned over the course of the improvements were not replaced.

three scans per day and where ten more cancer patients could be treated per day through improved scheduling.

Scheduling

Scheduling staff allows an organisation to reduce operating cost but can also ensure greater safety and punctuality [42]. Ernst [43] agrees that scheduling staff well can lead to "enormous benefit" but that good scheduling must be supported by competent decision support systems. Mazzei [44] points out that improved scheduling of doctors, patients and cases can improve operating theatre utilisation by up to a quarter.

2.3. Utilisation benchmarks

Utilisation is defined as the ratio of the time that an asset is used, against its capacity [45][11] and is is useful for establishing whether an asset is used well, or whether there is wastefulness in planning access to the asset [45] . Utilisation may be expressed as a percentage, or in calculations 100 % is often equated to unity. i.e. 75% = 0.75.

$$Utilisation = \frac{Time\ In\ Use}{Time\ Available} \times 100\ \%$$

Equation 1: Utilisation [39]

Several authors have undertaken theatre utilisation studies which are shown in Table 1. Studies were either based on historical data – largely from theatre records, which were processed by comparing used minutes to available minutes as per Equation 1 or were mathematical or simulation models, based on procedure duration-predications and frequency-

[11] In other words, if an asset is available ten hours per day, and is used for five, then the utilisation on that particular asset is 50%.

distributions [12]. The former category explored actual utilisation whilst the latter investigated theoretically feasible utilisation.

Author	**Country**	**Hospital Type**	**Utilisation (ave)**	**Method Used**
Strum [46] (1997)	USA	Teaching	72 %	Historical
Dexter [47] (2003)	USA	General	80 %	Simulated
Van Houdenhoven [48] (2007)	Netherlands	General	85 %	Mathematical Model
Faiz [49] (2008)	UK	General	74 %	Historical
Leung [50] (1997)	Hong Kong	Teaching	72 %	Historical
Overdyk [51] (1998)	USA	Teaching	82 %	Historical

Table 1: Utilisation studies

In their historical descriptive models, Strum [46], Faiz [49], Leung [50] and Overdyk [51] used data from theatre records which had been captured electronically[13]. All of these studies investigate theatre utilisation and the average numbers of cases per day. Some studies also investigated the overall average procedure duration. Forecasting particular procedure durations fell outside of the scope of all of these papers.

In their simulation study, Dexter *et al* [47] used a random number method to estimate an upcoming procedure-duration based on historical data. No differentiation was made between types of procedures, however because they were randomly stepping through a data set, they were able to implicitly introduce the natural variation of different procedures into their model without the significant complication of statistically modelling each procedure individually.

[12] Distributions were found to be either lognormal or normal distributions
[13] It wasn't mentioned whether the data were captured specifically for their studies, however considering that the number of cases investigated ranged between 7300 and 54 000 it is unlikely and it is assumed that theatre records were already available electronically.

Such a simulation has been called a data driven simulation in other literature [38] however Dexter didn't use this terminology[14]. The simulation studies proposed reasonable and achievable utilisation benchmarks.

The National Health Service (NHS) of the UK [52] proposes that theatre utilisation be kept range bound between 70% and 80% as this mitigates the risk of list-overruns due to surgical complications[15] . Table 1 shows that a theatre utilisation between 70% and 80% is realistic and achievable, and will therefore be used as the benchmark to attain in the remainder of this paper.

2.4. Efficiency and management of operating theatres

Dexter argues that allocating theatre time to surgeons on the basis of utilisation alone is unwise. Utilisation as a holistic measure is weak as a comprehensive assessment of an entity's performance, as it views only one operational characteristic, to the exclusion of others [47]. High utilisation linked with regular complications was found to lead to high overtime costs [49]. Macario discusses the game theory employed by a surgeon who purposefully keeps a patient in theatre longer than necessary, only to appear to have better utilisation [7]. This calls for a broader measure of a theatre's performance, which we call efficiency.

Measuring the efficiency of operating theatres has been investigated by several authors. During the last two decades of the previous century [53], the trend was to use ratio analyses

[14] Data driven simulations will be discussed in greater detail in section 3.2.5.1.

[15] Surgical complications may extend the duration of procedures significantly and are defined as "any undesirable, unintended and direct result of surgery affecting the patient, which would not have occurred had the operation gone as well as could reasonably have been hoped" [149]. The inherent variation in theatre operations means that higher utilisation has a direct link to over-runs and over-time spending [49].

and Data Envelopment techniques [54] which are still being used in many hospitals [55], however their complexity makes application by most hospitals unfeasible. In response to this deficiency, Macario published a redefined framework to measure “efficiency” to measure institutional performance (not narrowly, as the trend in the twentieth century was) but rather on the basis of eight discreet yet inter-related, high-level operational characteristics [56]. Macario indicates that the particular metrics were extracted from published work and the benchmark levels were arrived at, partly from these papers and largely also from his experience and involvement in operating theatre management [56]. Macario’s model is preferred over a data envelopment model or statistical process control [57] because the information required for evaluating a theatre should be readily available from the theatre management system [56]. Macario does not elaborate on the derivation of the benchmark values in each category [56].

Figure 4 shows the eight principles of efficient theatre complexes [56]. For this study they were categorised under headings related to cost, time and resource management, which aligns Macario’s framework with the key elements identified in Section 1.5.

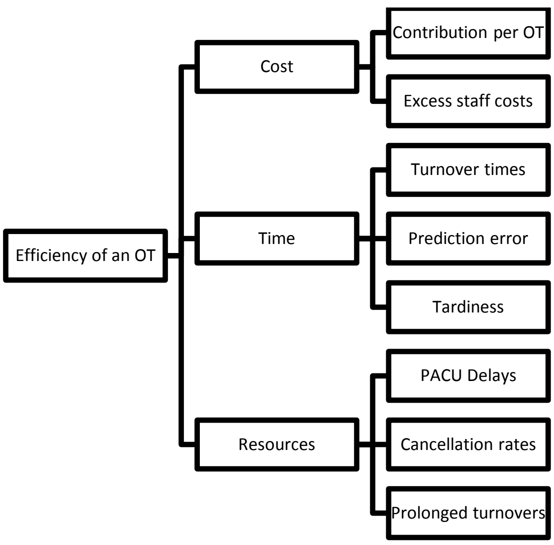

Figure 4: Metrics for efficient OT use [56]

Macario's framework was chosen for this research, because it aligns well with the key elements and questions in this research, and because it is largely based on readily accessible data.

Sections 2.4.1 to 2.4.8 are taken from Macario's paper on this topic [56] and discuss the major categories as presented in Table 2 and propose infrastructural and management criteria in terms of time, cost and resources necessary to achieve benchmarks.

2.4.1. **The Contribution per operating theatre**

This is monitored in financial terms. It is an indirect measure of theatre utilisation. A theatre's rate per minute is set, therefore the only way to raise the hourly contribution by a particular theatre, is to bill it out for more time, which is a homologue for higher utilisation.

2.4.2. **Excess staffing costs**

This category measures the daily expenditure on staff in excess of budget. Excess staffing costs are incurred in several ways. Chief amongst them is an operating theatre running longer than anticipated, resulting in staff being paid overtime. Alternatively excess staffing costs, includes the hiring of locums, who command higher wages than regularly employed professionals. A locum would be hired to stand in for another staff member who is absent, through illness or another cause. Consequently there is a duplication of payment for the role of a particular staff member.

Theatre hours also may be extended by:

- Too many cases booked for a list
- Lists spilling over into the next, extending an otherwise properly booked list

- A lack or a shortage of instruments or equipment
- Surgeons or anaesthetists acting in a tardy way
- Poor discipline in adhering to schedules
- Complications occurring and extending expected surgical durations
- Emergency cases

Some excess staffing costs are justifiable due to complications and emergencies. All other excess costs however are likely due to poor management, planning, scheduling and control. To achieve the benchmarked figures therefore requires appropriate scheduling of time and resources for procedures and also strict monitoring of operational discipline.

2.4.3. Turnover times

This is the time between when the preceding patient is "clocked out" and the next patient is "clocked in". Largely, the turnover times are used to clean, prepare, set up and equip theatres for the next procedure. This is also a time gap that surgeons can use to take refreshments, scrub, change staff or partners and take comfort breaks. To make these change overs most effective, theatre management must anticipate:

- Instrument and equipment requirements
- Staffing and support requirements
- Surgeon absence[16]

To change over from one theatre arrangement to the next rapidly, efficiently and precisely, a thorough knowledge of future needs is required. If expected theatre usage is realised, then theatre management can be prepared to rapidly perform turnovers[17].

[16] I.E. ensuring that the surgeon is back at the theatre by the time the theatre is ready to be used.
[17] Single minute exchange of dies (SMED) [39] is a viable strategy that presents great potential for a further research study.

2.4.4. <u>Prediction error</u>

This measures forecasting error of a given procedure. The greater the complexity of the calculation and the greater the depth of the database, the greater the precision becomes for predicting procedure-specific durations.

In order to calculate prediction error, a baseline must exist. Errors between actual and predicted procedure times are then used as a measure of the efficiency of an operating theatre. In order to accurately predict procedure duration, a management system needs to have access to historical data, which is surgeon and procedure specific.

Creating low levels of error between forecasts and actual times requires teamwork between surgeons, staff and management.

2.4.5. <u>Tardiness</u>

This measures whether or not a surgeon begins an operation at the scheduled time, and can only be measured if every patient has a *specific procedure start time* assigned to them. Tardiness is any deviation from this start time. Depending on the complexity of the system, measurement can either be measured as absolute error or only as late starts [46].Potential causes of start time tardiness include:

- Medical professionals who do not adhere to schedules or theatre use constraints
- Ad-hoc list sequence changes[18] usually by the surgeon
- Other schedule over-or under-runs – the domino effect
- Complications or emergency cases
- Unavailability of nurses, instruments or equipment

Accurate procedure time predictions are required to create a baseline schedule.

[18] This means the entire support structure must change its schedule also.

2.4.6. <u>Post Anaesthesia Care Unit (PACU) delays</u>

This tracks whether a post-operative patient has immediate access to the PACU (recovery unit). This is a clear capacity question, and the ability of the PACU to handle demand rests on:

- Levelled output from the theatres
- Low number of complications, i.e. no extended stay PACU prior to discharge
- The PACU being appropriately sized to deal with the number of theatres
- Appropriate scheduling of many successive short procedures.

2.4.7. <u>The case cancellation rate</u>

This tracks how many booked cases are withdrawn from the operating theatre after they have been scheduled.

There are a variety of potential causes for surgeons withdrawing a case:

- Patient condition becomes better so there is no need for surgery
- Patient is unable to undergo surgery
    - Religious reasons[19]
    - Ate or disobeyed pre-operative instructions
    - Becomes too ill for surgery
    - Changes his/her mind – withdraws consent
- Surgeon is overscheduled, and withdraws cases to fit into programme
- Theatre complex overburdened, hence no available slot

[19] For example, Jehovah's Witnesses are not permitted to receive any blood products. The potential need for such products is not always explored prior to surgery.

2.4.8. <u>Prolonged turnovers</u>

Prolonger turnovers refer to the time between two lists, when one has been concluded and the next has not yet started. This gap increases with poor planning or scheduling, due to unfilled lists or an unanticipated early end to a list. Doctor or patient tardiness may also extend turnovers.

2.4.9. <u>Summary</u>

No evidence was found in literature that this measurement model was tested, neither by the author nor by others; however it has been cited at least 58 [20] times in academic papers. This research report will in part test the validity of this model for a South African private hospital.

The metrics employed are not entirely independent of each other, for example higher case cancellation rates are related to lower utilisation. The author points out that all eight metrics are equally weighted, which is probably not valid, as some dimensions (such as excessive staffing costs) more significantly impact the overall efficiency of an operating theatre [56] than perhaps the PACU delays. Nevertheless an equally weighted scorecard was compiled which should be used as an evaluative tool for operating theatre complexes.

[20] Google scholar

2.5. The measurement model

Table 2 shows the quantitative model for assessing theatre efficiency, based on the work presented in section 2.4, benchmark values represent acceptable service levels as determined by Macario's work in this field [7].

Metric	Points 0	1	2
Excess Staffing Costs	>10 %	5 % – 10 %	<5 %
Start Time Tardiness (mean tardiness of start times of elective cases per OT per Day)	>60 Min	45 Min – 60 Min	<45 Min
Case Cancellation Rate	> 10 %	5 % – 10 %	<5 %
PACU admission delays (% of workdays with at least one delay in PACU admission	>20 %	10 % – 20 %	<10%
Contribution (mean) per OT hour	<$ 1000 / hr.	$1000 – $2000 / hr.	>$2000 / hr.
Turnover Times (mean setup and clean-up turnover times for all cases	>40 Min	25 Min – 40 Min	<25 Min
Prediction error (error in case duration estimates per 8h of OT time)	>15 Min	5 Min – 15 Min	<5 Min
Prolonged turnovers (% of turnovers that are more than 60 min)	>25 %	10 – 25 %	<10 %

Table 2: Scoring system for OR Efficiency, as developed by [56]

The model in Table 2 is unsuitable for the target site and will be adapted to suit those conditions. The following three dimensions were particularly problematic. The earnings in US dollars should be measured with a more internationalised metric, whilst the prediction error and case cancellation rates will need attention as they are not currently measured.

Earnings per theatre are measured in US Dollars and a direct conversion to Rand would be inaccurate[21]. Using utilisation as a proxy value for earnings is more valid because theatres earn income only whilst cases are being performed, similarly utilisation only increases when

[21]Simply using an exchange rate conversion does not consider that medical costs in the USA are higher than in South Africa [154] and as such that OT earnings may be different.

surgery is being performed, therefore theatre utilisation and earnings[22] are proportional. Thus the US – centric metric of Dollar - earnings was generalised by measuring utilisation. The model is updated to include the best practice benchmarks proposed in Section 2.3.

The model contains two elements currently unevaluable from available data from this case study, and from the practice of medicine in the South African context. They are the "case cancellation" and the "prediction error" metrics.

The researcher believes that to satisfy either of these, a full booking administration and management system is required [56]. This should include surgery duration intelligence, which can forecast expected durations. At present such a system has not been observed at any South African hospitals and does not exist at the target site. This is a significant departure from global best practice, and is assumed as a given at most hospitals [56].

Because forecast procedure durations are not used at the target site [23], it is impossible to measure the error of a forecast against actual procedure duration. Therefore this dimension remains dormant until a system predicting surgical durations is in place. This particular metric of efficiency is independent of the others and therefore the absence of its measurement does not negatively affect the outcome of the model.

Without a comprehensive booking system, theatres have no expectation of which patients or procedures to expect. Cancellations are unreported affairs between doctors and patients and are not recorded centrally. Therefore this metric too remains impossible to evaluate with

[22] Not profit
[23] and haven't been observed in South African hospitals

current data. This metric is tacitly included in the measurement of utilisation, because rising case cancellations will reduce the utilisation of the theatre.

Table 3 shows the revised scorecard developed for this study. It forms the basis of the evaluation of the efficiency of the operating theatre complex at the test site.

Metric	Points 0	Points 1	Points 2
Excess Staffing Costs	>10 %	5 % – 10 %	<5 %
Start Time Tardiness (mean tardiness of start times of elective cases per OT per Day)	>60 Min	45 Min – 60 Min	<45 Min
Case Cancellation Rate	> 10 %	5 % – 10 %	<5 %
PACU admission delays (% of workdays with at least one delay in PACU admission	>20 %	10 % – 20 %	<10%
Utilisation by theatre complex	**< 60 %**	**60 % - 75 %**	**> 75 %**
Turnover Times (mean setup and clean-up turnover times for all cases	>40 Min	25 Min – 40 Min	<25 Min
Prediction error (error in case duration estimates per 8h of OT time)	>15 Min	5 Min – 15 Min	<5 Min
Prolonged turnovers (% of turnovers that are more than 60 min)	>25 %	10 – 25 %	<10 %

Table 3: Revised OT Measurement Tool

Note: the bolded line indicates the updated metric, where earnings are replaced by utilisation

The case-cancellation and prediction-error metrics could be cut from this tool; however in the interest of completeness the model should retain these dormant metrics. The researcher feels that the value of the model is not compromised through missing dimensions. Dormant metrics may be problematic, however the metrics are either fully independent (as in the case of prediction errors) thus not compromising any other dimension, or implicitly covered by another metric, as in the case of case cancellation rate and utilisation, that the model remains useful. Results will be presented with no-score being awarded in them, and the totals adjusted accordingly.

Chapter 3: Method

3.1. Introduction

This chapter is divided into two major sections, namely methodology (3.2) and method (3.3). Although often treated as synonyms, these two sections are different. It is common practice in social sciences research and when using complex methods to include a section on methodology separately from the literature review and from the method.

The methodology, will explore the "science of science" or, in other words discuss the elements which make up scientific enquiry, in particular focusing on accepted and recognised practice, which can be seen as the rules of competent research. Establishing these "rules" allows for a method of actual research execution.

The method will outline the way in which the research was conducted. The method allows repetition of this work, and scrutiny of the actual research practice. Where appropriate, the method will refer back to the "rules" as established in the methodology, as justification of the method.

3.2. Methodology

This section on methodology will explore the two major paradigms of scientific research, namely qualitative (3.2.1) and quantitative (3.2.2) methods. It will combine these in a section on hybrid methods (3.2.3) and introduce single case studies (3.2.4) as a research framework. Finally, the usefulness of simulation (3.2.5) as a research tool will be explored.

3.2.1. Qualitative research

Qualitative research is an approach to research that is mostly followed in the social sciences [58] [59]. The key characteristic of qualitative research is that it is not numerically intensive, but rather descriptively rich [60]. A qualitative study will endeavour to establish the quality or the value of certain behaviours. It also tries to explain such behaviours on the basis of more general principles[24]. Because of the reduced rigour, less informed critics lambaste this approach as "mere common sense" [61].

Qualitative methods rely to a large extent on observation and interviews, to gain the perspective of those who participate in the system under investigation [62].

3.2.1.1. Observation

There are two chief forms of observation in qualitative research [62], Direct Observation (DO) and Participant Observation (PO) [62] [63]. Both are valuable research methods and only differ in terms of the placement of the researcher. In the case of DO, the observer is positioned outside the system, and is in effect looking into the subject group. The direct observer does not form part of the social fabric of the system and plays no role within it. In

[24] These principles include socio-economic or other contextual factors but also the perception or experience of subjects. [65] [78]

PO by contrast, the observer is embedded within the society and does play a role, whilst recording the behaviour within the system [63].

PO is a frequently used method for social sciences research [62] [64] [63]. Due to deep embedding, research is often highly subjective due to the researcher's own involvement and observational- and qualitative- bias.

DO is the less subjective form of the two approaches, because there is greater distance between the researcher and the subject group. It is however also more prone to error, as the "insider's perspective" which PO creates is lost and therefore so are nuances and intricacies of the system [62] [63].

3.2.1.2. Interviews

A research interview is a form of data collection which is based on dialogue, allowing the qualitivist to understand the subject's world from their perspective through discourse. Research can be conducted through structured or unstructured interviews. [65]

In structured interviews the discourse is pre planned or even scripted. Where very specific phenomena are being investigated, with narrowly defined responses, scripted interviews shorten the process [66] and simplify data processing. Structured interviews may present the subject with a finite group of answers, often in the form of a Likert scale[25] [62]. Responses can be recorded in sound format or through check boxes or free-text inputs. This simplifies generating data volumes as different researchers (assistants) can conduct the same interviews and produce normalised data. As a consequence of the narrowness of responses in highly

[25] Options may be: "strongly agree", "agree", "neutral", "disagree", "strongly disagree" [66].

structured interviews, the richness of the data collected in this way tends to be low [66]. Analysis of structured interviews is typically quantitative [66].

Unstructured interviews by contrast are aimed at identifying and exploring emerging issues. To achieve this, unstructured interviews are less, or not, scripted. Responses of subjects, are recorded, either in sound format, a verbatim transcript or through note taking, which may be in summary during or after the interview. [66]

Because an unstructured interview has fewer specific questions and is generally more open ended, it allows the generation and sharing of issues which may not yet have been identified. An unscripted, unstructured interview is more probative, and able to identify emerging trends, however is generally more cumbersome to process as themes can emerge unexpectedly [66].

Interview processing

To process open ended or unstructured interviews, thematic content analysis may be undertaken. This analysis typically follows the steps of condensation, tabulation, quantification and classification [67].

Interview analysis requires that the interviewer identifies the key elements that emerged in conversation [66] this is known as content condensation, and takes the original signal (discourse) and filters out all noise to arrive at the core meaning. An extended discussion can usually be reduced to one core topic. Condensation can take place actively during the interview through note taking and encoding[26] [66]

[26] Commonly occurring themes can be represented by a shorthand representation, i.e. a code. [66]

These condensed elements are tabulated. This reduces the bulk of interview notes and gives a better overview of the issues faced by the informants [66].

The frequency of issues occurring is recorded by increasing the count of that particular issue whenever it is mentioned by an informant.

Issues are clustered to understand underlying issues or so-called “major themes”. This approach is known as categorisation [67] and is a form of root cause analysis [45] to find the true source of issues.

The example in Table 4 shows how this analysis may be conducted and should be read from right to left. The discourse here is fictitious about a fictitious sport created for this report – it is for illustrative purposes only. Column four is the original discourse, the meaning of which is **condensed** for column 2. The **frequency** of this topic (assuming more informants than shown) is then recorded in column three. The four topics that emerge in this example are **clustered** and subsequently **categorised** under one **major theme**, in this case ‘poor leadership’. If there are more major themes these would have a separate hierarchical network of their own.

Categorisation	Tabulation / Condensation	Frequency	Signal
Poor Leadership	Poor coaching skills	3	"I hate that we have had 20 coaches in tha last five years, and it doesn't matter whether they're local or not, we end up with poor results and it seems none of them can make a difference."
	Corruption amongst administrators	5	"so I see all these big bosses driving around in their fancy cars, flash, and then me as a player, I struggle, I don't get paid and I don't know where all the money goes. Well, I do know, and that's why I'm angry"
	Tournaments are poorly arranged	2	"we come to the stadium in the morning and there are like no people selling tickets, and people are just walking in. but then there is noone selling food, and people have to go outside to get something to eat. Someone has forgotten to arrange a ref or a ball, there's always something."
	Stadia are empty, poor marketing and too expensive	5	"I love this sport. But I don't go to matches, because it is too boring to sit there with five other people. I could watch on TV and have my friends around and it would cost less. There is also nothing extra, it is basically just one match and its too much bucks for just that."

Table 4: Thematic Content Analysis

Selection of informants

Selecting people to interview is often a matter of finding willing participants, also referred to as convenience sampling [68]. Interviewees should have knowledge of the topic of the interview, with the ideal subject having insight into the topic, working in the relevant field or industry or having strong views related to the matter. [66]

The number of required subjects depends on the conclusions that the research seeks to elicit. If the research seeks to predict the winner of a national election, 1000 interviews are generally needed. If the research seeks to show a statistical difference between the views of two groups on a particular issue, the Fisher significance test proposes as few as six[27] interviews would suffice. Between these extremes it is generally accepted in literature, that unless specific statistical inferences are sought, 15 ± 10 interviews is a sufficient number to gain a sense of prevalent issues [66].

[27] **Three** from each group, e.g. three males and three females.

3.2.1.3. Complications in Qualitative Research

Power Relationship

An issue that has great bearing on the outcome of any qualitative approach is the power relationship that the researcher has towards his or her subjects [63] [69]. There are three ways in which a power relationship can manifest itself within research: the researcher may be in a position of power (positive[28]), the subjects may be in a position of power (negative) or there may be a neutral power balance. A deeper discussion of this can be found in Appendix 2.

Observers' bias

As the agent and synthesiser researchers [68] need to be aware of their biasing function in research. Where possible this needs to be compensated against, as qualitative research is prone to letting the researchers see what they want to see [70]. This can be improved by focusing on ensuring the validity and rigour of research

Rigour, validity and consistency

Qualitative research may at times be one sided, and therefore research findings may be questioned [70]. To ensure validity of results, qualitative methods should attempt to triangulate results, in other words, backing up findings via different pathways. If several data sources support one outcome, then this builds a coherent justification for such a conclusion [68]. For example claims of insufficient theatre time should be investigated, perhaps by checking theatre records.

[28] The use of the word "positive" is conventional and not evaluative. In other words, it reflects where the power in the relationship lies, rather than whether or not the power relationship is good or bad.

Similarly extended experimental time in the field will improve the consistency with which observations are made [68]. This should improve the validity of the results through more rigorous analysis.

3.2.2. Quantitative research

Qualitative research approaches remain uncommon in engineering, whilst by contrast quantitative methods have been the most common in these fields since the advent of the modern scientific method of enquiry some 300 years ago. The scientific method is strongly quantitative, focusing on numerical analysis, experimentation and reductionism [71].

The quantitivist builds mathematical abstractions or models which represent the system being investigated. This is the basis of empirical physics where complex natural phenomena are reduced to discrete relationships, expressed as equations of characteristics, devoid of context [64] [71] [72]. Examples of quantitative work in industrial engineering range from the creation of technical models for stock market investment [73] and the creation of scheduling models for freight trains [74] to determining average patient queuing times [75] and optimised supply chain models [76].

3.2.3. Hybrid approaches

Many natural scientists consider pure case study, or pure qualitative research deficient, this is highlighted by Yin [62] when he identifies the principal perceived deficiency of these methods as “a lack of rigor”. In light of this, it is fortunate that this study can draw on multiple perspectives for analysis.

The hybrid between qualitative and quantitative methods is advanced by King *et al* [59], as it overcomes the numerical reductionism inherent to a quantitative study, but equally and importantly overcomes the bias, interpretation and "*Fingerspitzengefühl*[29]" [77] necessary for qualitative research.

Combining the understanding extracted from personal narrative [58] and empirical tools [78] of qualitative research and the measurement, abstraction [59] and narrow precision [58] of the quantitative approaches may give a more balanced result. To achieve this, it is recommended that a phased approach is followed where the character of a particular phase remains either qualitative or quantitative

Cook *et al* identify four major weaknesses of hybrid methods which must be considered in planning research. These are cost, duration, researcher expertise and faddism [70]. Hybrid methods are often prohibitively expensive as data collection and processing, if budgeted for accurately, are far greater than in single mode research. Research is also prone to take longer as the rigour of both methods must be ensured. Unless the phases can take place concurrently, Cook [70] recommends that such research should be restructured. Researchers may not be adequately trained in both research paradigms and therefore research studies may represent a learning curve for researchers or alternatively result in deficient research in one or both components. Finally, Cook [70] talks about faddism, the fact that one form of research is fashionable in a particular scientific domain, and therefore there is a perception of inadequacy when hybrid methods are applied in these fields.

[29] The intuitive, instinctive, nuanced, fine and tactful expertise necessary to understand a system – www.leo.org

3.2.4. Single Case Study Research

Broadly, a case study is a research method in which the researcher attempts to understand a complex system. In order to understand such a phenomenon, a particular instance of a phenomenon is chosen and investigated as representative of the phenomenon as a whole [62]. For example, should one wish to study poor driving habits, a case study at a major intersection may be an appropriate approach. On the basis of the observations and conclusions made from such research, the researcher may, within limits, extrapolate the observations to a more generalised theory [62].

To understand this section, it is necessary to consider differences between, on the one hand, qualitative and quantitative research, and on the other hand the description of what "case study" research is. It is important to think of a case study as a research framework whereas qualitative and quantitative paradigms are approaches to the interaction with data [62].

Many theorists view a case study as intrinsically linked to qualitative research [79]. This is a view that has in recent times been refuted by Yin [62] and others [80]. The consequence is that in modern times, case study is seen as a worthwhile vehicle to pursue research which is qualitative, quantitative or both, depending on the needs of the particular study

This research uses a hybrid qualitative – quantitative[30] single case study which is justified because:

Firstly the study is able to achieve greater depth and precision in analysis than had it been done at various different sites. This approach is supported as valid by Yin [62].

[30] Often referred to as mixed methods [72]

Secondly, the study, by virtue of the fact that it was instituted through agreement with the leadership of a private hospital group and then delegated to one of their flagship sites is indicative of a willing participant, which is helpful to effective and successful research [62] [80].

Thirdly, the tool that is developed in order to measure the hospital in question is able to be reused at further sites. This is characteristic of case study research [80] and as such can be used in an instrumentalist manner [65] literally to vet a theoretical tool which will be useful in future research.

Baxter *et al* [65] have identified four characteristics which justify a case study approach. They are: (a) the study attempts to answer "how" or "why" questions, (b) the behaviour of the system cannot be manipulated by the presence of the researcher, (c) contextual issues play a role and lacking those, the research would lack precision and (d) the boundaries between the context and the phenomena are unclear.

The research that was done satisfies these conditions. The research attempts to understand how appropriate scheduling can alter the efficiency of healthcare provision, the theatre complex remains unaltered due to data collection and it is clear that the context drives the actual performance characteristics of the operating theatre, and a boundary between surgery behaviour and the environment in which it exists cannot be drawn.

3.2.4.1. Data in case study research.

"A hallmark of case study research is the use of multiple data sources" [65]. These sources may include documentation (including data-bases), archival records, interviews, direct or participant observation [62]. The complexity arises from having to integrate the various sources and types of data into a holistic picture which describes, explores or explains the system under investigation. The strongest unifier of the data sources is that they are open-ended and represent a breadth of views [68]. Therefore the course of research as well as the methods and expected outcomes remain dynamic as the research progresses [68].

The researcher acts as the synthesiser in bringing together data sources as disparate as pictures, conversations, observations and information from other sources such as the media or uninvolved third parties [68].

Cresswell [68] cautions against sanitising results by ignoring important outlier results or the contrarian views of interviewed participants.

3.2.5. Simulation as an analysis tool

Healthcare is a high risk industry, in which the effects of poor decision making or bad management can be matters of life or death. It follows that this industry is risk averse and avoids ideas that are not rigorously and thoroughly tested [81].

Simulation is useful as an evaluative because it is able to mimic reality without real world risk from experimentation[31]. It is also able to highlight and identify problems [82]. It is therefore suited to the needs and idiosyncrasies of healthcare [34].

Simulation dramatically reduces the need for experimentation, as the majority of operational experiments can be simulated prior to implementation. As in a "real life" experiment, a

[31] Possibly the best explanation of what simulation is, and how it works is taken from fiction [104] and therefore has been relegated to Appendix 3, however the author considers this the single most comprehensive and illustrative description of what simulation and its uses are.

simulated experiment permits the researcher to find errors in ideas, problems with concepts and the ability to reject bad hypotheses without the need for expensive experimentation time, physical movements and equipment purchases [82].

Because real experimentation is reduced, harm to patients can be reduced, as the initial testing (and rejecting of bad ideas) can be done in a virtual environment where harm is theoretical. [83]

As a result of a shorter real-experimentation phase once the implementation takes place, downtime is reduced, which yet again saves cost, including the mitigation of other risks such as harm to patients or lost opportunities through unavailability of infrastructure [82].

A simulation can provide a rigorous and thorough evaluation of a plan. It is able to present the results in a logical and visual way, which allows medical professionals to overcome the numerical abstraction which constitutes the underlying body of knowledge making up the simulation [83]. As a result "selling the idea" is simplified as the access to the solution is more immediate, yet explicit and easily understood; therefore loopholes can be identified. [83]

The logic of standard procedures can be built into a simulation. The algorithms that define a particular activity can be codified and incorporated as a regular process, which is initiated by the highly changing environment which sets the bounds of the simulation [82].

Many papers have described simulation models in healthcare, from the general functional overview [84] [85], to more specialised questions, amongst which to determine capacity [36], to set layouts [32], to determine staffing levels [37], to determine instrument requirements [86] and to effectively manage queues in health [75].

As stated, because medical care is highly variable, mated to inherent risk aversion due to the potential severity of harm from reckless experimentation and the need to have high infrastructure availability; it is the researcher's conclusion that simulation makes an appropriate contribution to this research.

Simulation in healthcare nevertheless needs to be approached cautiously. Carter [87] highlights some common pitfalls in this domain. Getting accurate data is problematic so the sourcing must be thought through well in advance [87]. It was also found that the level of detail required to get accurate results from simulations was difficult to achieve, due to high variation within and across procedures [87].

To compensate for this, researchers have used a variety of techniques, including severely simplified models, for example using overall average times rather than procedure specific behaviour [48] or simplifying the simulation by using data driven simulations [38].

3.2.5.1. Data driven simulations

Data driven simulations are run to 'script', rather than to probability distributions, and are useful in simplifying systems with a great deal of variation and opportunity for complication [38]. Healthcare systems particularly have been identified as benefiting from such models [83]. Dexter [47] used a data driven model to establish utilisation benchmarks (see section 2.3). In this study, he used a VBA macro to use a random number generator to extract surgery durations from a large database of historical cases. These were sequenced randomly to estimate a realistic maximal utilisation figure.

This approach is desirable because medical procedures have large variability, both in terms of duration and frequency of occurrence. It was found that 50% of cases have fewer than five identical procedures performed in the preceding year [56], which further complicates model creation, making the creation of a probability distribution problematic both for individual case duration as well as for case occurrence rates.

3.3. Method

This project was conducted in six phases as shown in Figure 5.The qualitative phase of this research (3.3.1) enabled an understanding of the theatre environment. The pilot study (3.3.2) aims to verify the claims by surgeons of inadequate theatre time. The analytical methods that were employed to gather and process the data which were extracted from the billing data will be described (3.3.3). A simulation, which does meta-processing of the data, will be described (3.3.5). The simulation will be used to find an improved solution to the question of loading and scheduling within the theatre complex. The current state, as well as the simulated state will be measured against the model developed in the literature, which is the final summative phase of this research (3.3.6)

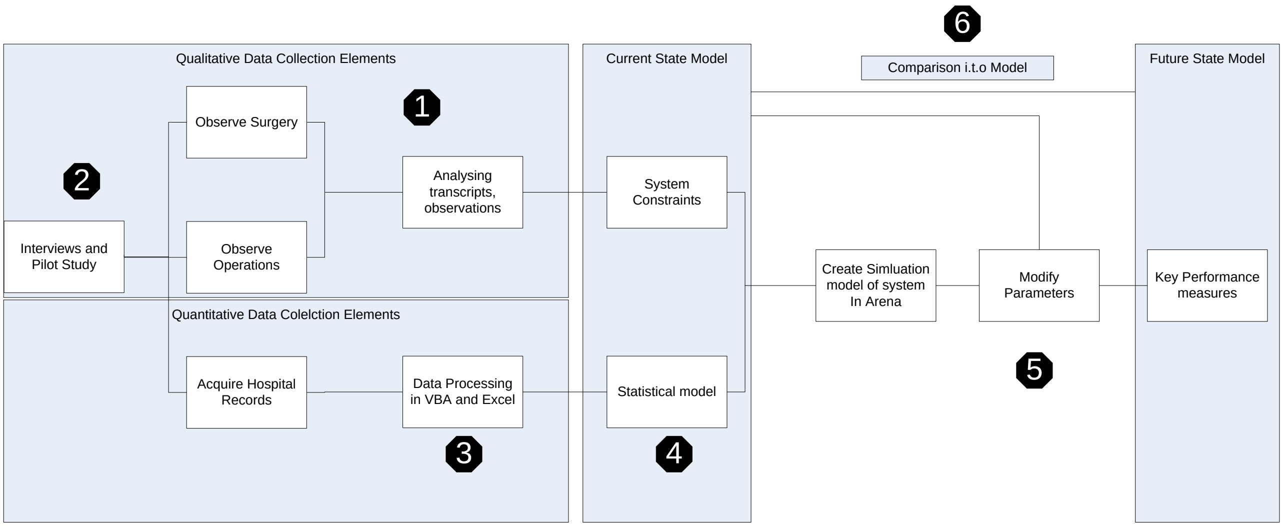

Figure 5: Flowchart of method

Note that the numbers in octagons indicate the different phases of this study.

3.3.1. **<u>Phase one: The operating theatre environment</u>**.

During phase 1, the operating theatre was investigated. To understand the tacit and real constraints on theatre utilisation, operations had to be understood qualitatively. This phase was conducted on site, intermittently, over a period of twenty weeks. This is consistent with the practice of qualitative research [65], and included direct and participant observation techniques [88] as well as unstructured interviews [66].

3.3.1.1. Ethical Considerations[32]

This report is written so that the identity of the hospital, the surgeons, the anaesthetists, nurses, staff and other individuals remain anonymous.

The hospital is not named in the report and its identity cannot be inferred from the information presented. This report maintains the anonymity of the participants. Where names were recorded, they have been blacked out in the interview notes.

Discussions with surgeons and nursing staff were conducted informally and were unstructured and took the form of a discussion, with the objective of gaining an understanding of how an operating theatre works. Participants were informed of the researcher’s interest in the operating theatre and the intention to use the information for an MSc. Only willing, un-coerced participants were involved, who informally consented to the research. Only work related matters were discussed. Personal identifying details as well as non-work related comments were not recorded.

This research was scrutinised and approved by the ethics committee of the school of Mechanical, Industrial and Aeronautical Engineering at the University of the Witwatersrand, Johannesburg.

[32] The research was strucutres in line with the requirements of the Human Research Ethics Committee as outlined in [157]

3.3.1.2. Interviews

Seventeen unstructured interviews were conducted with ten surgeons and seven nurses. These numbers are adequate as a representative sample [66]. Surgeons and nurses are both important actors in the smooth running of the theatre, and therefore the views of both are necessary to understand constraints and problems encountered.

The matron was interviewed first and recommended further interview candidates. The interviewed surgeons had previously complained about poor utilisation and were also those who use the theatre most. Impromptu interviews were conducted with other surgeons who represented a group who used the theatre relatively infrequently or haphazardly. No pilot interviews were conducted as the interviews were themselves exploratory.

Notes were taken of the interviews, with meaning condensation taking place at the same time, so full transcripts were not required of the discourse [66]; copies of these notes are in Appendix 6. Interviews were open-ended and unscripted. Informants were asked which frustrations they felt in the theatre complex, what they believed to be the causes of these frustrations and whether they had potential solutions for such problems.

The notes were analysed using thematic content analysis as discussed in 3.2.1.2. Emerging topics were clustered together on the basis of thematic similarity, thus revealing four major themes.

3.3.1.3. Operations of the theatre complex

During phase 1 the operations in the theatre complex, as well as the surgery[33] in the theatres were observed. The researcher was a direct observer (DO – see section 3.2.1.1) and had

[33] See the distinction between "operations" and "surgery" in section 2.2 of Chapter 2

access to the operating theatre complex, which included the corridors and common spaces between theatres, lunch areas, the common recovery area, store rooms, the instrument washing and sterilisation unit and by special arrangement with surgeons, theatres during surgery.

Observations were usually done silently, with occasional questions for clarification, this is consistent with the practice of Direct Observation (see section 3.2.1.1) Times spent in particular locations varied. To get an in-depth understanding of surgery, several hours were spent in one location[34], and at other times to get a holistic impression of the theatre complex, the observer made notes, spending no more than ten minutes in a single location.

This observation phase lasted for a period of roughly twenty weeks, during which visits were intermittently scheduled. The observation took place on different weekdays and at different times of the day, though not during the night.

Observations were recorded in note form (which can be seen in Appendix 6). Issues such as wastefulness of resources, and inefficient practice issues were identified as a result of the observer's experience in industrial engineering and accepted best practice derived from lean thinking [39]. Notes were made of instances where wastefulness or other forms of inefficiency were evident.

Softer issues were also observed, how certain people react towards each other, what certain individuals say about others, and the extent to which there was conflict, or the absence of it, amongst individuals.

[34] Similar to "standing in an Ohno Circle" [39]

Observing Operations

This phase investigated how the matron schedules resources, theatres, scrub sisters, surgery assistants and other features. The intricacies of this aspect of the theatre management were investigated. The researcher was involved as a participant observer (PO) (Section 3.2.1.1) assisting the matron in setting up schedules, which highlighted the difficulties presented by certain individuals being unwilling to work together or a lack of agreement of what the common goal of the theatre complex as a whole was.

3.3.2. <u>Phase 2: Pilot Study</u>

Phase 2 was conceived as a pilot study to quantitatively explore theatre utilisation

"Activity sampling" is used in field research to get a sense of activity in a system [89]. The objectives of activity sampling are similar to those of a time study. Activity sampling is less precise than a full time study however the process is significantly faster and cheaper [90]. Therefore this technique is suited to exploratory or preliminary enquiry. This technique can be used to establish a baseline rapidly, as was the case in Cameroon where sampling was used to gauge the utilisation of twenty rural health centres, which yielded acceptable accuracy and a significantly truncated research duration [90].

To conduct such a study, the work-system (in this case the theatre complex) is broken up into units (in this case individual theatres). The expected activity is identified and coded for simplified measurement before the study begins. Each unit is observed at regular intervals and the activity at that time is recorded, in a prepared record sheet (an example is shown in Appendix 4), using the codes shown. It is assumed that the activity observed is valid for the full duration of the time interval[35]. This information is aggregated over the period of enquiry, giving a baseline understanding of which activities take place, idle time, utilisation of the system and others. [91]

For this study the likely activities in the theatre were identified, see Table 5. It was decided that no-activity, preparation and cleaning could be classified as non-value adding. Utilisation was measured as all value adding activity divided by available time. Theatres were observed at 15 minute intervals.

Value Adding Activity[36] (VA)		Non Value Adding Activity (NVA)	
Activity	Code	Activity	Code
Surgery Preparation	Prep	No activity	0
Surgery	op	Preparation	prep
Anaesthesia	An	Cleaning	cl
End of surgery	OpEnd		

Table 5: Activity investigation codes: summary

To calculate the utilisation of the theatre (complex) Equation 2 was used, which gives a diachronic and an average utilisation for the theatres and for the theatre complex suggesting whether further investigation was required.

$$Utilisation = \frac{\sum VA}{\sum NVA + \sum VA}$$

Equation 2: Utilisation of theatres [48][37]

NVA: Non Value-Adding activities; VA: Value Adding activities.

[35] For example, if a theatre is observed to be idle, it is assumed that it will be idle for the next 15 minutes, until the next observation is made, at which point this assumption may be changed or extended based on a new observation.
[36] It may be argued that many of the activities listed as value-adding, are indeed non-value adding. This may be a valid concern. However it was decided to consider utilisation of the theatre complex as an absolute in binary terms. i.e. the theatre has activity or it is idle.
[37] This is equivalent to Equation 1, as the VA activies have been defined as the time when the theatre is in use for surgery, which these categories describe, whilst the sum of VA and NVA is equivalent to total available time.

3.3.3. <u>Phase 3: Data collection for full study</u>

Phase 2 showed a need for further, more in-depth, analysis of the utilisation of the theatre complex. To satisfactorily evaluate the utilisation of the operating theatres, the researcher decided that the following information would be necessary (indicated with a *) or otherwise useful:

1. Date of operation *
2. Sex of patient
3. Age of patient
4. Reference number
5. Discipline *
6. Procedure *
7. Anaesthesiologist *
8. Surgeon *
9. Assistant surgeon *
10. Operation *
11. Time in *
12. Time out *
13. Theatre number *
14. Remarks
15. Other items billed

The information marked with an asterisk was necessary to show the relationship between surgical duration, and the participants in that surgery, i.e. the surgeon, anaesthetist and the theatre. Surgical duration was the difference between the end time and the starting time. This included the time taken for anaesthesia as the patient was ‘clocked in’ by this point.

Unstarred information would augment this model, but would not be critical to establishing a modelled baseline.

To get a sufficiently large and representative data set, it was estimated that a year's data would be desirable, as this could show seasonal and cyclical trends. This was the opinion expressed by doctors and hospital management as volume changes and other trends exist over the course of the year.

All the data required for the model, including many additional points of information must be recorded by the hospital-billing – system. After a protracted negotiating process, the billing data for a period from October 2007 to February 2010 was made available for this research.

The data set contained on the included CD is significantly truncated. Circulating an unedited database is in violation of the National Health Act [6]

3.3.4. <u>Phase 4: Data processing and analysis tool creation</u>

Once received, the data from Phase 3 had to be processed to create a snapshot of the actual operating environment within the theatre complex. The data were imported into Microsoft Excel. The data consisted of 28 columns and 28 992 rows. The data headings are contained in Appendix 7. Each row represented one billed instance, i.e. one complete procedure.

Initial ad-hoc data processing proved deficient for two reasons. Firstly any analysis would have to be redone should the database get corrupted. Secondly this analysis was not general, but rather idiosyncratic, which meant that future analyses would have to repeat the method step by step.

A processing tool was created to analyse any billing data from hospital theatres, being able to adapt to the various theatre and database architectures.

This processing tool was created using the embedded programming language Visual Basic for Applications (VBA) - which ships together with the Microsoft Office suite. Code written in VBA runs and interacts with programmes such as Microsoft Excel. This means that such code (also referred to as “macros”) can manipulate and automate many of the steps one would normally have to perform manually. The figure below outlines the programmatic structure.

The code has several advantages over an *ad-hoc* manual process, which includes its [92]:

- flexibility to analyse and interpret a limitless number of data sources in many formats.
- repeatability and accuracy of analysis.
- ability to safeguard against data losses.
- commodity – in its present form, this code may have commercial value.

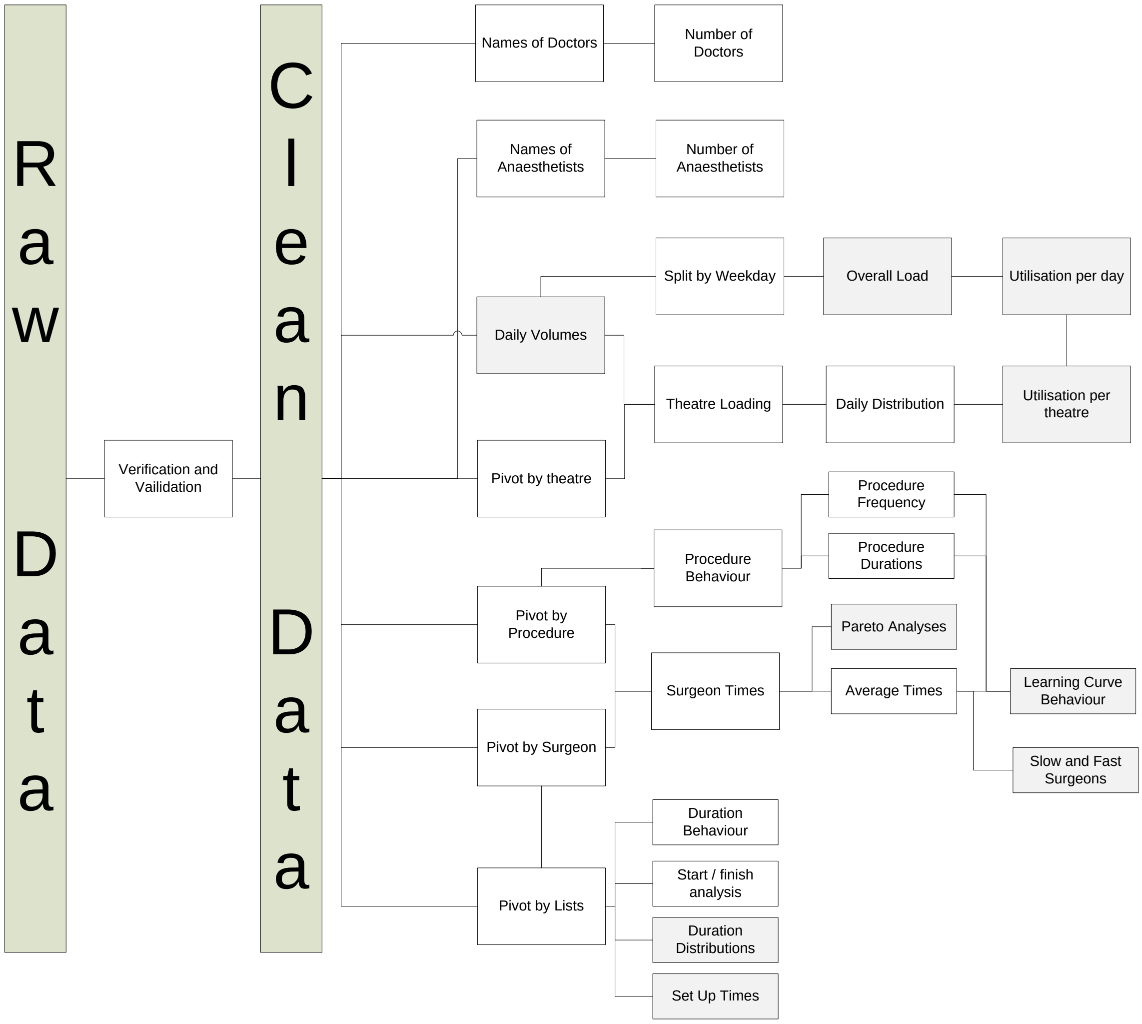

Figure 6: Programme structure of the analysis tool

The code was written in three parts, i.e.:

- Part 1: Data validation, verification and correction
- Part 2: Data analysis, processing and graphing
- Part 3: Creation of numerical behavioural models for the operating theatre

This code spans 2200 lines and is contained on the included data CD.

3.3.4.1. Part 1: Data validation verification and correction

Validation

The code explored several common errors found in data capturing. The major tests that were performed are listed in Table 6.

Validation Type	Examples
Data type errors	Test whether the correct data type was entered into a field, e.g. there should be no text in number fields.
Format check	Are data type formats consistent? E.g. dates always written dd.mm.yyyy
Presence checks	Does every important data field contain data? i.e. is there information missing
Uniqueness check	Are all records distinct, i.e. do exact duplicates exist?

Table 6: Typical data validation actions [93]

Verification

Data verification tries to establish whether the data is a real reflection of the activity that took place. Verification was performed, and the data set is considered to be a mostly truthful representation of reality. This is justified on two grounds, firstly on the basis of interested parties and secondly due to the absence of expected errors.

Doctors, the hospital, anaesthetists, patients and medical aids all have a vested interest in billing data being correct. Incorrect data would necessarily impoverish one (or more) of these parties. The billing data therefore goes through at least five rounds of checking, querying and correction before being finalised. Because large sums of money are involved for each of the parties, checking of billing information may be performed by affected parties.

Common errors which would be expected could include that procedures (should not but are recorded to) finish on the next (or later) calendar day[38], that start and end times are inverted, that surgeons concurrently use the same theatre for different cases etc. Only three such errors were found out of more than 30 000 data sets, giving confidence in the accuracy of the dataset.

[38] This was observed, but all of these procedures began before midnight and finished after, thus having a procedure spanning two days.

Correction

The integrity of the data was satisfactory, and only minimal cleaning was required. Fewer than 0.01% of records had to be deleted as a result of duplication, missing data or other errors. Keystroke and field errors[39] were easily corrected.

At the conclusion of this part, it was assumed that the data were comprehensive, accurate, and complete and formed a reliable basis for further analysis.

3.3.4.2. Data analysis, processing and graphing

Because of the size of the analysis, it was decided to change the file format from the Microsoft Excel legacy .xls to the newer .xlsm[40] format. This was done because it was anticipated that the analysis would exceed the 256 column - limit of the older format, whilst the new format allows for as many as 16 384 columns [94].

The analysis performed the following tasks (see Figure 6), it:

- compiled a list of available doctors by tabulating all unique instances of doctors.
- compiled a list of available anaesthetists by the above method.
- showed overall daily complex loading by tabulating summed theatre load per day.
- split amalgamated data up by theatre by filtering data into theatre subsets.
- profiled total daily use of theatres.
- measured set up times as the gap between clocking out and clocking in again

[39] A common error that was detected was that surgeon and anaesthetist were switched around in the record.
[40] The more familiar format is .xlsx which is incompatible with VBA macros, for which the file extension is .xlsm

- calculated a standard procedure time by filtering by procedure, then statistically analysing all instances of such a procedure. This included average times, standard deviations, variances and was done as an analysis:
    - Generally
    - By doctor (in other words, determining on average how long does Dr X take to perform procedure Y?)
- profiled list behaviour w.r.t.:
    - average length.
    - starting and finishing times.
    - list duration distributions.
- investigated regular trends, related to:
    - weekdays.
    - months.
    - times of month.
    - theatres.

3.3.4.3. Part 2: Numerical models

Using the data processed above, it was possible to establish a variety of numerical models that reflected the various aspects of the operating theatre.

In particular the data extracted at this point should be able to define the system in terms of flow, loading, surgical and procedural behaviour, operational deficiencies and opportunities.

The tool creates models which show:

- An analysis of learning curves per doctor (and per doctor per procedure)
- A distribution of loading per theatre per weekday
- A frequency distribution of procedures (and per doctor)
- A distribution of operating-list lengths
- The utilisation per theatre (and per theatre per doctor)
- The daily volumes (filtered for holidays and weekends) – annualised trends

Using this information, it would be possible to design a volume forecasting model.

3.3.5. <u>Phase 5: Creation of a simulation model</u>

A simulation was included in this project as a minor part, to test assumptions and to propose a realistic capacity for the operating theatre complex under current conditions.

The simulation was created in Rockwell Arena® version 13.50. Arena is a discreet event simulation package [82]. The project was undertaken in the free student version which is available for download from the Rockwell website[41]. The simulation used eight modules[42].

[41] www.arenasimulation.com
[42] AdvancedTransfer; AdvancedProcess; BasicProcess; FlowProcess; Packaging; ContactData; Script.; blocks.

Arena uses entities, which are the “dynamic objects in the simulation [which] usually are created, move around for a while, may get altered and then are disposed of as they leave the system” [82]. In the case of this simulation, it was decided to create patients as entities which move through the virtual operation theatre environment. Surgeons, Anaesthetists, nurses and equipment were defined as resources, i.e. consumable by the system if available. Surgery was modelled as a seize-delay-release activity and statistics were gathered for resource utilisation.

The simulation was developed in two parts. The first part was used to validate the model by running it using the recorded times from the Excel data set [95]. The second part used a data-driven simulation approach to test the effect of improved scheduling [38].

The two models are similar and share four basic stages: creation logic, routing, operational/executive functions and data collection as can be seen in Figure 7.

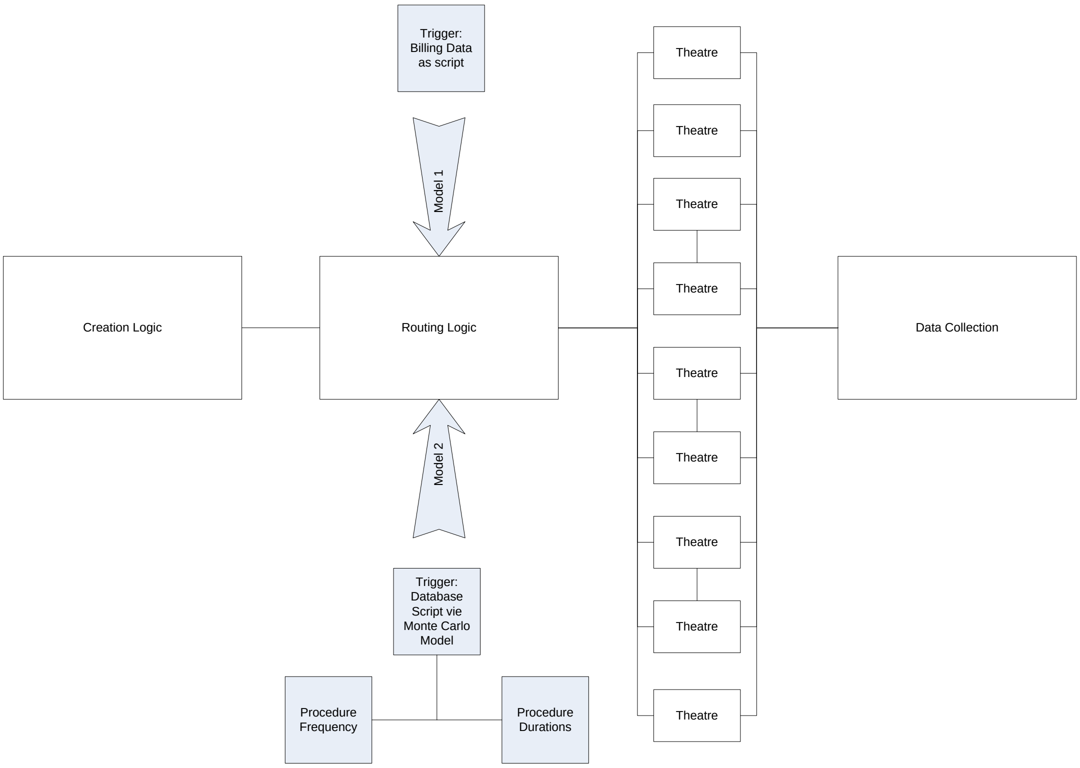

Figure 7: Overview of the programmatic logic for the simulation models

3.3.5.1. Creation logic

The creation logic generated new patients as entities for the system subject to the read-in excel file. The file was defined in a low level block. The total creation logic can be seen in Figure 8.

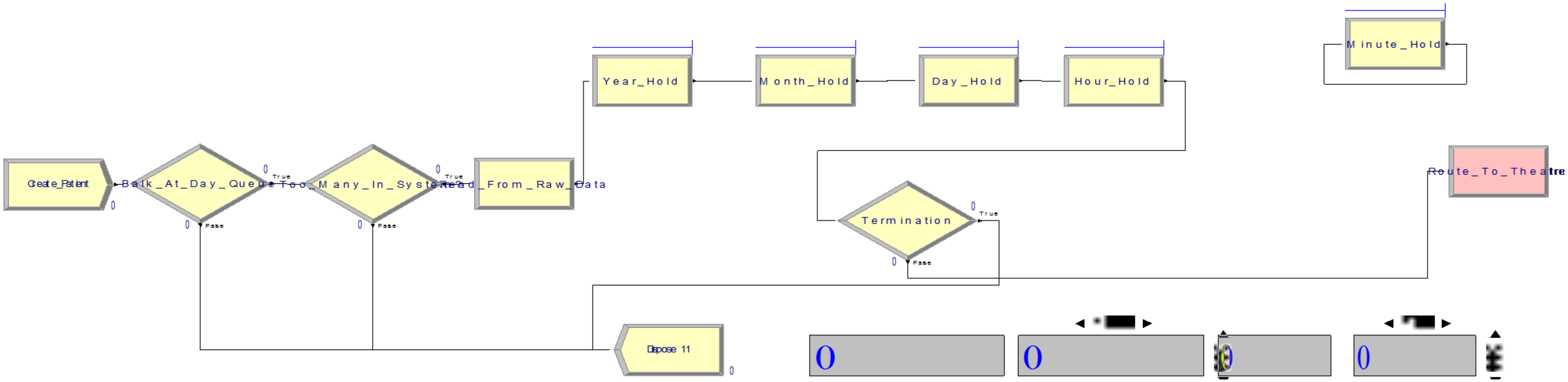

Figure 8: Creation logic

Entities represent patients in need of surgery. To accommodate irregular patient arrival rates, an excess of entities is created, and discarded if the particular arrival time does not correspond to the schedule. Twenty new entities (patients) were created per minute by the "create" block. Data from the excel dataset was attached to this entity as attributes using a "read from file" block. The attributes that were attached to the entities were carried by that entity throughout the simulation and they were:

- Start time
- Starting date
- Theatre number
- Procedure number (IPC10 code)
- Procedure duration
- End time
- End date
- Doctor ID
- Anaesthetist ID

Once the attributes had been attached, the entities were placed in a "queue" process for release to the theatre processes. The queues compared the entity attributes to the current (simulation) time. Once the current time equalled or surpassed the entity attribute time, that entity was released to the routing logic. The queues used the first-in-first-out principle, which was appropriate as the dataset was sorted by starting time. Separate queues were created for year, month, day, hour and minute as Arena doesn't have a unified date stamp compatible with the excel database. The syntax for all queues was similar to that shown in Figure 9

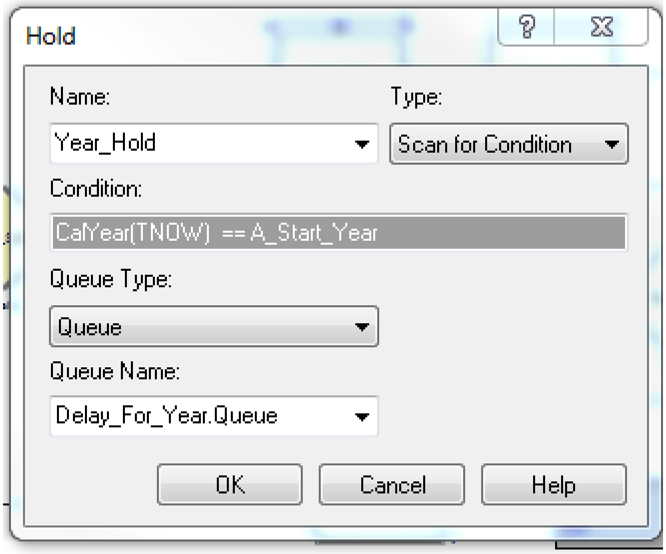

Figure 9: Queue Syntax

Two discard paths were created for unneeded entities as the student version has limits on the number of active entities. Discarded entities had no statistics recorded for them and therefore don’t alter the results of the simulation.

3.3.5.2. Routing Logic

A low-level “stations” block was programmed to route entities to theatres by the ‘theatre-number’ attribute read in during the creation logic. This routing took place in zero time. For example, an entity with the attribute “Theatre 3” would be routed from the common routing station to the arrival station for theatre three.

3.3.5.3. Theatre logic

Ten theatres were created, each of which is similar to Figure 10. The purpose of the theatre is to mimic surgical procedures and once complete, to discard entities from the system.

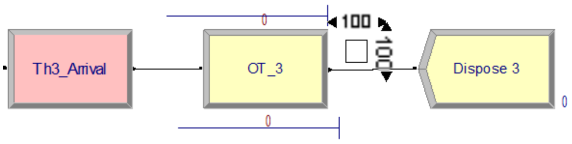

Figure 10: Sample of theatre process

The arrival “station” at each theatre was a zero delay process used for routing purposes and the patient was passed on to the theatre process. The theatre used a seize-delay-release process based on attributes assigned to represent surgery as can be seen in Figure 11. The theatre was only able to accommodate one entity at a time, which is consistent with reality.

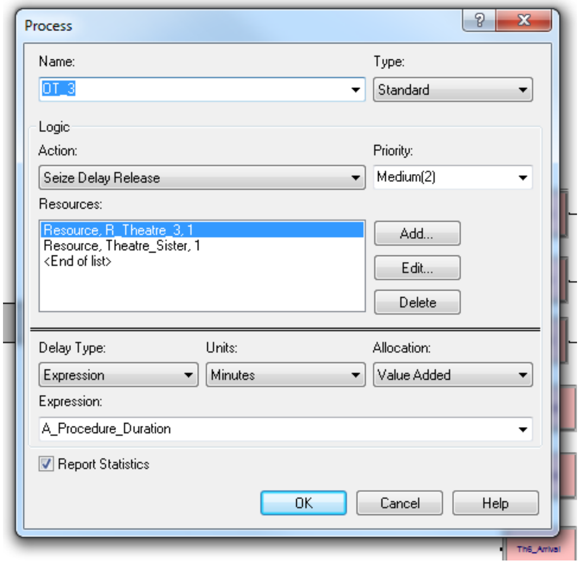

Figure 11: Operating theatre syntax

The theatre relied on an available surgical sister and an available theatre (as resources) prior to surgery beginning. Nurse availability was based on actual staffing levels as shown in Figure 12.

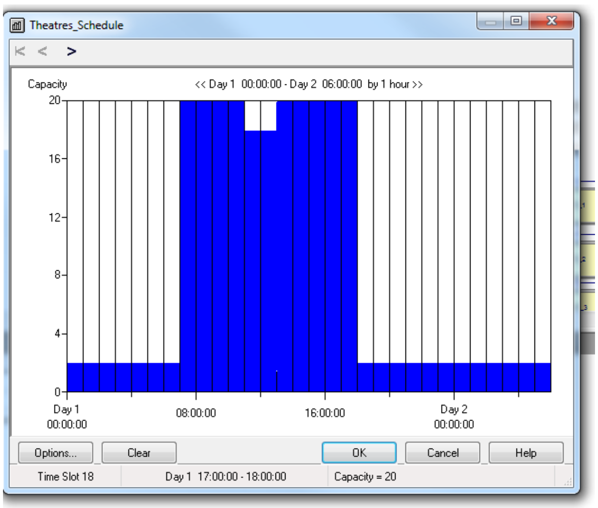

Figure 12: Nurse (Resource) schedule

Entity disposal occurred at the end of surgery and statistics were recorded by Arena.

3.3.5.4. Data collection

Data collection and analysis is automated in Arena, and all data related to utilisation of resources (such as nurses and theatres) as well as overall number of entities which went through the system (treated patients) are recorded and reports can be generated to show this

3.3.5.5. Data driven simulation

The simulation was constructed to be “data-driven” [96] (see Section 3.2.5.1.). To create this data driven simulation, an excel database was sampled from the historical billing data using Monte Carlo (random number) methods. This database communicated with the Arena model and provided the creation schedule for patients, which is similar to work done by Giribone [38].

This ‘script’ was created by duplicating procedures from the dataset as frequently as they occurred, similar to Dexter [47]. For example, if hip replacement surgery was in the historical record 436 times, then the ‘script’ would contain 436 lines of “hip replacement surgery”. The mean procedure duration was computed in Phase 4 but the different historical values are used as indicative durations in the ‘script’. Using a random number generator, a VBA code steps through the list of over 30 000 procedures, rearranging it randomly, creating a different sequence of procedures. This randomised list of historical data forms the ‘script’ for the simulation model. This approach is consistent with Giribone [38]. This is preferable to using occurance distributions for all procedures, as some procedures occur as rarely as four times over the course of three years.

A simple scheduling algorithm was used which tested whether the next procedure’s mean duration + 10 % would fit into the remaining time for the proposed four-hour list. If not, then the list was ended at that point and the next time slot started. If the procedure could fit in, then the list was extended by one further procedure and the test was repeated. This is similar to the work done by Van Houdenhoven [48] and Dexter [47].

The ‘script’ was read into the simulation model and the results were analysed to see whether operational improvements could be made using a simple scheduling technique.

3.3.6. Phase 6

This was the summative phase, in which the outputs from the analytical models and from the heuristic models are compared against base criteria [56] and also against utilisation benchmarks as contemplated in section 2.3 . On the basis of this comparison, the conclusion will be reached how improved scheduling would affect the operations in the hospital under investigation.

Chapter 4: Results and Analysis

The results broadly follow the method as outlined in Chapter 3. More specifically, the results are presented as per the flowchart below.

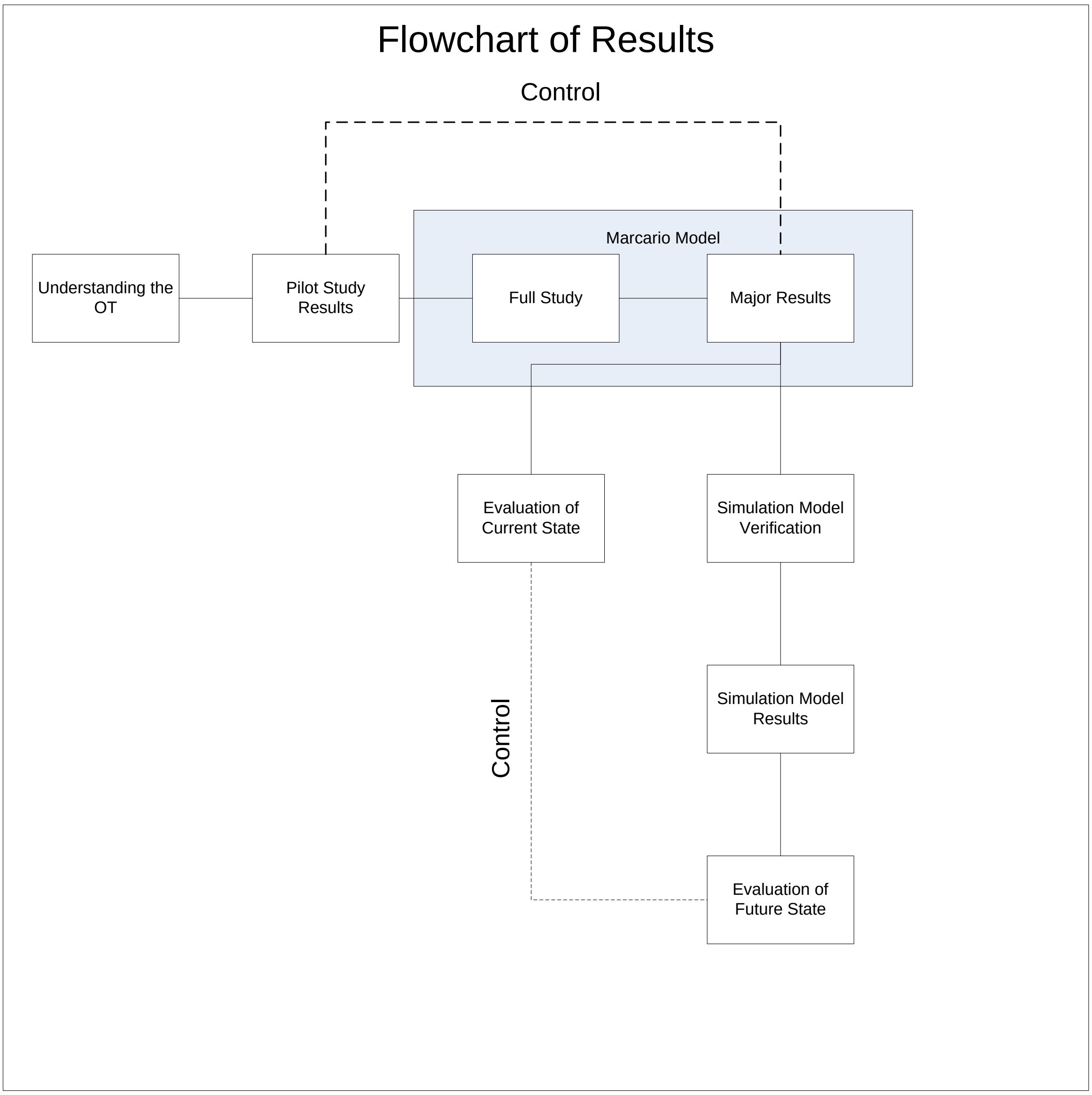

Figure 13: Flowchart of results

The qualitative investigation of the hospital, including observations will precede the results from the pilot study, which leads into the results from the full investigation. The major results are evaluated against the measurement model. Parallel to this, the simulation verification and calibration is presented, together with outputs due to changed operational strategies. These changed outputs are measured against the measurement tool and the results from the current state are compared to the updated (future) state.

4.1. Phase one: Qualitative assessment of the operating theatre complex.

The theatre complex consists of nine major theatres and one minor theatre. The major theatres are clustered on one floor in a single complex. The minor theatre is one floor below this cluster but it shares the facilities via an elevator. All equipment in the theatre complex can be moved from one major theatre to the next. Explicit theatre reservation exists only for one theatre, where heart surgery is performed daily. All other theatres have undergone some form of implicit reservation, as surgeons regularly operate in "their" theatre. No justification exists for this as infection control is adequate in all theatres[43] and specialist equipment can be transported to any theatre [44].

.

[43] Theatres are equipped with laminar flow ventilation, which implies approximately 300 complete air changes occur in the theatre per hour and consequently there is a very low presence of colony forming bacteria – which could lead to sepsis [150]. Some surgeons remain cautious, especially when performing open bone surgery, though literature suggests that such caution is generally unnecessary [150]

[44] All major specialist equipment is mobile, on wheels, thus every theatre can be equipped to perform any surgery.

The minor theatre ‘downstairs’ is used for two lists per week – dedicated to perform one particular procedure. The theatre was built at the request of a single surgeon who has almost exclusive use of this facility, though it could reasonably be used by others also.

The power balance during phase 1 was negative (see 3.2.1.3). Surgeons and nurses were suspicious of the researcher in the theatre. Many surgeons were unavailable for interviews and some medical professionals felt (and expressed) an academic superiority towards the researcher. Despite the negative power relationship, surgeons did not materially block the research contrary to Shaffir’s [63] predictions. The relatively long embedding period (in excess of half a year) ultimately led to a more neutral power relationship.

4.1.2. Interview results

Seventeen interviews were conducted which is a sufficient number of interviews as per section 3.2.1.2. Four major themes emerged. These related to resource dedication and reservation, operation and staff scheduling, staff morale and support and management functions. Elements of these themes were identified in the interviews. The tabulation is shown in Table 7.

Thematic Content Analysis: Interviews with Surgeons and staff.				
		Frequency		
Major Theme	**Condensed Topic**	**Doctors**	**Nurses**	**Total**
Dedication or reservation	Dedicated theatre expected by surgeons	|||	|	4
	Dedicated machinery wanted by surgeons	||	|	3
	Familiarity with particular nurse	||	||||	6
Support and management functions	Patients can't be found	||||	||	6
	Laundry and CSSD are inadequate	|	|	2
	Weak stock control	||||	|	5
	frequent over-budget equipment breakdowns	||	||	4
Staff morale	General staff shortages	|	|	2
	Too few nurses available to fill vacancies	||||||	|	7
	Night staff don't arrive - poor overtime pay	||		2
	Surgeon egos can be divisive	|||	|||	6
	Strained inter-personal dynamics	|	||	3
Operation and staff scheduling	Insufficient surgery time	|||||		5
	Too many doctors	||		2
	Too few slots	|||		3
	Poor scheduling	||||||	|	7
	Surgery overruns and prejudices next list	|||		3
	Time allocated to surgeons who don't fill lists	||||	|	5
	No preparation or anticipation for next case	|||	|	4

Table 7: Thematic content analysis of interviews

4.1.2.1. Dedication and reservation

Two surgeons indicated a desire for bespoke equipment or a set up specifically tailored to their needs, in many cases for their exclusive use. A particular surgeon demanded that the hospital purchase an expensive machine for him, as he had not learnt how to set up the existing machine to his specification after others had used it.

Three surgeons indicated a need for theatres dedicated to them personally or their speciality generally. Two surgeons asked that a particular scrub sister, or even a particular nurse be assigned personally to them whenever they are performing surgery, this view was strongly reinforced by the frustration of four nurses. One surgeon claimed "I will only perform surgery if <name removed> scrubs for me, and if I could, I would refuse to do surgery if they moved me out of *my theatre*[45]"

4.1.2.2. Operation and staff scheduling

Scheduling and allocation of theatres caused frustration for most surgeons. Five surgeons implied that they personally do not have enough theatre time whilst other surgeons get allocated too much time. A majority of surgeons identified poor scheduling as a severe operational constraint.

Surgeons and nursing staff were aware that there were too many surgeons vying for too few surgery slots, and that doctors who didn't have a list allocation of their own would have to "*beg borrow or steal operating time from others who don't use their full list* ~ interviewed surgeon".

[45] Emphasis by author

4.1.2.3. Staff morale

The health sector faces severe human resource issues, both in public and in private hospitals. Surgeons and nurses are aware of this and expressed the shortage of nurses as a significant worry. One surgeon linked the 1996 closing of nursing colleges to a skills and approach deficiency in recently qualified nurses. This is exacerbated by high levels of emigration by "good" nurses who leave South Africa for less stressful and higher paying positions.

It was claimed that nurses often have a poor bedside manner and lack respect and professionalism. Surgeons did concede that nurses work under stressful conditions, are poorly paid and work unpleasant hours, including night shifts.

The hierarchy in hospitals is strongly embedded. Surgeons and anaesthetists are at the top of the pyramid. Nurses, by rank, follow after this. Nurses implied that a large portion of their low morale was due to the treatment from surgeons. One nurse claimed that surgeons "shout at us, as if we're not real people and they treat us as if we're stupid".

The egos of surgeons were mentioned as a source of conflict by nurses as well as by surgeons. Doctors demand a particular type of food at the (free) lunch buffet whilst some surgeons require that nurses drop other activities to perform non surgery related tasks.

There is an adversarial relationship between doctors and staff in the theatre complex. This leads to interpersonal friction. Some heated arguments were observed and amongst themselves doctors or nurses frequently complain and gossip about the other group.

4.1.2.4. Support and management functions

Interviews showed unhappiness related to the management and support functions in the theatre complex.

Doctors highlighted stock control as unreliable, meaning that as a consequence medication or consumables were often not sufficient or accessible for surgery. Similarly other support functions such as the laundry were criticised for inadequate service.

The receiving area was criticised by at least four surgeons. Porters are lax about ensuring that patients are in reception at the right time for surgery. There is no supervisor for this area which makes monitoring it problematic. Anaesthetists were seen to go into the wards to fetch patients themselves. One surgeon claimed "I lose up to half an hour per list, because I can't find a patient"[46].

It was seen that surgeons make frequent sequence changes to the patients on their surgical lists, and hence "knowing which patient to bring next" becomes more complicated.

4.1.3. Further Observation

In addition to the themes above, several observations were made that came from being directly involved in the operations of the theatre complex.

4.1.3.1. Training

Training is inadequate. Setting up machines is an easy matter and surgeons should not request dedicated machines simply because they are unable to set these machines up. The lack of training appears to be one of the causes of frequent breakdowns.

[46] It is my observation that this was an exaggeration but this situation is nevertheless problematic.

4.1.3.2. Machinery

Machinery shortages are due to either missing machinery or breakdowns. Machines can be located in any of 13 stores or broken or away for repair. The hospital should implement a comprehensive maintenance strategy which may reduce these problems. Currently the strategy is only reactive and this means that occasionally several similar machines break at the same time, compromising theatre operations.

4.1.3.3. Lack of anticipation

There is a lack of anticipation of upcoming procedures. The following illustrates this point: a patient was admitted to the hospital after an MVA[47] at 07:43. At 12:00 the patient was wheeled into the OT for an emergency[48] splenectomy[49]. At this point, having been aware of this surgery for several hours, the theatre was not prepared, the equipment and instruments had to be hastily gathered. This led to further delay for a critically injured patient.

A similar observation can be made for planned cases, where surgeons wait an extended time for machinery, equipment, instruments or even people before they can start or continue with a procedure. One case was observed where a simple short laparoscopic[50] procedure which takes less than twenty minutes on average was delayed by more than half an hour for a specific machine to be found. During this time the hospital was earning income, however the patient was anaesthetised for the full duration.

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[47] Motor Vehicle Accident

[48] Emergency cases are very rarely wheeled directly into the theatre as patients are usually first stabilised prior to surgery

[49] The surgical removal of a spleen

[50] Keyhole surgery

4.1.3.4. Recovery Area (PACU)

During the observations period, it became evident that the PACU doesn't function as a bottle neck to theatre operations. There was sufficient capacity in this section to accommodate significantly higher demand. The PACU never reached capacity and always had available beds.

4.1.3.5. Facility layout

The facility layout is poorly matched to its purpose. Key aspects are that the flow was poor, with entering and exiting patients causing congestion in the receiving area. The "central functions" were not central at all but clustered on one side of the complex. It was problematic that at least 13 storage rooms exist in this complex, with no properly defined system for keeping track of equipment, thus extending searching time.

Some theatres internally have a poor layout. For example, anaesthetics machines need piped Nitrous Oxide however this is located on the opposite end of the room. As a result a long hose was slung to the machine, causing a tripping hazard. Other issues included non-adjustable lights, causing tall surgeons to bump their heads. One theatre is awkwardly shaped and makes walking around the patient impossible, with machines in the theatre.

4.1.3.6. Idleness

Significant underutilisation of the theatre complex was observed; theatres were frequently empty or in disuse. It was estimated that overall there was more staff idly outside, than in theatres performing work.

The impression of the theatre complex is that it is not busy. Very busy times, when all theatres are concurrently busy, are soon followed by a dropping work rate whilst tension, urgency and haste also reduce significantly. Two hours before a list change-over, the majority of theatres are empty, cleaned and ready for the surgery that would happen in the theatre at the start of the next list. This was indicative of low utilisation.

4.1.4. Summation

Phase 1 enabled an understanding of the operating theatre complex and also highlighted areas and opportunities for the implementation of industrial engineering tools. This is aligned with two of the objectives of this research as stated in section 1.6. The human dynamic in the theatre complex is characterised by a strong hierarchy and conflict, leading to low staff morale which leads to high staff turn-over. This is consistent with the findings of Gray-Toft [97]. Staff frustrations are driven by weak support and control functions. This weakness causes many surgeons to feel that they have inadequate or unfair theatre allocations, corroborating the departure point for this research as presented in section 1.2.

These issues arise from inadequate scheduling and in turn from low levels of anticipation and high levels of idleness. Idleness relates to utilisation [98], which can be scientifically measured. Although this phase proved that doctors *believe* that they have inadequate theatre time, it did not prove that this was in fact the case. Further measurement of this was necessary to independently verify these claims.

4.2. Phase 2: Pilot Study

The pilot study was conducted by activity sampling as outlined in section 3.3.2. The key result from this was that the overall utilisation of the theatre complex was below 50 %. Table 8 shows the breakdown of the various theatres, looking at the number of minutes used, the amount of minutes available and ultimately, based on these figures, utilisation.

Consider the following sample calculation for Theatre 1. During the nineteen 15-minute time steps, four were value adding (VA), fifteen were non value adding (NVA)[51].

This means that VA time was

$$4 \text{ x } 15 \text{ minutes} = 60 \text{ minutes}$$

Similarly, NVA time was

$$(19\text{-}4) \text{ x } 15 \text{ minutes} = 225 \text{ minutes}$$

Based on this, utilisation for Theatre 1 in terms of Equation 2 is:

$$\frac{60}{225 + 60} X\ 100\% = 21.1\%$$

The calculations for all other theatres were done similarly and the results are presented in Table 8 the raw data which these values are calculated from, is shown in Appendix 5.

Theatre Number	1	2	3	4	5	6	7	8	9	Overall
Value Adding Periods	4	12	14	7	10	0	16	15	7	85
Time Busy (mins)	60	180	210	105	150	0	240	225	105	1275
Time Available (hrs)	04:45	04:45	04:45	04:45	04:45	04:45	04:45	04:45	04:45	42:45:00
Time Available (mins)	285	285	285	285	285	285	285	285	285	2565
Utilisation	21.1	63.2	73.7	36.8	52.6	0.0	84.2	78.9	36.8	49.7

Table 8: Theatre utilisation pilot study results

The low utilisation, with substantial variation (Range: 0.842, Variance: 0.071) presented sufficient uncertainty to justify further and more in-depth analysis of the theatre complex.

This result is in conflict with surgeons' claims of inadequate theatre time, and required more rigorous testing. This gives a baseline for theatre complex utilisation, which addresses the second objective of this study (see section 1.6)

[51] It was observed during the pilot study that as many as 20% of cases had anaesthetised patients with no surgeon in the theatre. This means that a patient, who is ready for surgery, is waiting for the surgeon to either finish scrubbing or arrive, showing a lack of reliability in adhering to schedules.

4.3. Phase 3 – Data collection for full study

The data collected consisted of 28 columns and 28 992 rows (a reduced set of the raw data is included on the enclosed CD). Each column represented a data category; a list of these categories can be seen in Appendix 7. All the categories that were required are included in this data set. (section 3.3.3)

4.4. Phase 4 – Data processing and analysis tool creation

4.4.1. <u>Operation Volumes</u>

Over the test period, 2240 different procedures (identified by CPT codes) were performed of which 1154 procedures (51 %) were performed more than five times. The incidence of procedures ranged from 4 to 1743. The data showed 12 487 lists in this time, so the average list consisted of 2.3 surgical procedures. The mean list duration was found to be 135 minutes (360 minutes are allocated as a rule).

The theatre complex daily volumes were found to vary between 200 and 5500 minutes which translated to utilisation between 5 % and 76 % per day (Figure 14). This graph creates context to show how the theatres operate. There is no consistent level of loading from day to day, which may lead to waste or the inability to meet demand.

Seasonality can be seen in the period surrounding Christmas with lows below 1000 minutes per day which is indicative of South Africans (including surgeons) favouring the Christmas break for annual holidays. Additional lows follow no pattern and recur erratically. Peaks are explained by independently operating surgeons coincidentally having a higher workload on a particular day.

Overall volumes follow a gently downward trend, as shown by the trend line. Senior surgeons suggested that this trend may be because medical treatment (with medicine) is used increasingly frequently to treat cases which would previously have required surgical interventions.

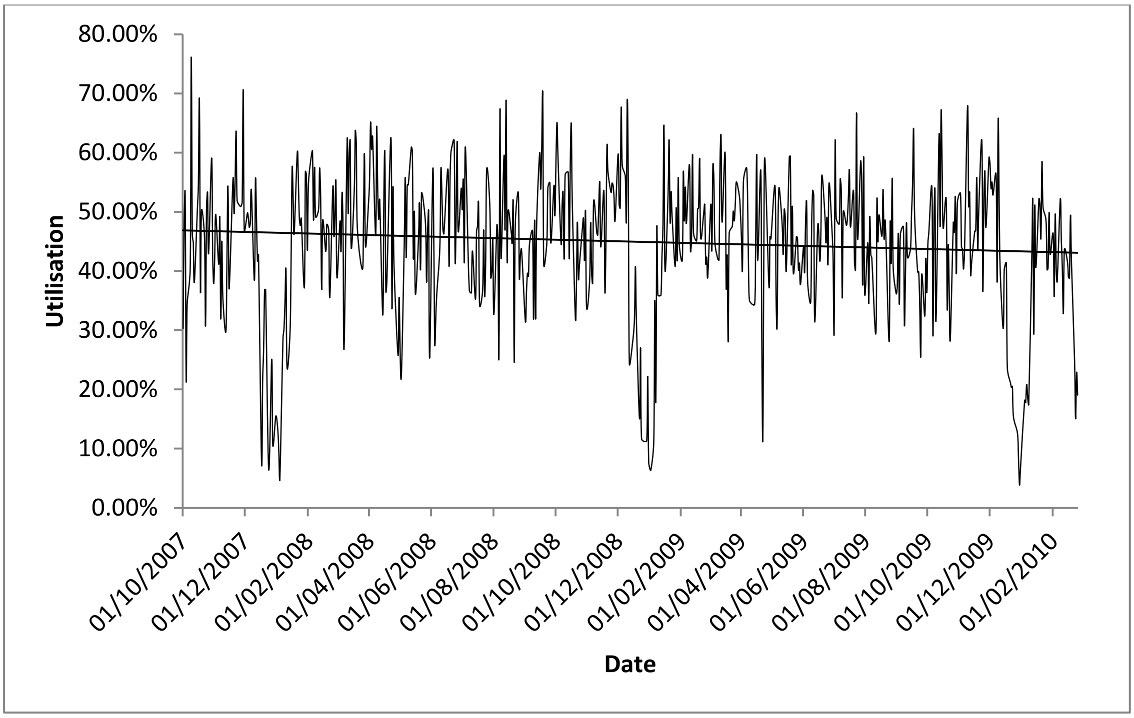


Figure 14: Theatre complex load, filtered for holidays and weekends

4.4.2. <u>Theatre Utilisation levels</u>

Pivoting the above data identified utilisation behaviour by weekday over the three years of available data. Figure 15 shows the load distribution by weekday over the course of the period under investigation. From this it can be seen that (as expected) weekends (Saturday and Sunday) are significantly less busy than normal weekdays. Note that the total number of minutes available per weekday per theatre, over the three year period of enquiry amounts to roughly 85 000 minutes. The daily number of minutes available per theatre is 720. The gap between the bar and the dashed line indicates the extent to which operating complex has fallen short of capacity. The error bars indicate the standard deviation of average day-to-day utilisation, which can be as large as a third of the mean. This is not unexpected in light of the significant variation which was seen in Figure 14.

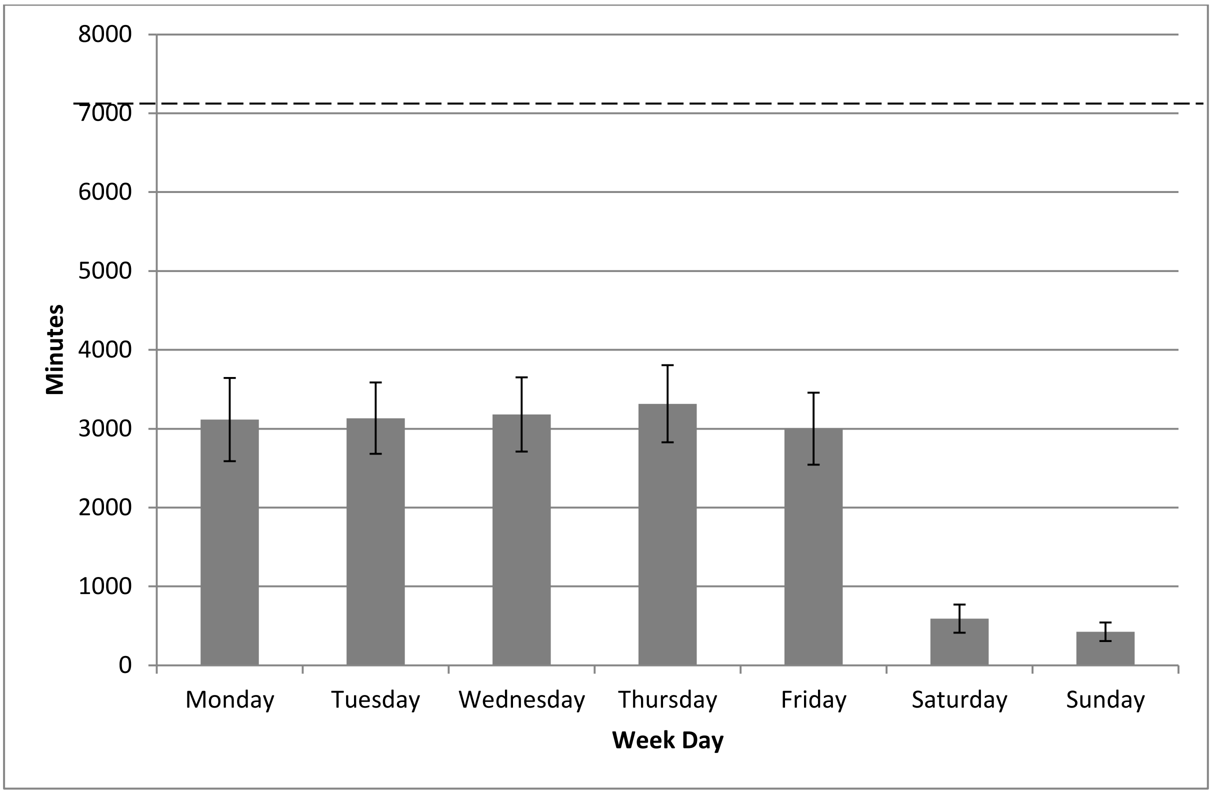


Figure 15: Theatre complex distribution of load throughout week

The trend of systemic underutilisation is common to all theatres individually; graphs similar to Figure 15 are available in Appendix 8 showing the behaviour of the remaining theatres. These graphs are included to show that no theatres are utilised to an acceptable level, which would typically be above 70 % as per section 2.3. Utilisation was calculated for each theatre and these results are presented below:

Sample calculation:

The filtered and summated data shows that for theatre 1, there were 187 904 billable minutes over the period of investigation, during which period there were 453 600 working minutes.

Applying Equation 2 we get: the average utilisation for theatre 1:

$$\frac{187\ 904}{453\ 600} \times 100\% = 41.42\ \%$$

Similarly, we can calculate average utilisation (overall or per day) per theatre or for the theatre complex. Table 9 summarises the utilisation as broken down by theatre, by weekday and also presents the overall view of the theatre complex. It can be seen that even the best performing theatre in this complex (Theatre 9 – 63 %) is performing below the benchmark utilisation of 70% - 80 %.

It is justifiable practice to take average utilisation levels for the theatre complex, as theatres are not differentiated and surgery can be performed in any other theatre, thus utilisation can be levelled across the entire complex [3]. Localised better utilisation is likely due to individual surgeons who do make better use of their time allocations.

It is particularly worrying that the theatre complex has an overall utilisation of 47 % and it is curious that surgeons believe that they have inadequate theatre time, considering that the hospital could theoretically perform twice as much surgery or cope with half as many theatres.

		Theatre 9	Theatre 8	Theatre 7	Theatre 6	Theatre 5	Theatre 4	Theatre 3	Theatre 2	Theatre 1	Gastro Thr	Total
TOTAL Minutes		286277	273627	214912	208711	178234	163471	284163	242698	187905	63639	2105329
Average Use Per Day		450.12	426.21	311.47	295.62	322.30	317.42	432.52	353.27	311.10	336.71	2395.14
Standard Deviation of Sample		201.07	209.46	184.43	165.39	169.10	182.09	190.49	207.24	167.41	113.68	1452.73
Maximum Mins / Day		1117	1084	1109	982	1369	2022	1273	1557	910	823	5481
Minimum Mins / Day		25	11	13	11	13	5	15	1	10	13	40
UTILISATION		**63.1%**	**60.3%**	**47.4%**	**46.0%**	**39.3%**	**36.0%**	**62.6%**	**53.5%**	**41.4%**	**14.0%**	**46.4%**
	Monday	63369	53445	35218	35268	37929	28764	56337	43098	39132	21	392694
	Tuesday	45370	62256	34789	31726	26835	28973	56746	52190	23498	32487	394870
	Wednesday	64063	43116	41219	41824	40882	29368	49954	51069	38225	730	400827
	Thursday	53048	63311	52589	26527	45587	43189	52212	42590	37571	13	417782
	Friday	48588	37215	35312	37518	25247	31457	52964	37094	36257	30388	372040
	Saturday	7346	9565	9203	18185	353	1351	12044	9857	6045	0	73949
	Sunday	4493	4719	6582	17663	1401	369	3906	6800	7177	0	53167

Table 9: Utilisation summary of operating theatre complex

4.4.3. Overall List Behaviour

To understand why utilisation levels may not correspond to perception, it is necessary to understand how the time allocated to lists is used. Figure 16 [52] shows a histogram of list durations. This was compiled from all lists that took place over the period of investigation. This shows 99 % of all lists run shorter than the six hours allocated by the hospital. In fact 96 % of lists are shorter than four hours and the bulk of lists (> 86%) last no longer than two hours. This is an indictment of the current scheduling philosophy as a whole, showing that the allocation is correct only in exceptional cases.

The average list duration over the period of investigation, was 72 minutes with a standard deviation of 69 minutes, giving a coefficient of variation of 0.7 [53]. This shows that in most cases, significant over-allocation, with its associated losses, have become entrenched. We can see this because the mean of 72 minutes is significantly below the actual allocation of 360 minutes. Even with the large variation in this system, 96% of all list durations fall within two thirds of the actually allocated time. It can furthermore be seen that only one percent of lists (124 out of 12 400) in the three years of data exceeded the allocated six hours.

Despite significant variation it is clear that the automatic granting of a six hour list is generous. The large amount of "unused time" [54] at the end of lists does contribute to the overall low utilisation that can be seen in Figure 15.

[52] The is a positively skewed lognormal distribution. This is common in human activity systems. The Kolmgorov-Smirnov test (see Appendix 11) shows that in the log-normalised form, the p value is ,01, showing insignificant deviation from the sample function. The skewness parameter is 1.96, showing positive skeweness, as the visual inspection supports.

[53] $Cv = \delta / \bar{x}$ the coefficient of variation, expresses the standard deviation in terms of the mean of the data. [153]

[54] This is measured as the difference between the six allocated hours of list time and the actual time used.

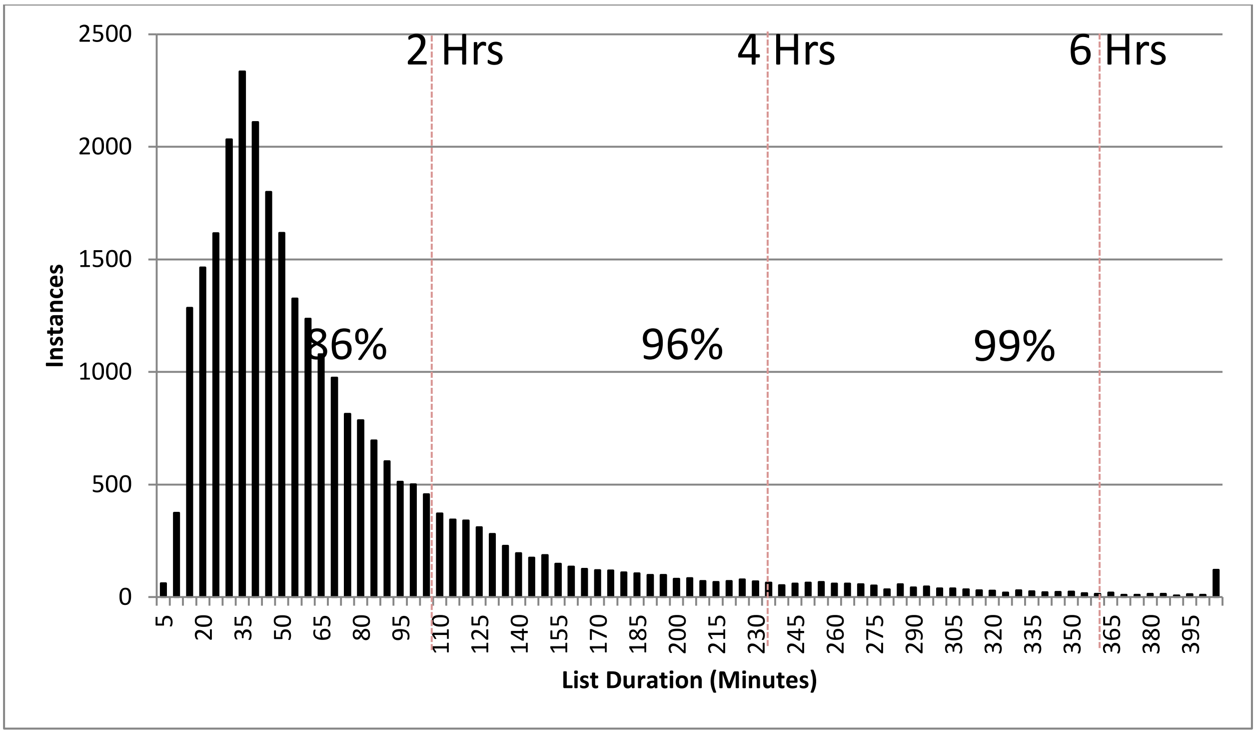


Figure 16: Overall list duration behaviour for theatre complex

4.4.4. Start time tardiness analysis

In light of the average list behaviour, it is surprising that one of the chief findings that emerged from interviews with surgeons in phase 1 was that they felt that they have inadequate theatre time. Surgeons should fit into current schedules, due to the slack in the system. One reason that allows the reality to conflict with the data is starting-time tardiness.

Figure 17 shows that despite the fact that lists should begin at 07:00, the most common starting time for this complex is between 07:30 and 08:30 Appendix 9 shows that a similar trend is present in all theatres individually. Tardiness in adhering to published starting times suggests significant discipline and control issues [56]. Surgeons need to proactively adhere to starting times and the complex management has to enforce this.

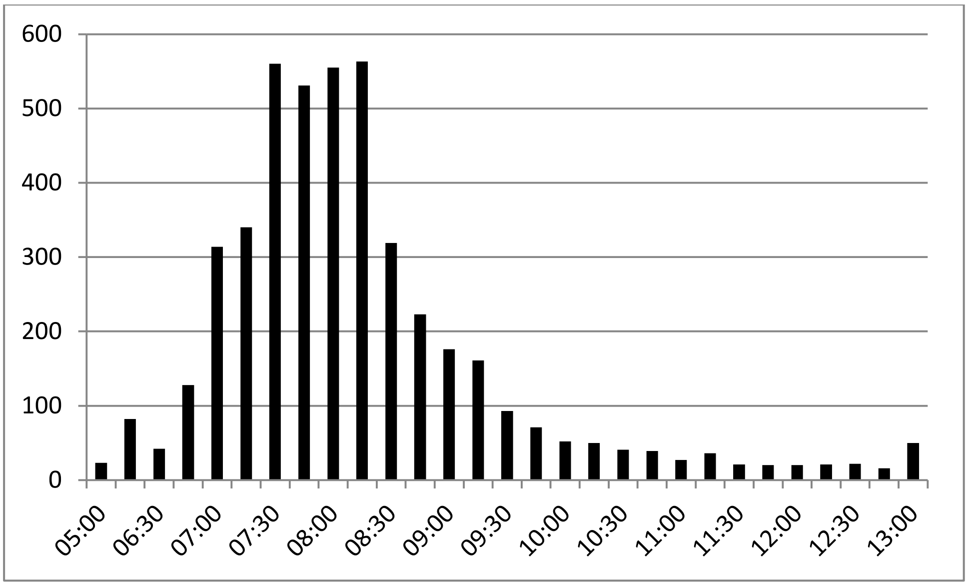


Figure 17: Theatre complex starting time analysis

The average starting time for the theatre complex is 64 minutes late. This was calculated by dividing the total late-start minutes by the number of lists in the time frame. On-time starts were defined as a start between 05:00 and 07:30. This analysis is shown in Appendix 10. Uncertainty exists how many cases before the official starting time of 07:00 are in fact emergency cases (and therefore not part of a planned list), and therefore excluded from the scope. To accommodate this uncertainty, all surgery after 05:00 was *deemed* planned, though the opposite is likely true because it is uncommen that scheduled lists start before 07:00. This means that the average late start-time is an optimistic scenario. At R 120 per minute (which is the usual charge out rate for an operating theatre), that means the hospital is deprived of over R 69 000 per day in unrecoverable revenue.

Macario's model measures accumulated late starts over the course of a list. This is not measured in the hospital in question as there is no patient – time allocation. Nevertheless, the single late start is already beyond the worst-case benchmark of 60 minutes per day.

4.4.5. Excess staff costs

Overtime payment data released by the hospital, shows that the budgeted support staff hours amount to 986 hours on average per month over the period of investigation. The actual monthly support time per month on average amounted to 1 115 hours. This means that the average excess cost amounted to 13 %[55] - above the benchmark of 10 %.

4.4.6. Set up times

Set-up times were well within international standards (see 2.4.3). The analysis was performed for all theatres. Table 10 shows the average set up times.

THEATRE	Average Set Up Times
Theatre 9	00:10
Theatre 8	00:09
Theatre 7	00:06
Theatre 6	00:09
Theatre 5	00:02
Theatre 4	00:07
Theatre 3	00:17
Theatre 2	00:04
Theatre 1	00:08
Gastro Thr	00:07

Table 10: Average set up times

It must be noted that there are two sources of error in this measurement. The change over time was the time between the first patient being clocked out and the next patient being clocked in. This means that setups at the start of a day do not get counted, and for theatres that do few long procedures the set up times contain errors. Another source of error was observed that a theatre change-over often begins whilst the first patient is still in the theatre and usually continues whilst the next patient is already in place. Thus as a simple measure the calculated average set up times are optimistic.

[55] This is a conservative value as overtime is actually paid at 150 % of hourly wage, and therefore the 13 % in monetary terms is realistically 19.6 %.

4.4.7. Prediction Errors and Case Cancellation rate

As discussed in Section 2.5, these two categories are included as dormant metrics in this model as they cannot be measured currently. This is due to the fact that there is no model that forecasts surgical duration, therefore actual procedure times have no basis for comparison. Similarly, without a rigid booking system, cancellations cannot be tracked, as this information is not stored nor administered by theatre staff. These metrics do not prejudice the results of the evaluation however, as prediction error is independent of all other metrics and case cancellations are implicitly measured through theatre utilisation.

4.4.8. Current State Evaluation

On the basis of the results, the theatre complex is now measured using the tool developed in section 2.5

Table 12 shows that the overall score for the hospital was 5 out of 12. The additional four points for categories 3 and 7 have been omitted as currently not monitor-able. It is of future concern however that with an adequate planning and control system, these aspects do become and indeed should be evaluated also.

Macario [7] states that a score of 5 out of 16 represents a dysfunctional theatre complex. This is seemingly not the case in this hospital as it does function, and the level of care is very good. Nevertheless, operationally, this hospital is far from efficient. The two aspects which passed convincingly, are where systemic wasteful overcapacity is beneficial. A PACU designed for higher volumes will not become a bottleneck because it has capacity in (costly) excess of demand. Similarly short change overs which cut into billed theatre time earn revenue for the hospital even though the patient ceases to derive value from these actions, as such, though seemingly world class, these change-over times may be artificial.

By contrast, the deficiencies of this theatre relate directly to a lack of adequate or comprehensive planning, scheduling or control. As a result the utilisation of the theatre is poor, the utility of the assets is lower than it could be and costs are higher than necessary. The theatre complex is inefficient and according to the criteria as developed for this research has numerous problematic focus areas.

4.4.9. Procedure Behaviour

Standard procedure behaviour was investigated, overall and per surgeon. A comprehensive set of 2239 different procedure-durations was compiled. This sheet reflects the average duration of the same[56] procedure performed by all the surgeons operating in the hospital. Furthermore the standard deviation of the procedures was calculated to investigate the extent to which procedures were spread. Table 11 shows a sample of these results

Procedure	**Average Duration (minutes)**	**Occurrences**	**Std Dev**
45378	33.9	1740	12.153
41899	49.2	1678	35.9757
43235	19.4	1495	14.0631
20680	51.2	655	29.8676
45380	34.2	583	10.8547
42820	40.6	474	11.225
43239	18.4	450	7.86101
59820	30.1	354	11.2466
77781	60.3	324	12.2563
59812	28.9	312	6.98464
69436	16.2	309	8.0779
58120	27.1	276	13.038

Table 11: Procedure behaviour

To further enhance this, a per-doctor average time was calculated. In other words, the same calculation is repeated, only the time is now surgeon specific.

[56] Procedures are codified using the so called IPC (international Procedure Codes). Therefore comparison is possible and relatively accurate.

	Characteristic	Measurement	Score	Pass/Fail	New	Score	Pass / Fail	Comment
1	Excess staffing costs	13% **0 : > 10 %** 1 : 5 % - 10 % 2 : < 5 %	0	Fail	5 % - 10 %	1	Pass	Maturing discipline will improve this even further
2	Start Time Tardiness	64 mins **0 : > 60 Min** 1 : 45 - 60 min 2 : < 45 min	0	Fail	< 45 Mins	2	Pass	Discipline remains challenge, however this score is realistic
3	Case Cancellation Rate	- 0 : > 10% 1 : 5 % - 10 % 2 : < 5 %	-	-	-	-	-	no comprehensive booking system, no data, this will emerge as booking time becomes critical to the success of the theatre complex
4	PACU Admission Delays	< 10 % 0 : > 20 % 1 : 10 % - 20 % **2 : < 10 %**	2	Pass	< 10 %	2	Pass	Higher throughput may push the bottleneck into this area
5	Utilisation by theatre complex	47% **0 : < 60 %** 1 : 60 % - 75 % 2 : > 75 %	0	Fail	86%	2	Pass	this is highly dependent on better marketing - in other words getting patients into the (more efficient) theatre
6	Turnover Times	00:08:29 0 : > 40 min 1 : 25 min - 40 min **2 : < 25 min**	2	Pass	< 25 min	2	Pass	
7	Prediction Error	- 0 : > 15 min 1 : 5 min - 15 min 2 : < 5 min	-	-	-	-	-	this will be measurable one a good booking system with forecasting ability has been implemented
8	Prolonged turnover Percentage	18% 0 : > 25 % **1 : 10 % - 25 %** 2 : < 10%	1	Pass	< 10 %	2	Pass	will improve due to better understanding of daily demand
	TOTAL SCORE		5			11		
	TOTAL		12			12		

Table 12: Current State Analysis

4.5. Phase 5: The simulation.

4.5.1. Verification of the simulation model

To verify the simulation model it was run “to script” see section 3.3.5. If the results were similar to the actual results derived from the theatre record, then the model could be considered useful as a testing tool for strategic changes [95]. Three results were compared: total number of procedures (number of entities that passed through the system), total time operated and overall average theatre utilisation. The outputs of the simulation can be seen in Appendix 12,

The number of surgeries and total operating-time were identical and therefore the model was acceptable from these perspectives. The utilisation output was analysed for all theatres and found to differ (See Figure 18). This was expected because the simulation model and the real situation were analysed differently.

The two terms in the definition of utilisation are ‘productive time’ and ‘available time’ (Equation 1). In both scenarios, only work that took place on working days during working hours was recorded as ‘productive time’. This is because there were no data in the data script for non-working day procedures. ‘Available time’ was computed differently for the two scenarios. For the real situation, only twelve hours per working day were considered as ‘available time’. By contrast the time on all days between the start date and end dates of the simulation were counted internally by Arena as ‘available time’ (this also included non-working hours).

The same ‘productive time’ was recorded in both models, because this value is absolute. However in the case of the real situation, this was divided by 630, the actual number of working days, whereas in the case of the simulation model, the productive hours were divided by 881 days, which includes non-working days. As a result, the utilisation figures from the two systems do differ nominally but are actually the same because the Arena output includes ‘blank days’.

Although Arena allows the programmer to specify the number of working hours per day, a way to specify which days to exclude from the utilisation statistics was not found. Thus it is easier to treat all days as equal and to only post process for “blank days” after the event.

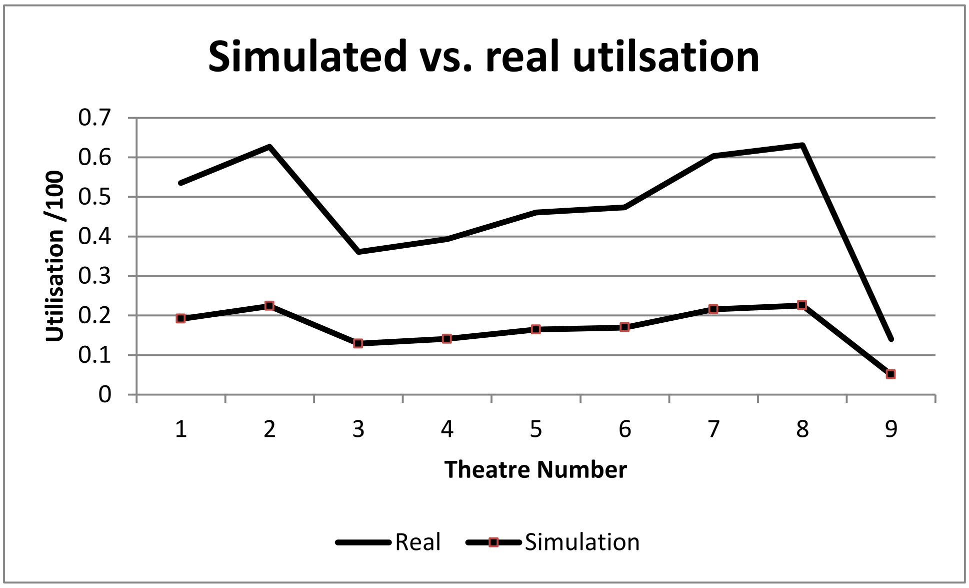


Figure 18: Simulated vs. Real results: Model Verification.

4.5.2. Model Calibration

To correct for the discrepancy of Arena counting non-working days and non-working hours, the utilisation, and only the utilisation outputs, were normalised using a correction factor based on the following reasoning:

- The real situation took place over 630 days (the number of working days, excluding weekends and holidays)
- The simulation model, used the actual number of days for the period under investigation, which was 881

- The real model assumed a 12 hour normal working day.
- The simulation model ran for 24 hours a day .

a correction factor K was calculated

$$K = \left(\frac{Simulation\ Days}{Actual\ Days}\right) \times \left(\frac{Simulation\ Duration\ of\ Day}{Actual\ Duration\ of\ day}\right)$$

$$K = \frac{881}{630} \times \frac{24}{12} = 2.796$$

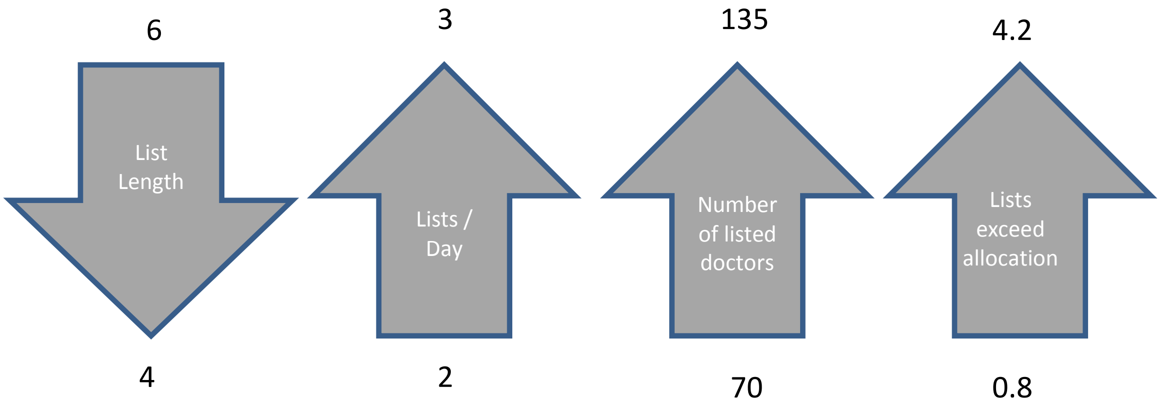
The value for the correction factor (K) is equal to 2.796. This factor is used only to correct the utilisation figures which the model has output. Other values such as total minutes spent and the number of patients are absolute and not influenced by the number of “blank” days counted. Table 13 shows that simulated and measured utilisations are similar with the maximum error being 0.2%

UTILISATION				
	Real	**Model**	**Calibrated Model**	**Error (%)**
Theatre 1	0.414252646	0.148	0.4139301	0.077862
Theatre 2	0.535048501	0.1913	0.535032623	0.002968
Theatre 3	0.62646164	0.2238	0.625929435	0.084954
Theatre 4	0.360385802	0.1288	0.36023106	0.042938
Theatre 5	0.392932099	0.1406	0.393233595	0.07673
Theatre 6	0.460121252	0.1644	0.45979803	0.070247
Theatre 7	0.473791887	0.1695	0.474061838	0.056977
Theatre 8	0.603234127	0.2155	0.602715788	0.085927
Theatre 9	0.631122134	0.2257	0.631243403	0.019215
Gastro Theatre	0.140298	0.0503	0.140680298	0.27249

Table 13: Calibrated utilisation figures from simulation model

We may conclude that the model is a good approximation of the real situation, and may be used to test alterations.

4.5.3. Modelled changes



The following altered structure was developed based on observations and results.

The key change is that list durations are reduced from six hours to four hours per surgeon per list. The operating day remains fixed at twelve hours, meaning that three lists can be accommodated. The number of surgeons who do have a list increases, but not by a factor of 3/2 as might be expected. This is because several surgeons who currently have one or two six-hour lists may in future make good use of two four-hour lists. This change significantly increases the number of surgeons who do have regular and scheduled access to the operating theatre at the hospital.

Currently fewer than 1% of lists exceed the allocated six hours. The modified state will raise this to 4.2 %, however this is if the current state, which lacks planning, scheduling and control is measured against future state scheduling norms. A revamped system should rigorously specify the permitted number and sequence of procedures per list. As such over-runs would be far fewer than the number presented here. Over-runs cannot be entirely ruled out in the medical field as complications (see footnote 15) may still extend the duration of a single procedure significantly.

4.5.4. Simulation Outputs

Having input the changed management philosophy into the simulation, the following results were achieved:

Simulated	Category	Theoretical Max
5895.78791	Maximum Mins/Day	6480
5081.016253	Minimum Mins/Day	0
5574.186676	Average Mins/Day	6480
149.867086	Stdev	-
1599791.576	Minutes total	1859760
26663.19293	Hours Total	30996
287	Days	-
814.7716567	Max/Min Range	6480
86.02%	**Utilisation**	**100.00%**

Table 14: Simulated Changes

The simulation predicts a theoretical utilisation of 86 % as feasible, which is comparable to the 85 % simulated capacity as proposed by Strum [46] and is generally in line with the levels as set in section 2.3. This level may within reason represent the actual capacity of the theatre complex. This is a best case scenario dependent on a variety of factors, including

- doctor discipline and adherence to the theatre management system
- Support system competence to enable the execution of medical procedures
- The availability of enough surgeons and sufficient demand from patients

The range between busy and quiet days has become narrower, which can be seen in the reduced standard deviation[57], however this is an artificial change as the simulation didn't model off-seasons (such as the New Year break), unexpected peaks or troughs in demand (such as one large bus accident or an ill surgeon, thus recording zero theatre hours). It did however show that on the whole the utilisation can be increased significantly, that the range

[57] Coefficient of variation = 0.02

is tightened, that the mean daily hours rises and that variation is reduced. These aspects can be seen in Figure 19

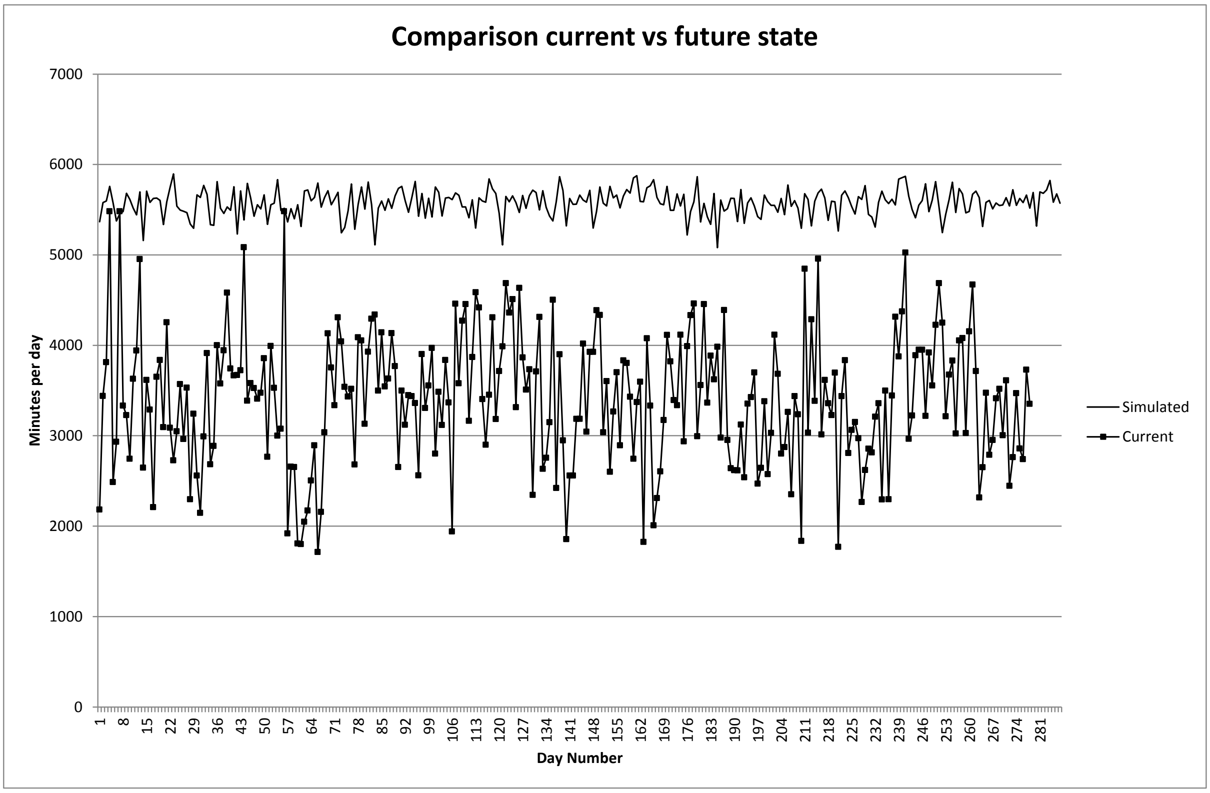


Figure 19: Comparison between improved and current state

4.6.1. <u>Usefulness of the measurement tool</u>

Changing the original metric of "revenue dollars per hour" to a "utilisation" figure improves the model in two ways, firstly, it internationalises the tool, rather than making it USA-centric. It furthermore immunises the measure against inflation, meaning that the benchmarks needn't be updated regularly to reflect future values of money.

Two categories were unevaluable using this model as no data or observation existed for them. This was not because these aspects were not measured, but rather that without a competent scheduling and planning system, are not measurable at all. Case cancellations, without clear knowledge of which cases are expected are not plottable. Similarly, without an expectation of what procedure duration should be, there can be no measurement of the extent to which the prediction is inaccurate. Therefore, the original model was evaluated out of 12, rather than 16. These categories have been left in the model as they are useful for a comprehensive theatre evaluation in the future.

The label "dysfunctional" is given to theatres which have a score of 5/16 or lower. As discussed, the scores are out of 12 for this particular scenario. It would be false to extrapolate which score now reflects as dysfunctional, however it is maintained that a score of 5/12 remains "dysfunctional". Those cases where the complex scored highly were examples of overcapacity. For example the PACU is excessively large and as a result bottlenecks infrequently occur here. This means that the good result here is coincidental, rather than engineered.

The criticism emerges that the theatre is not "dysfunctional" in the classical sense. Treatment does take place, the quality of medical care received in the theatre is not obviously poor, in fact, the quality seems excellent, patients do not wait excessive amounts of time to get into theatre and recovery rates of patients is comparable with global best practice. "Dysfunctional" in this case needs to be interpreted differently. What dysfunctional means in our context is that the theatre can and should be far more agile and flexible – it should be much more highly loaded, and the management of the theatre should have a far stronger predictive – planning – control function. Because these categories are weak, the theatre is dysfunctional as an effective revenue generator for the hospital.

It is concluded that this modified model is a good current and future measurement tool to gauge the efficiency of an operating theatre complex.

4.6.2. <u>Usefulness of simulation</u>

The use of a simulation as a proofing tool was successful in exploring the complexities of this system without putting patients at risk. The use of simulation also safe-guarded doctors' practices; these are commercial ventures and therefore should not be exposed to risk. Finally the hospital's operations were not compromised during an experimental phase.

4.6.3. <u>Scope of improvement</u>

This work tested whether industrial engineering can make an improvement to the way in which the theatre complex runs. The modified tool was useful to track this improvement. I believe that the changed system presents a significant opportunity to improve the efficiency of the operating theatre in question and theatres elsewhere. The deficiencies that have been identified are common to many private operating theatres in South Africa based on my observations.

4.6.4. **Feasibility of implementation**

The question remains whether this improved model will actually result in improved results from the theatre complex. The answer is yet again twofold and now rests on aspects of change management and discipline.

The current state operates easily, there is always spare capacity. By contrast the new model will be more tightly packed and consequently there will be less opportunity to have a *laisez faire* attitude. It is likely that surgeons and support staff will prefer to maintain status quo, as it is easier be conservative, than to implement potentially stressful changes. It will be important that the hospital employ change management specialists to assist the transition towards a new agile system which will be busier and possibly more stressful, because there will be less slack to cover up mistakes.

The second aspect that needs to be addressed as a matter of urgency is operational discipline. Surgeons should realise that theatres which are at their disposal free of charge are not therefore valueless. Surgeons need to adhere to starting and other scheduled times in the theatres, as tardiness and ill-discipline will compromise the proposed system.

This work makes the proposal that the volume of surgery can be almost doubled. It is assumed that enough patients can be found to make up the time being made available to surgeons. Finding these patient numbers will be a marketing function. Should the hospital fail in finding such numbers, they may choose to shut down underutilised theatres, thus cutting overheads.

4.7. Phase 6: Evaluation of the upgraded state.

The new state makes several fundamental improvements over the existing situation. The improvement to utilisation through improved scheduling is explicit. A large proportion of the improvements is implicit and stems from having a planned schedule as a departure point. Assumptions have to be made to back up some of the improvements. For example tardiness will improve if surgeons do adhere to starting times as published and keep to their schedules, this may be enforced through penalty charges [98]. Further derived improvements are a reduction in overtime cost, and with a revised shift structure, there will be fewer long turnovers.

The score sheet presented in Table 15 is an optimistic view, subject to operational discipline. I do believe that it is a realistic scenario provided that the scheduling principles are followed.

	Characteristic	Measurement	Score	Pass/Fail	New	Score	Pass / Fail	Comment
1	Excess staffing costs	13% **0 : > 10 %** 1 : 5%- 10% 2 : <5%	0	Fail	5% - 10%	1	Pass	Maturing discipline will improve this even further
2	Start Time Tardiness	64 mins **0 : > 60 Min** 1 : 45 - 60 min 2 : <45 min	0	Fail	< 45 Mins	2	Pass	Discipline remains challenge, however this score is realistic
3	Case Cancellation Rate	- 0 : >10% 1 : 5%- 10% 2 : <5%	-	-	-	-	-	no comprehensive booking system, no data, this will emerge as booking time becomes critical to the success of the theatre complex
4	PACU Admission Delays	< 10 % 0 : >20% 1 : 10%- 20% **2 : < 10 %**	2	Pass	< 10 %	2	Pass	Higher throughput may push the bottleneck into this area
5	Utilisation by theatre complex	47% **0 : < 60 %** 1 : 60%- 75% 2 : >75%	0	Fail	86%	2	Pass	this is highly dependent on better marketing - in other words getting patients into the (more efficient) theatre
6	Turnover Times	00:08:29 0 : >40 min 1 : 25 min - 40 min **2 : < 25 min**	2	Pass	< 25 min	2	Pass	
7	Prediction Bias	- 0 : >15 min 1 : 5 min - 15 min 2 : <5 min	-	-	-	-	-	this will be measurable one a good booking system with forecasting ability has been implemented
8	Prolonged turnover Percentage	18% 0 : >25% **1 : 10 % - 25 %** 2 : <10%	1	Pass	< 10 %	2	Pass	will improve due to better understanding of daily demand
	TOTAL SCORE		5			11		
	TOTAL		12			12		

Table 15: Evaluation of simulated future state

Chapter 5: Conclusion

The chief finding of this research is that the theatre complex that was studied is inefficient. This is strongly supported through low utilisation, but also through other dimensions, such as high overtime costs and general tardiness as presented in this report. Facing future risks such as the introduction of NHI, operating theatres could significantly improve their operating theatre efficiency, thus increasing revenue and becoming more agile organisations.

4.7.1. <u>National Health Insurance (NHI)</u>

This research report has highlighted the deficiencies in the running of a private hospital theatre complex. It is nevertheless believed that efficiency gains *could* translate into other hospitals and also into the present and future public healthcare industry.

Consider a little Gedankenexperiment, to frame this section. Government is fully intent on implementing national health insurance.

Picture healthcare as a rectangular box in front of yourself. Consider the base of the box as the number of people that can get access to healthcare. Think of the height of the box as the quality of this service. Therefore the volume of the box represents the current healthcare system. In order to implement the NHI, we will have to enlarge the base of our box and also make it taller. The new volume is the proposed healthcare system under NHI. The reasoning that has been used to cost NHI is that the box has to be made this *much larger, therefore it will cost* this *much more than the current system.*

The error in this reasoning is that it chooses to perpetuate current inefficiencies. Using a simple multiplier means that the new system will be as wasteful as the current one. If the focus instead is on improving efficiency of the existing system, gains can be similar for less or even no additional cost.

NHI places private healthcare under similar pressure, as it is likely that the private healthcare market share will drop due to increasing affordability issues. The excesses inherent to this system will have to be overcome to offer private healthcare to a potentially declining clientele who can collectively uphold an inefficient system such as that.

4.7.2. Summary

This work has revealed a very small part of the malaise that faces healthcare in South Africa's private healthcare sector. This exists beyond the operating theatres of one hospital, but is a systemic difficulty facing many complex systems. Similar improvements can be made in both private and public hospitals in areas as diverse as emergency vehicle routing, queue management in casualty, layout of facilities narrowly and hospitals broadly, laundry, kitchen and procurement services. This work can extend into questions surrounding quality, service measurement and cost. Expanding this research even further would serve as an important mechanism to make medical care in South Africa better, more affordable and even more profitable.

4.8. Conclusions

To conclude this research, we reprise the research questions which have guided this research:

Q1: How efficiently is the test site running?

Q2: How can the efficiency of the test site be modified using scheduling methods?

Q3: Why are there impediments to the efficient running of the Operating Theatre complex at the test site?

On the information presented in this research report the following conclusions can be made.

1. In the current state, the theatre complex is utilised 47% and the best theatre has a utilisation of 63%, which remains well below the best practise benchmark between 70% and 80 %
2. Theatres are implicitly reserved, though no justification exists for this.
3. The current state efficiency score for a South African private theatre complex is five out of 12 this classifies this theatre complex as dysfunctional
4. A lack of proper planning, and scheduling allows the current system to be operating uncontrolled
5. This study shows that lean thinking, defined as the pursuit of waste minimisation, can significantly increase the utilisation (up to 86%) and by extension the efficiency (up to 11/12) of an operating theatre complex
6. Non adherence to starting times, changes in patient sequences and the casual adding or removing of patients from surgical lists highlights poor discipline by surgeons
7. Interpersonal politics and egos complicate the smooth and goal-aligned operations within a surgical theatre
8. Industrial engineering is a necessary contributor for healthcare improvement

4.9. Recommendations

In order to capitalise on the theoretical gains that have been achieved, it is necessary to implement several aspects into the management philosophy of the theatre complex as follows:

1. Introduce a full scheduling system with procedure duration prediction intelligence.
2. Reduce the fixed duration list from six hours down to four hours.
3. Prioritise the administrative and operational function in the theatre to support surgery.
4. Prioritise surgeons' adherence to published schedules through a system of incentives or, if this proves unsuccessful, sanctions.
5. Collectively lobby the government to make amendments to law which would permit the direct hiring of doctors by hospitals.

5.4. Future Work

This work is and remains incomplete. The small amount of work that has been done in this field can be significantly expanded. The following remain inadequately explored in the South African context:

1. The measurement model has not been completely tested. This is because two characteristics have been unmonitorable in the current context. Expanding the study to also evaluate these characteristics is advisable
2. No broad South African study into Utilisation benchmarks in operating theatres exists, neither in private nor public healthcare networks. These should be established.

3. A real time and dynamic operations scheduling system incorporating predictive intelligence should be created using the information gathered for this study.
4. The current simulation may be enriched to more thoroughly simulate the complexity, especially through the use of agent based modelling techniques.
5. An understanding of hospitals from the systems engineering perspective is lacking. It is my view that much of the difficulty experienced by the health sector is because there is a lack of integration between the functions of a hospital, the various systems which define it and the way in which they either do or don't work together. The intuitive reality, is that hospitals are highly complex systems of systems and an understanding of that may show even greater benefit than that which was presented in this work.
6. [4] Must be augmented by the management systems for the hospital, including records keeping, management and distribution as needed.

It is my belief that this work presents significant opportunity for further study. It is evident that a systematic understanding of healthcare in this country is lacking. Building on this, I believe there is sufficient scope to expand this work into a doctorate in industrial and systems engineering

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Appendices

Appendix 1: Procedure Costs in Public healthcare facilities [99]

Category	Attending Professional	Annual Income	Primary Health Care Clinics	District Hospital	Regional Hospital	Central Hospital
H1	General medical practitioner	R36,000	FREE		R20.00	R20.00
H1	Specialist medical practitioner	R36,000	FREE	R35.00	R35.00	R40.00
H1	Nursing practitioner	R36,000	FREE	R15.00	R15.00	R20.00
H1	Allied health practitioner	R36,000	FREE	R15.00	R15.00	R20.00
H2	General medical practitioner	R72,000	FREE	R65.00	R65.00	R75.00
H2	Specialist medical practitioner	R72,000	FREE	R110.00	R110.00	R120.00
H2	Nursing practitioner	R72,000	FREE	R50.00	R50.00	R60.00
H2	Allied health practitioner	R72,000	FREE	R50.00	R50.00	R60.00
Private	General medical practitioner	Above R72,000	FREE	R97.00	R97.00	R106.00
Private	Specialist medical practitioner	Above R72,000	FREE	R163.00	R163.00	R172.00
Private	Nursing practitioner	Above R72,000	FREE	R76.00	R76.00	R85.00
Private	Allied health practitioner	Above R72,000	FREE	R77.00	R77.00	R86.00

Appendix 2: Power Relationships

Positive power balance

In a positive power balance, in field research, the researcher is usually highly revered; this researcher would be a person with a university qualification, whereas often the subjects are not. The researcher is frequently from a different - typically higher - social class, better-spoken, more educated, more accomplished, more thoughtful etc. Beyond this, the researcher would be studying the subjects, which often creates the sense within the subjects, that they are lab-rats in experiments. All these factors combine to elevate the researcher tacitly to a position of greater power within the structure being investigated. A typical feature of such a power relationship is that the subjects try to impress the researcher [100]. This may manifest as exaggerated responses to aspects of perceived prestige or any form of behaviour that is overtly to please the researcher – yet not a real reflection of the conventional behaviour of the group.

In a group where the power lies with the researcher, the results have to be filtered against the group's natural behaviour. This filtering is unscientific and requires much experience from the researcher to apply appropriately.

Negative power balance

The other extreme of power relationships, is where the researcher enters a corporate or political environment, where the researcher is viewed as ignorant and uninitiated. The power is now held by the subject. It is commonly observed in such circumstances that the researcher is viewed with great suspicion, as the researcher may endanger certain practices if they are discovered. As a consequence, a significant characteristic of this type of power structure, is that the researcher is frequently blocked in executing his research [101] [64] [62]. By contrast with a positive power balance, in this type of relationship, data will commonly be withheld; answers will be incomplete and not as forthright as in the positive power balance situation. The researcher will have to be conscious of purposeful deception and inaccurate answer given to mislead and to make the subject appear more able or accomplished than is the reality [101].

In a group where the power lies with the subjects, a researcher needs to establish a trust relationship with the subjects. This allows reticent or withholding subjects to be more comfortable sharing information with the researcher with reduced fear. In addition to this, prolonged embedding within a subject group would elevate the comfort that subjects feel when dealing with the researcher. [102]

Neutral power balance

A neutral power balance is preferable in most research studies. It allows individuals to participate freely, with little or no exaggeration or obfuscation. It is the ideal environment for inexperienced researchers, as results and observations can be interpreted with very little filtering to eliminate inaccuracies. A neutral power balance is however rare, as it requires that the subjects feel neither a need to impress nor the need to suppress potentially incriminating information [101].

Such a low level of emotional involvement in a study does carry with it the risk that the subjects may not be invested in getting a good result. The researcher needs to maintain the momentum and the drive in a neutral power balance as the subjects cannot be relied on to carry the research.

A neutral power relationship is common in long term research, where a researcher and a subject or group have interacted for an extended time, where the parties have become familiar with each other, and are therefore able to exhibit more or less natural behaviour.[58] It is this "natural behaviour" which scientific enquiry attempts to record and understand. Attaining "naturalness" represents the ideal state for research. [102]

In order to come to a neutral power relationship, researchers in the social sciences often follow an approach of deeply embedded participant observation. Such research could take place where a researcher becomes a legitimate and full time member of a particular society and can remain embedded within this society for extended periods, which may run into years [102] [103]

[58] A good example of this is the CBS reality show, "Survivor" where individuals are filmed in a location for as long as forty days. After a while, the participants become seemingly oblivious to the cameras surrounding them, and begin behaving in a natural manner.

Appendix 3: Extract from "Making Money" [104] by Terry Pratchett as an illustration of simulation.

" MOIST HAD SEEN GLASS being bent and blown, and marvelled at the skill of the people who
did it — marvelled as only a man can marvel whose sole skill is in bending words. Some of those geniuses had probably worked on this. But so had their counterparts from the hypothetical Other Side, glassblowers who had sold their souls to some molten god for the skill to blow glass into spirals and intersecting bottles and shapes that seemed to be quite close but some distance away at the same time. Water gurgled, sloshed and, yes, glooped along glass tubing. There was a smell of salt.
Bent nudged Moist, pointed to an improbable wooden hatstand, and wordlessly handed him a long yellow oilskin coat and a matching rain hat. He had already donned a similar outfit, and had magically procured an umbrella from somewhere.
…
'What's it doing?' said Moist.
Bent rolled his eyes. 'Hell knows, Heaven suspects,' he said. He raised his voice. 'Hubert? We have a visitor!'
…
'A visitor?' said Hubert nervously. 'Wonderful! We don't get many down here!' Hubert wore a long white coat, with a breast pocket full of pencils.
…
'Mr Lipwig is the Postmaster General, Hubert,' said Bent.
'Is he? Oh. I don't get out of the cellar very much these days,' said Hubert…., we're so close to perfection, you see,' said Hubert. 'I really think we're nearly there…'

'Mr Hubert believes that <u>this… device is a sort of crystal ball for showing the future</u>,' said Bent, and rolled his eyes.

' *Possible* futures. Would Mr Lipstick like to see it in operation?' said Hubert, vibrating with enthusiasm and eagerness. Only a man with a heart of stone would have said no, so Moist made a wonderful attempt at indicating that all his dreams were coming true.
'I'd love to,' he said, 'but what does it actually do?'
too late, he saw the signs. Hubert grasped the lapels of his jacket, as if addressing a meeting, and swelled with the urge to communicate, or at least talk at length in the belief that it was the same thing.
'The Glooper, as it is affectionately known, is what I call a quote analogy machine unquote. It solves problems not by considering them as a numerical exercise but by actually duplicating them in a form we can manipulate: in this case, the flow of money and its effects within our society become water flowing through a glass matrix — the Glooper. The geometrical shape of certain vessels, the operation of valves and, although I say so myself, ingenious tipping buckets and flow-rate propellers enable the Glooper to simulate quite complex transactions. We can change the starting conditions, too, to learn the rules inherent in the system. For example, we can find out what happens if you halve the labour force in the city by the adjustment of a few valves, rather than by going out into the streets and killing people.'
'A big improvement! Bravo!' said Moist desperately, and started to clap.
No one joined in. He shoved his hands in his pockets.
'Er, perhaps you would like a less, um, dramatic demonstration?' Hubert volunteered.
Moist nodded. 'Yes,' he said. 'Show me… show me what happens when people get fed up with banks,' he said.

'Ah, yes, a familiar one! Igor, set up program five!' Hubert shouted to some figure in the forest of glassware. There was the sound of squeaky screws being turned and the glug of reservoirs being topped up.

'It certainly looks very… complex, this thing of yours,' said Moist, striking out for normality.
'Er, yes,' said Hubert, a little bit thrown. 'And we are refining it all the time. *For example, floats coupled to ingenious spring-loaded sluice gates elsewhere on the Glooper can allow changes in the level in one flask to automatically adjust flows in several other places in the system*—'
'What's that for?' said Moist, pointing at random to a round bottle suspended in the tubing.
'Phase of the Moon valve,' said Hubert promptly.
'The *moon* affects how money moves around?'
'We don't know. It might. The weather certainly does.'
'Really?'
'Certainly!' Hubert beamed. 'And we're adding fresh influences all the time. Indeed, I will not be satisfied until my wonderful machine can completely mimic every last detail of our great city's economic cycle!' A bell rang, and he went on: 'Thank you, Igor! Let it go!'
Something clanked, and coloured waters began to foam and slosh along the bigger pipes. Hubert raised not only his voice but also a long pointer.
'Now, if we reduce public confidence in the banking system — watch that tube there — you will see here a flow of cash out of the banks and into Flask Twenty-eight, currently designated the Old Sock Under the Mattress. Even quite rich people don't want their money outside their control. See the mattress getting fuller, or perhaps I should say… thicker?'
'That's a lot of mattresses,' Moist agreed.
'I prefer to think of it as one mattress a third of a mile high.'
Slosh! Valves opened somewhere, and water rushed along a new path.
'Now see how bank lending is emptying as the money drains into the Sock?' *Gurgle*! 'Watch Reservoir Eleven, over there. That means business expansion is slowing… there it goes, there it goes…' *Drip*!
'Now watch Bucket Thirty-four. It's tipping, it's tipping… there! The scale on the left of Flask Seventeen shows collapsing businesses, by the way. See Flask Nine beginning to fill? That's foreclosures. Job losses is Flask Seven… and there goes the valve on Flask Twenty-eight, as the socks are pulled out.' *Flush*! 'But what is there to buy? Over here we see that Flask Eleven has also drained…' *Drip*.
Except for the occasional gurgle, the aquatic activity subsided.
'And we end up in a position where we can't move because we're standing on our own hands, as it were,' said Hubert. 'Jobs vanishing, people without savings suffering, wages low, farms going back to wilderness, rampaging trolls coming down from the mountains—'
'They're here already,' said Moist. 'Some of them are even in the Watch.'
'Are you *sure*?' said Hubert.
'Yes, they've got helmets and everything. I've seen them.'
'Then I expect they'll be wanting to rampage back to the mountains,' said Hubert. 'I think I would if I were them.'
'You believe all that could really happen?' said Moist. 'A bunch of tubes and buckets can tell you that?'' They are correlated to events very carefully, Mr Lips wick,' said Hubert, looking hurt. 'Correlation is everything. Did you know it is an established fact that hemlines tend to rise in times of national crisis?'
'You mean—?' Moist began, not at all certain how the sentence was going to end.
'Women's dresses get shorter,' said Hubert. And that causes a national crisis? Really? How high do they go?' ” …

Appendix 4: Sample activity sampling sheet

Time	Waiting Area	Theatre 1	Theatre 2	Theatre 3	Theatre 4	Theatre 5	Theatre 6	Theatre 7	Theatre 8	Theatre 9	Recovery
10:30											
Activity											
People											
Type											
Patient In?											
10:45											
Activity											
People											
Type											
Patient In?											
11:00											
Activity											
People											
Type											
Patient In?											
11:15											
Activity											
People											
Type											
Patient In?											
11:30											
Activity											
People											
Type											
Patient In?											
11:45											
Activity											
People											
Type											
Patient In?											

Appendix 5: Pilot Study Results - Sample

Time	Waiting Area	Theatre 1	Theatre 2	Theatre 3	Theatre 4	Theatre 5	Theatre 6	Theatre 7	Theatre 8	Theatre 9	Recovery
10:30											
Activity	0	op	0	op	op	prep	0	prep	anaesth / prep	op	
People	2	5	4	7	6	3	0	5	4	2	3
Type	nr	dr, an, nr 3	nr	dr 2, an, nr4	dr 2, an, nr3	nr 3	0	nr 5	dr, an, nr 2	dr 2	nr 3
Patient In?	2	1 down	0	1 down	1 down	0	0	0	1 up	1 up	2
10:45											
Activity	0	op	0	op	op	anaesth / prep	0	anaesth / prep	op	op	
People	2	5	4	5	5	5	0	6	5	4	2
Type	nr 2	dr, an, nr 3	dr, an, nr2	dr 2, an, nr2	dr, an, nr 3	an, nr 4	0	dr, an, nr 4	dr, an, nr 3	dr, an, nr	nr 2
Patient In?	1	1 down	0	1 down	1 down	1 up	0	1 up	1 down	1 down	2
11:00											
Activity	0	prep	prep	op	op	op	0	op	op	op	
People	4	5	5	6	4	8	0	7	3	4	2
Type	nr 4	an, nr 4	dr, nr 4	dr 2, an, nr3	dr, an, nr 2	dr 2, an, nr 5	0	dr, an, nr 5	dr, an, nr 1	dr, an, nr 2	nr 2
Patient In?	1	0	0	1 down	1 down	1 down	0	1 down	1 down	1 down	1
11:15											
Activity	0	anaesth /	anaesth /	op	anaesth /	op	0	op	op	op	

		prep	prep		prep						
People	2	5	5	6	5	7	0	9	4	4	3
Type	0	an, nr	an, nr 4	dr 2, an, nr 3	dr, an, nr 3	dr 2, an, nr 4	0	dr, an, nr 7	dr, an, nr 2	dr, an, nr 2	nr 3
Patient In?	0	1 up	1 up	1 down	1 up	1 down	0	0	1 down	1 down	0
11:30											
Activity	0	0	anaesth / prep	open	op	op	0	op	anaesth / prep	anaesth / prep	
People	2	0	3	5	5	5	0	5	5	3	2
Type	nr 2	0	an, nr 2	dr 2, an, nr 3	dr, an, nr 3	dr 2, an, nr 3	0	dr 2, an, nr	dr, an, nr 3	nr 3	nr 2
Patient In?	1	0	1 up	I down	1 down	1 down	0	1 down	0	0	2
11:45											
Activity	0	0	0	opend	opend	op	0	clean	anaesth / prep	0	
People	2	0	1	5	5	7	1	3	5	1	4
Type	nr 2	0	dr	dr 2, an, nr 2	dr, an, nr 3	dr 2, an, nr 4	nr 1	nr 3	dr, an, nr 3	nr 1	nr 4
Patient In?	1	0	0	1 down	1 down	1 down	0	0	1 up	0	3
12:00											
Activity	0	clean	anaesth / prep	op	clean	opend	0	anaesth / prep	op	0	
People	2	1	5	3	3	8	0	8	6	0	2
Type	dr, nr	nr 1	an, nr 4	dr, nr 2	nr 3	dr, an, nr 5	0	an, nr 7	dr, an, nr 4	0	nr 2
Patient	1	0	1 up	1 down	0	1 up	0	1 up	1 down	0	1

In?											
12:15											
Activity	0	0	anaesth / prep	endop	0	clean n	0	opend	op	0	0
People	1	0	4	3	0	2	0	7	4	0	4
Type	dr, nr	nr	an, nr 3	dr, nr 2	0	nr 2	0	an, nr 6	dr, an, nr 2	0	nr 4
Patient In?	1	0	1 up	1 down	0	0	1 down	1 down	1 down	0	1
12:30											
Activity	0	0	opend	clean	0	0	0	op	op	op	0
People	4	0	1	5	0	0	0	7	4	6	4
Type	an, nr 2	0	an, nr 3	dr, nr 2	0	0	0	dr, an, nr 5	dr 2, nr 2	0	nr 4
Patient In?	0	0	I down	0	0	0	0	1 down	1 down	0	1
12:45											
Activity	0	0	clean	clean	0	0	0	clean	op	opend	
People	3	0	3	4	0	0	0	5	5	3	3
Type	an, nr 2	0	dr, nr 2	nr 4	0	0	0	nr 5	dr 2, an, nr 2	an, nr 2	nr 3
Patient In?	1	0	0	0	0	0	0	0	1 down	1 up	2
13:00											
Activity	0	clean	0	anaesth / prep	0	0	0	anaesth / prep	op	0	
People	2	2	2	3	0	0	0	7	6	0	1
Type	nr 2	nr 2	dr, nr	nr 3	0	0	0	dr, an, nr 5	dr, an, nr 4	0	nr 1

Patient In?	0	0	1 up	1 up	0	0	0	1 up	1 down	0	2
13:15											
Activity	0	0	0	prep	0	clean	0	op	op	0	
People	0	0	5	6	0	2	0	7	6	0	1
Type	0	0	Dr, nr 4	nr 6	0	dr, nr	0	dr, an, nr 5	dr, an, nr 4	0	nr 1
Patient In?	0	0	1 down	0	0	0	0	1 down	1 down	0	0
13:30											
Activity	0	0	op	op	0	0	0	op	opend	0	0
People	1	0	7	6	0	0	0	7	5	0	0
Type	nr 1	0	dr 2, an, nr 4	dr 2, an, nr 3	0	0	0	dr, an, nr 5	dr, an, nr 3	0	0
Patient In?	1	0	1 down	1 down	0	0	0	1 down	1 down	0	0
13:45											
Activity	0	0	opend	opend	0	0	0	clean	0	0	0
People	2	0	5	7	0	0	0	1	0	0	2
Type	nr 2	0	dr, nr 4	dr 2, an, nr 4	0	0	0	nr 1	0	0	nr 2
Patient In?	2	0	a down	1 down	0	0	0	0	0	0	3
14:00											
Activity	0	0	anaesth / prep	anaesth / prep	0	0	0	anaesth / prep	anaesth / prep	0	
People	3	0	5	6	0	0	0	6	6	0	1
Type	nr 3	0	dr, an, nr 3	dr, an, nr 4	0	0	0	an, nr 5	dr, an, nr 4	0	nr 1

Patient In?	0	0	1 up	1 up	0	0	0	1 up	1 up	0	2
14:15											
Activity	0	0	prep	op	0	0	0	prep	op	0	
People	5	0	8	6	0	0	0	7	6	1	2
Type	nr 5	0	dr, an, nr 6	dr 2, an, nr 3	0	0	0	nr 7	dr, an, nr 4	nr 1	nr 2
Patient In?	0	0	1 down	1 down	0	0	0	1 down	1 down	0	1

Appendix 6: Interview and observation notes

Speak to
[redacted]
Complainers

Maintenance engineering

Speak to [redacted] for
maintenance record
See whether maint eng can
be done.

[redacted] → Clinical Engineer

phone Dr's wives & offices

EGOs. cause problems
with changing theatre.

Septic cases → Clean
instruments properly
"some don't change, others
want it done old way"
septic cases in past, theatre
had to be left to
stand. no more: Aircon
does evacuations now

Drs get given ~~food~~ & drink
and get given lunch.
demand particular food
or cooldrinks

[redacted]

Latex allergy is a big
problem

Christmas ~~boxes~~
differ greatly and
causes unhappiness.

nights/ emergencies.

Training nurses should
be taught.

Just ran out of printer
cartridges. no stock
keeping / ERP to monitor

interview with [redacted]
allocate 100 Hrs/month
cover Drs and within
legal reqs of labour law
- Mostly scrub for 1 surgeon
if wife-nurse is ill/dead/leave-
trouble → upset surgeons

- counseling; personal touch
understand them

- Tea & lunch breaks.

- oversee CSSD

Central laundry for [redacted]
Somewhere in [redacted]

[redacted] father was Hospital
Mngr.

Dr. Interviews
[redacted]

2 theatres have
Screens
1 with microscope.

" 5 "
"Lamino flow theatres" — hypo filters and circulat. & ventilati.
open bone surgery.

urology vs. ortho
don't like crossover for
infection control
tall drs -- lights can be too low.
Neuro vs Gynae
for infection control.
Plastics need 2 lights
look @ rate of flow through
theatre.
→ Air replaced 25 times / 1 ...

infection control (usually
Staff, currently she does it)
- H&S - She shouldn't do it
but does.

- Orders instruments, Stationery

- Capex for year

- Policies & procedures.

- Theatre checklists.

- Check Drugs cupboard
in recovery

Theatre checklists for
Audit

(2) Single store in theatre.
good for control & charging

10 mins to get item from central store during surgery.

(3) Shortage of theatre time
too many doctors joined Sunninghill from another poorly run Hospital

[redacted]
Traction tables not working together
Standardize?

Would like more theatre time.

More rush ↓ Quality,
↓

[redacted]
- map of theatre complex
- cost per theatre

[redacted]
(1) Shortage of Nursing staff biggest problem in med in SA.
ANC closed Nursing colleges in '96..

get around with theatre technician
varying quality.

[redacted]
(2) - Staff retention
- difficult access
- difficult transport
- location by taxi rank

Apparently, 40% of Nursing staff are due to retire in a few years

[redacted]

didier netter, with Holzketten.
will give thought to
scheduling and will
grab me.

[redacted]

→ Software available to [illegible] schedule
→ 45 minutes op, wasted
4 hrs, no staff,
in wards etc.
→ Don't reinvent the wheel.
→ Taiwan 35 theatres in
plastics hospital.
→ other hospitals have
40 - 50 beds
→ sepsis increasing

[redacted]

nice for extracted
teeth.

Nephew is 2nd Eng in
Atlanta
→ "tons of waste"
→ started late bc
noone called for
patient.

[redacted]

• Doing Utilisation
pilot study

• saw [redacted] fetch pt!

• Utilisation ok when working.
idle theatres evident.

integrate
staff — Roster

Theatre — list — Equipment

Doc — Patients

G-Scope [redacted]

Quirky, back to front
theatre [redacted]

NO (nitrous) piped to wrong
side of theatre.

~~Anaesthetist~~ - long walk to
Patient from Drugs

lights are always far
from table

[redacted] wants an own
rig because he
can't set it up for
him

- writes lists

Mon - 8th of June.

Met [redacted] - Scrub Sr.

Coordinate
- Staff req.
- Equip
- Theatre
- Surgeon's preference

Model emailed to me,
check what it does.

When is who on duty

[redacted] young
just engaged

gastro theatre badly arranged

18/06/2009

Depaty Nursing Mngr.

CSSD [redacted]

Trolley from theatre

Instrument washer broken

Hand wash
Cleaning fluid on floor
then rinse
Dry in basin

4 way valve broken (R 2a
Cidex oil prevents
rusting (Surgislip)

Drying Cupboard

~~Prepared~~ Expected
emergency OP. Splenecto
MVA; @ TR100
known about since early
Therefore unprepared
scramble to get [illegible]
[redacted] Sheet

Stuff being brought in whilst
anaesth.

Pulse Meter not working

Roller Cupboard great
re setup for Ley.

TRIDENT STEEL

HEAD OFFICE GERMISTON
Tel.: (011) 861-7111
Fax: (011) 865-2042

DURBAN
Tel.: (031) 702-5272
Fax: (031) 702-6002

PORT ELIZABETH
Tel.: (041) 405-6200
Fax: (041) 452-2413

CAPE TOWN
Tel.: (021) 907-1600
Fax: (021) 907-1636

[redacted]

has no time of his own, so has to 'squeeze' in on others' lists or on emergency list

needs 4-6 hrs/week and must beg borrow/steal time from others

Wanted to do surgery and has no scrubs sister.

[redacted] "this place is a fuck up".

→ shifting theatres

→ looking for ~~Theat~~ staff

No Management

No anticipation of surgery.

System

Book PT — Prepare Packs
— get Pt
— Ensure staff
— get equip: Med instr etc.

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[redacted]

Way overbudget on "Repairs

reps show Drs stuff other equipment who want it

hospital buys it and so $$ go up

o Cardiac theatres should be closer to ICU due to risk to babies if going from theatre to ICU

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"- Other skills — comp[illegible]
- Leadership
- Management
- Hobbies

character traits
"I [illegible], rather than risk taker" and

1045

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CAPE TOWN
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Fax: (021) 907-1636

Don't end weaknesses.

[redacted] (dutch sounding orthoped!
(full helmet hair net

Pretty happy
- electives overrun into night staffing
- Patients can't be found
- Stock control means
Sutures (eg) aren't in theatre
when needed.

[redacted] [illegible] for [redacted]
- Doesn't have enough time
- Staff (Not enough)
- (H) too busy
- Allocation to those who don't fill lists
- Noone knows where pt is
- No pref for NH case
2d [illegible] b4 of starts
- Theatres run over time
- wait for sutures etc.
No dedicated trolley.
- low staff morale
- Night staff don't arrive.
- Poor pay for overtime
- theatres not staggered

IDEA: Some 2 shift theatres
Some 3 shift theatres

[illegible]

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Set up Ramsy style [illegible] sheet

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Fax: (021) 907-1636

[redacted] wants dedicated
Scope set for orthopods dedicated
because they can't set it up!

Gynaes etc. change settings
TRAINING - Reqd.

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lines go black
once through
Autoclave

Different tables here
Different fixtures
Config. Mngmnt

Sterile instr.
Trays
through windows
to ward

Shelves, just enough.

Air Con in pack room
Where from?

from cupboard on
table

Tray liner into
wiped tray.

Pack according to
Checklist.

2 types of autoclave
steam & gas

Incubator keeps
biological indicators
alive, which check whether
~~Ste~~ steam autoclave is
working.

Steam indic...

3 months sterile
guarantee.

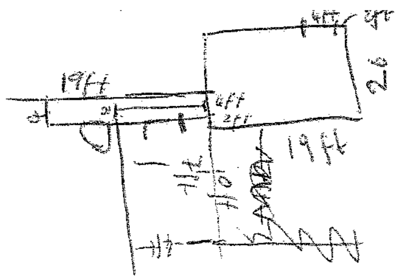
Gas autoclave, other room
expensive, use 1x or 2x
per day.

Big unsterile store in
Gas Autoclave room

Drills / blades etc
separately stored / sealed

There's a pharmacy store
in CSSD

Actually linen / laundry store



Collection
run

Nurses come in

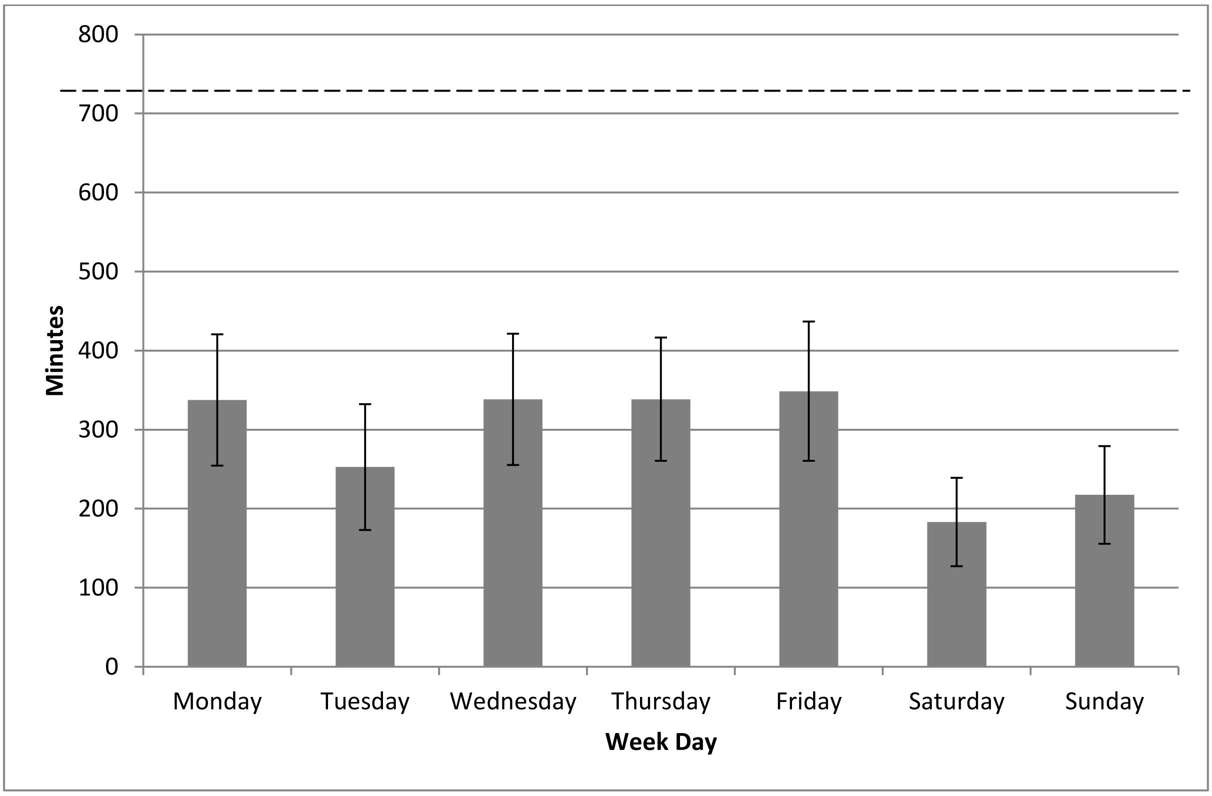
To do
- Draw Maps
- Time Changeovers
- Type in instruments
pack sheets
-

Appendix 7: List of data categories ion raw data set

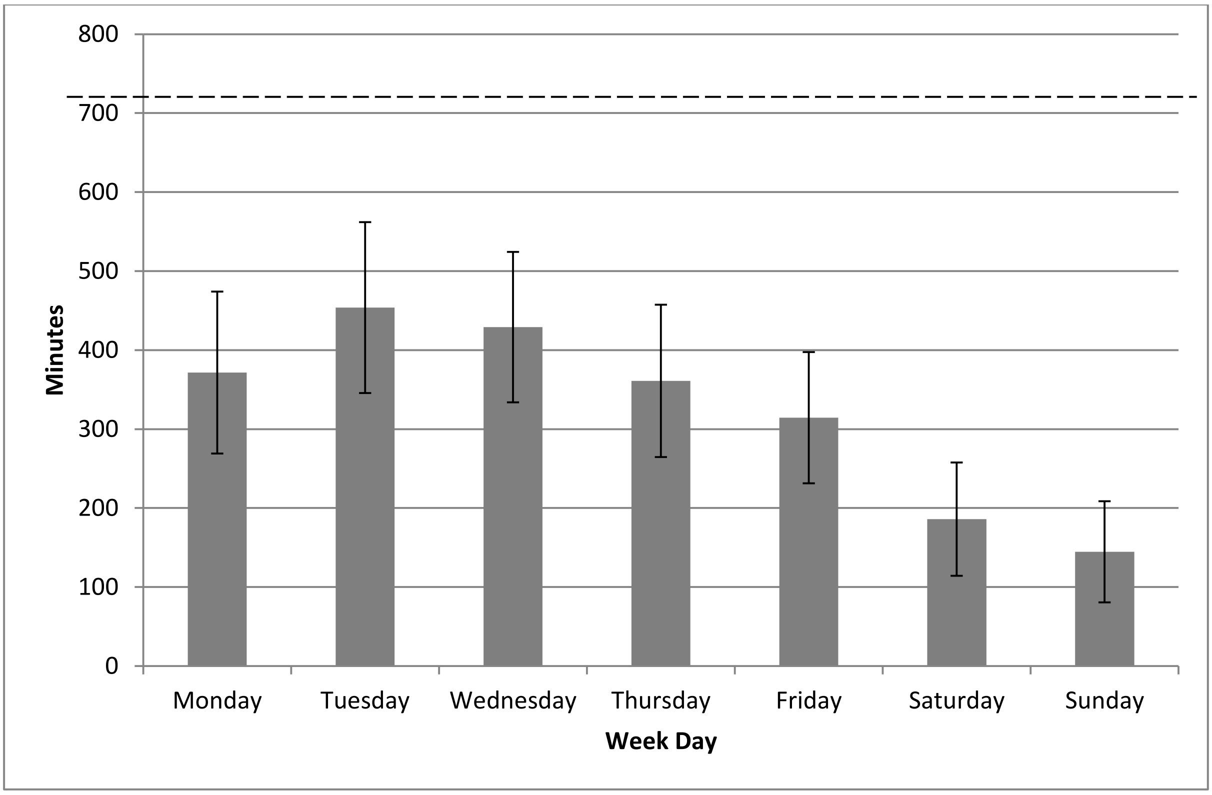
Case
Patient
Sex
Age in Years
Referring Physician
Primary ICD Code
Primary ICD Code
Primary CPT Code
Primary CPT Code
Movement
Start Date
Start Time
End Date
End Time
Movement Type
Nursing OU
Nursing OU
Billing OU ID
Organizational Unit
Identifier
OU Category
Cost Center
Cost Center
Medical Aid
Medical Aid
Medical Aid Plan
Anaesthetist
Anaesthetist Forename
Assistant Surgeon
Assistant Surgeon
Forename
Surgeon
Surgeon Forename
Surgeon Specialty
No of Ops
Operation Time - Minutes

Appendix 8: Graphs for all theatres

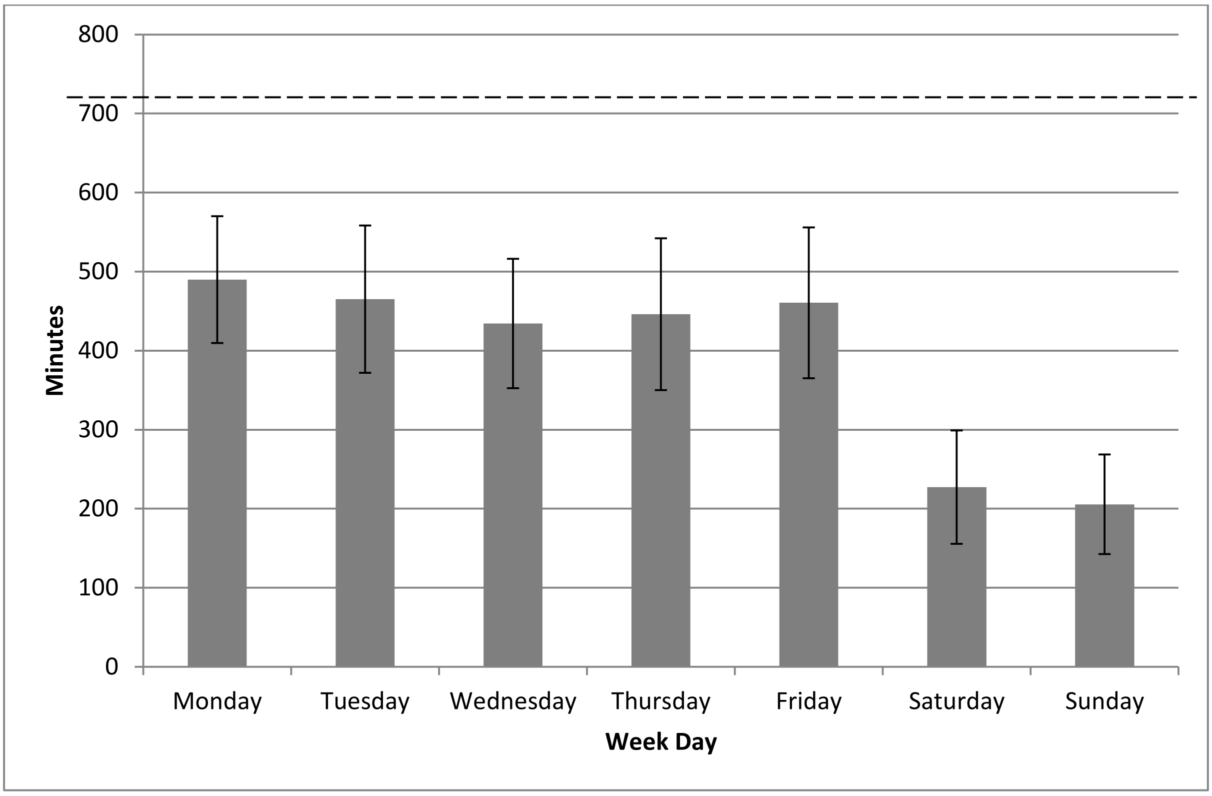
Theatre 1



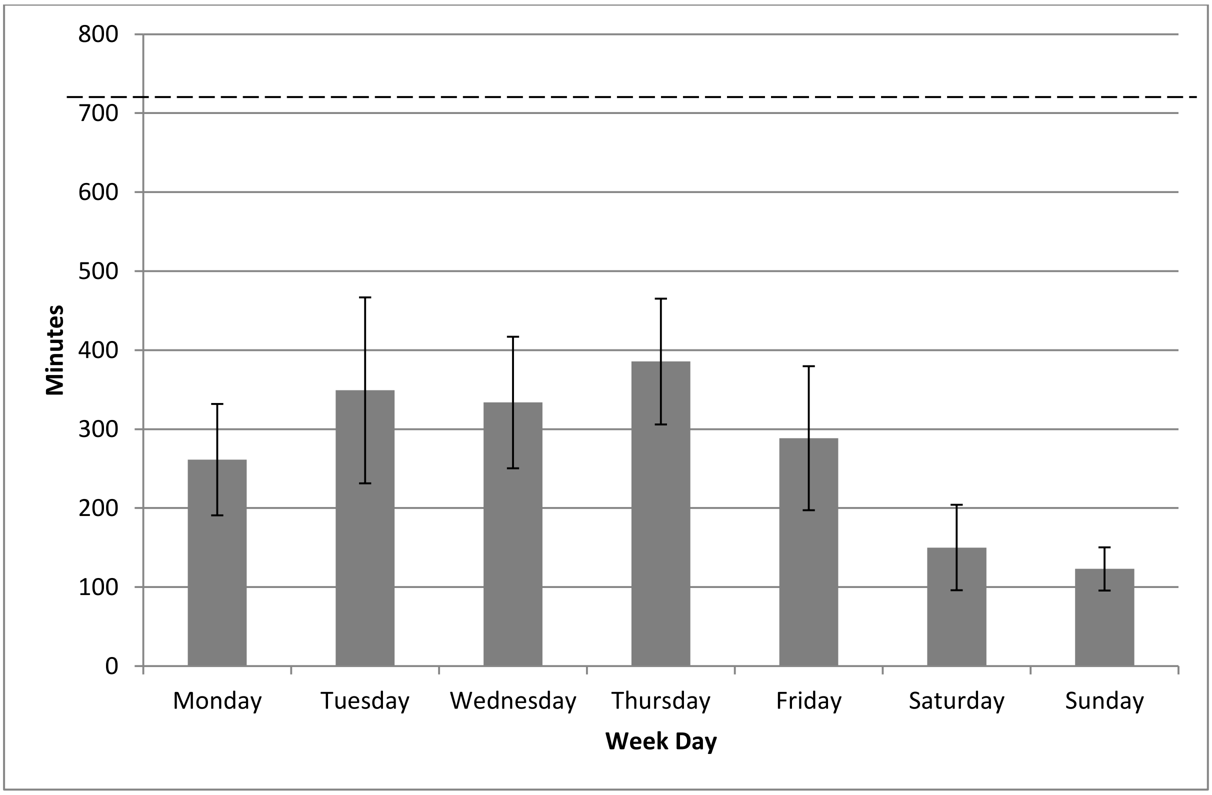
Theatre 2



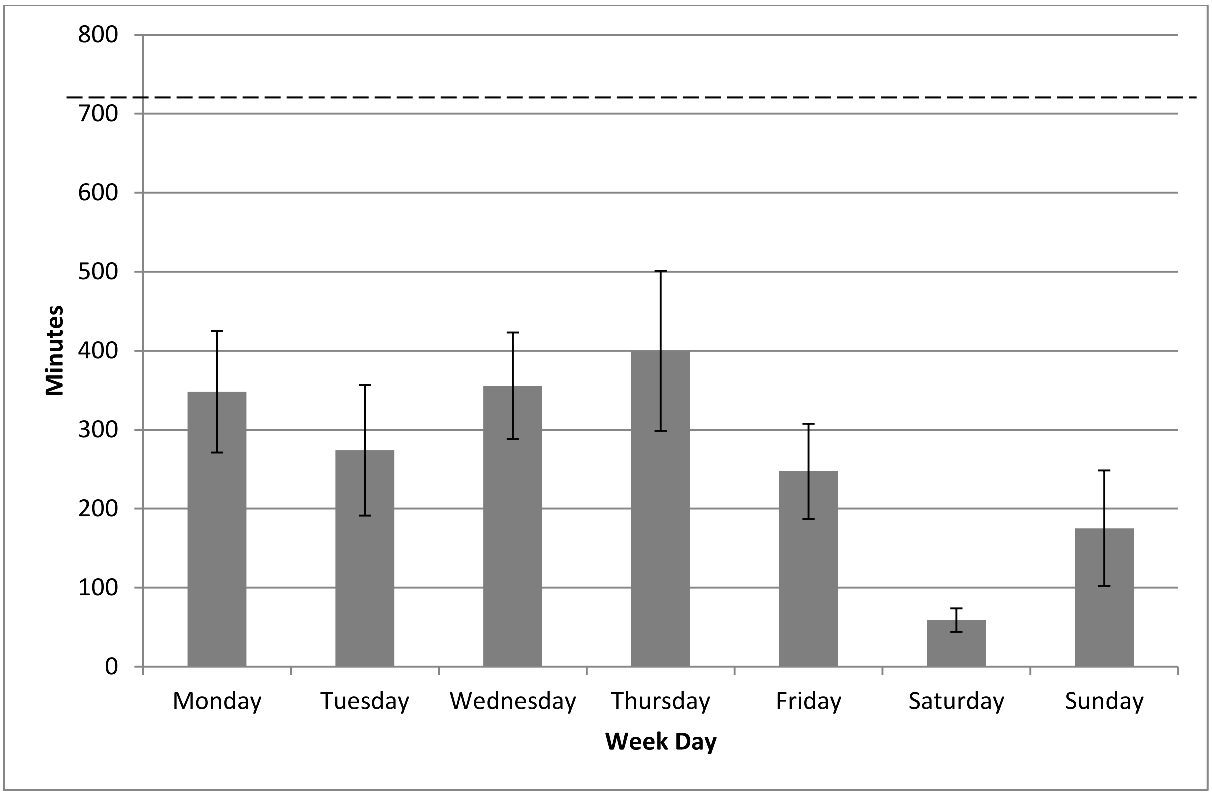
Theatre 3



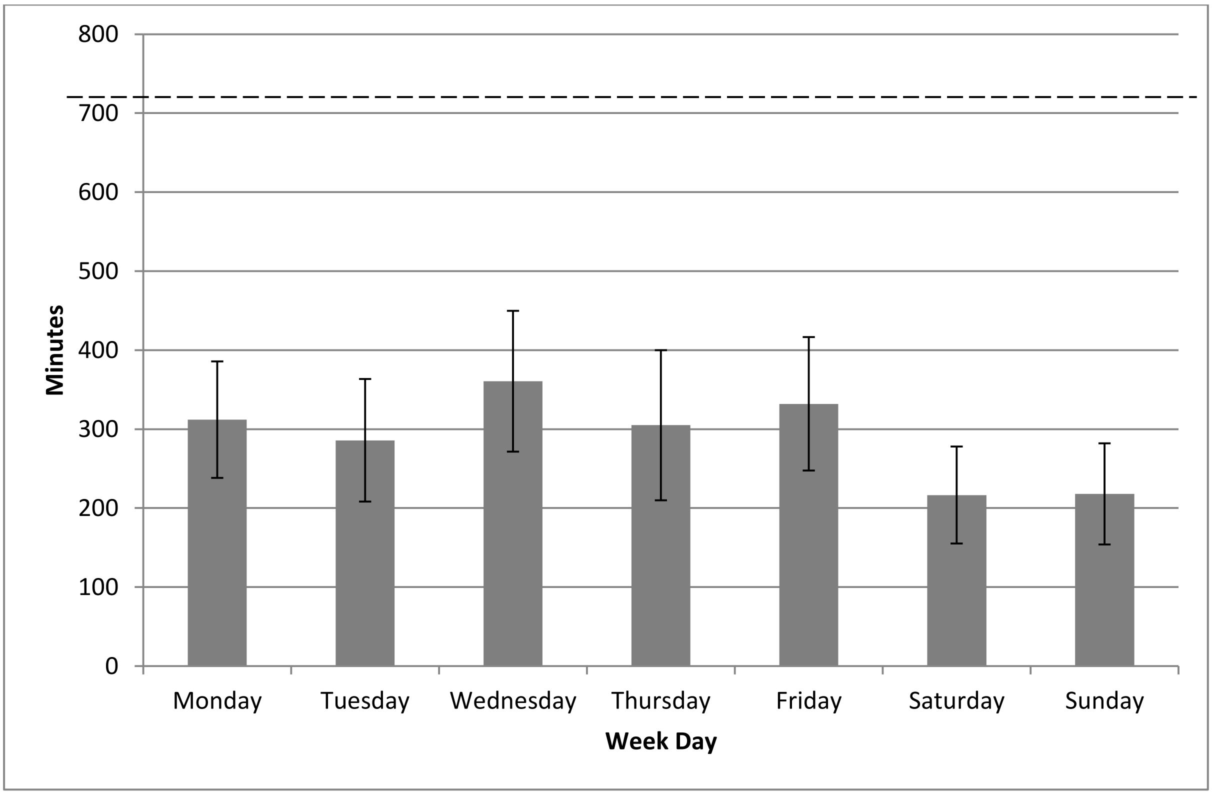
Theatre 4



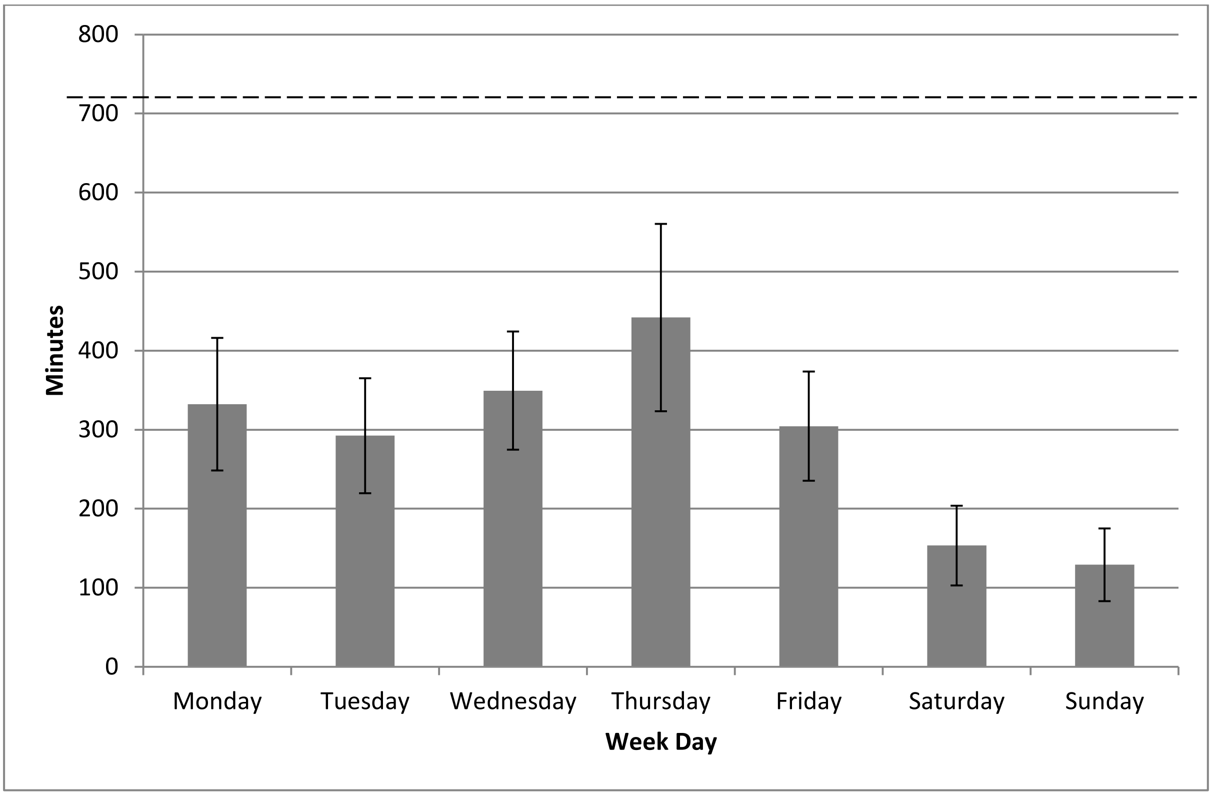
Theatre 5



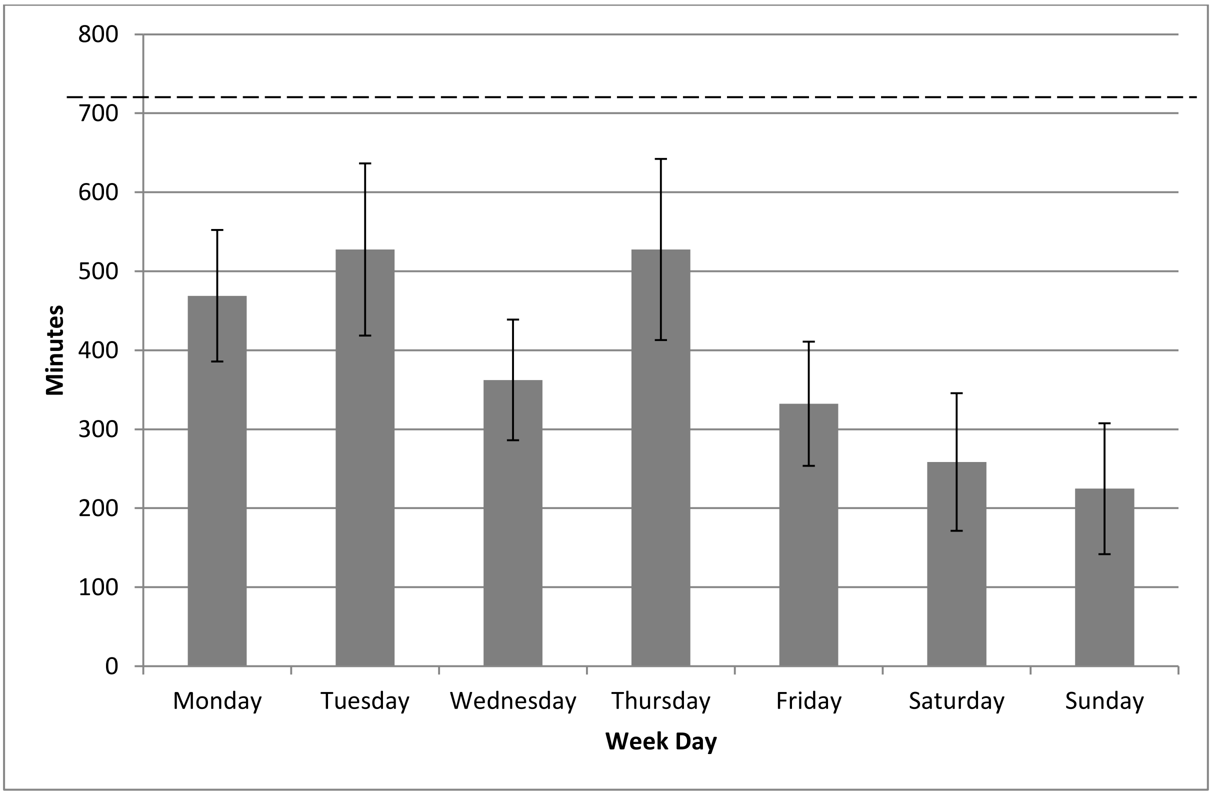
Theatre 6



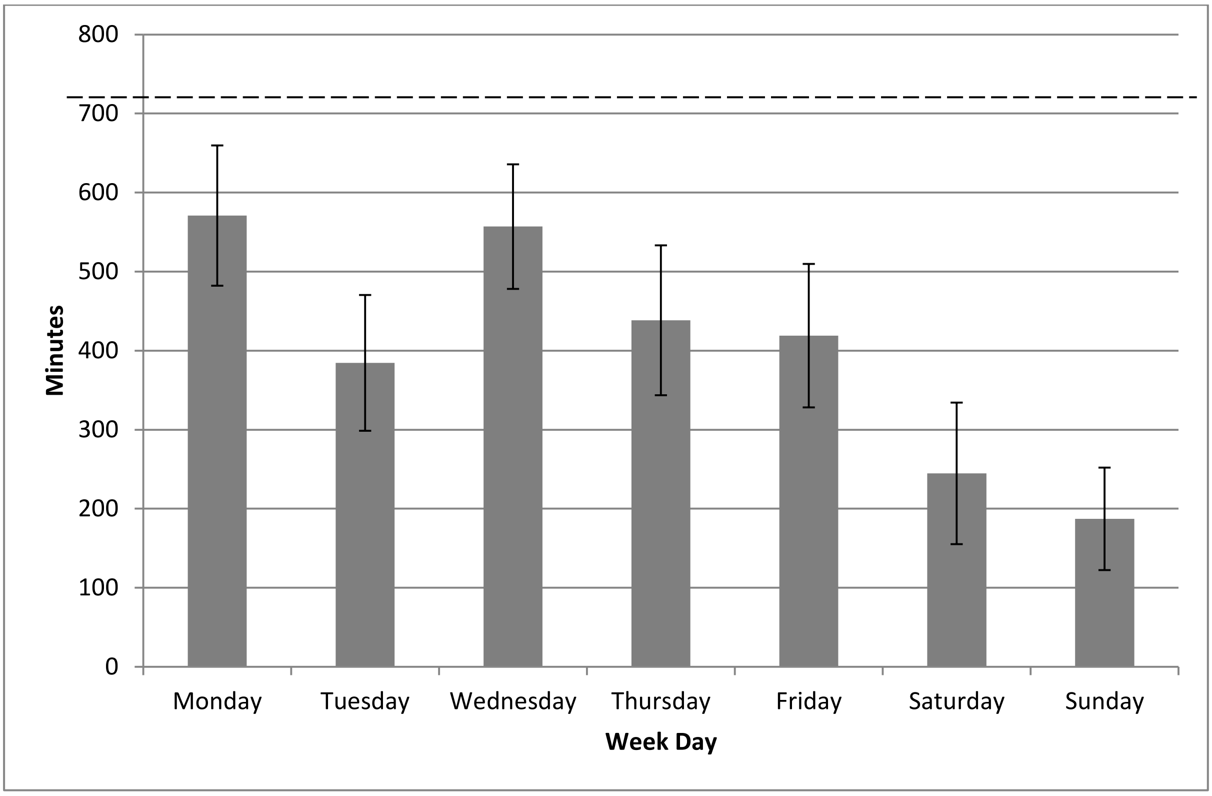
Theatre 7



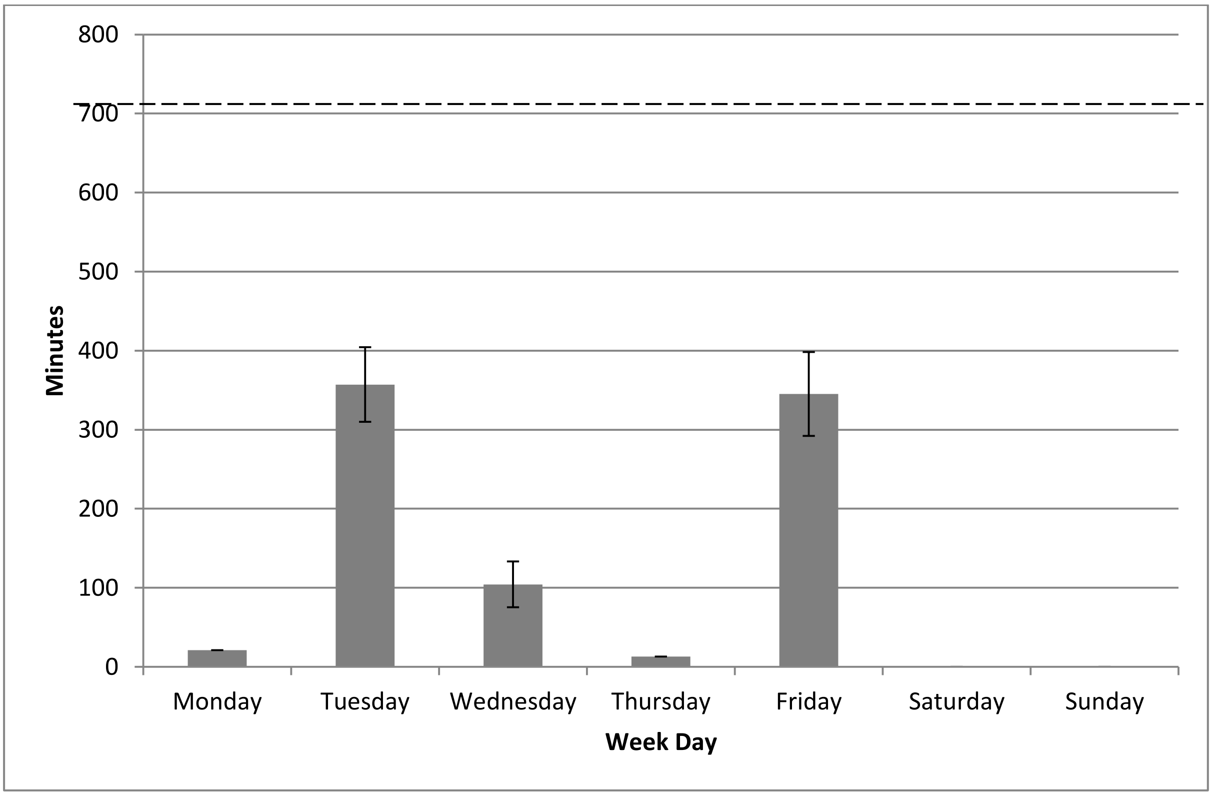
Theatre 8



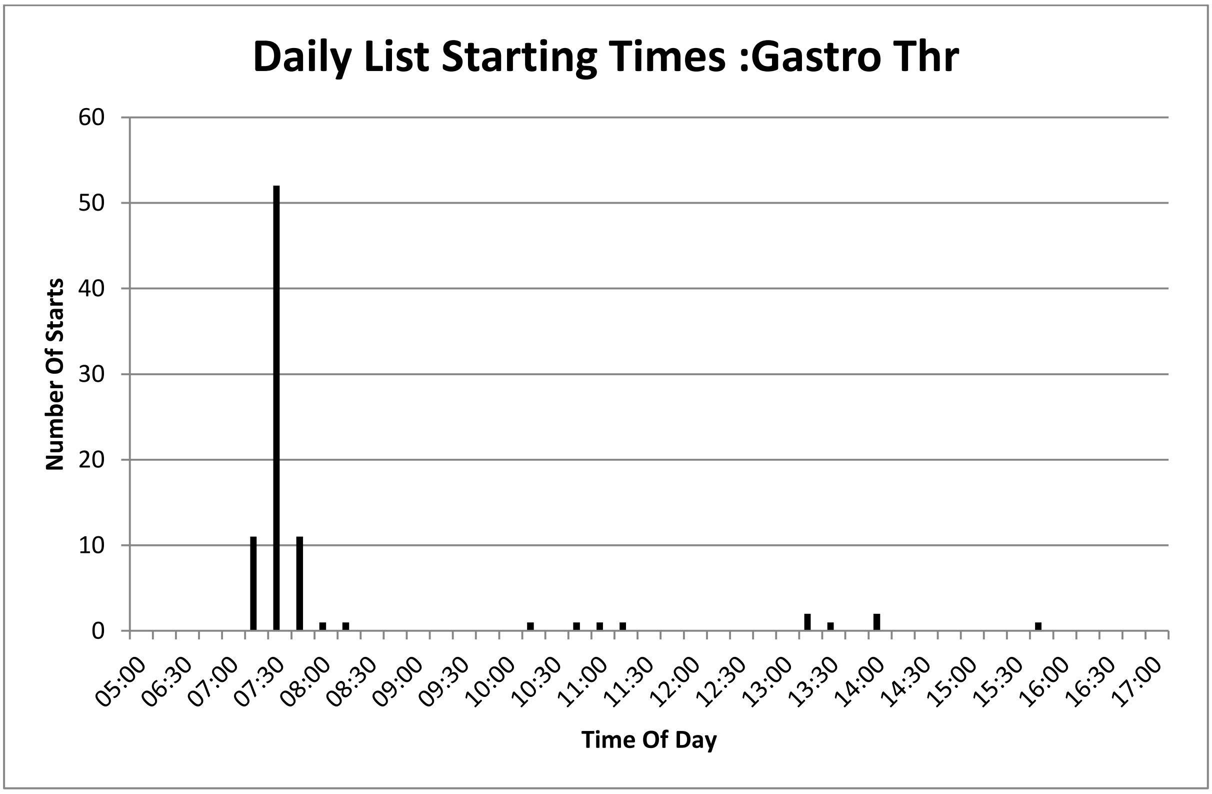
Theatre 9

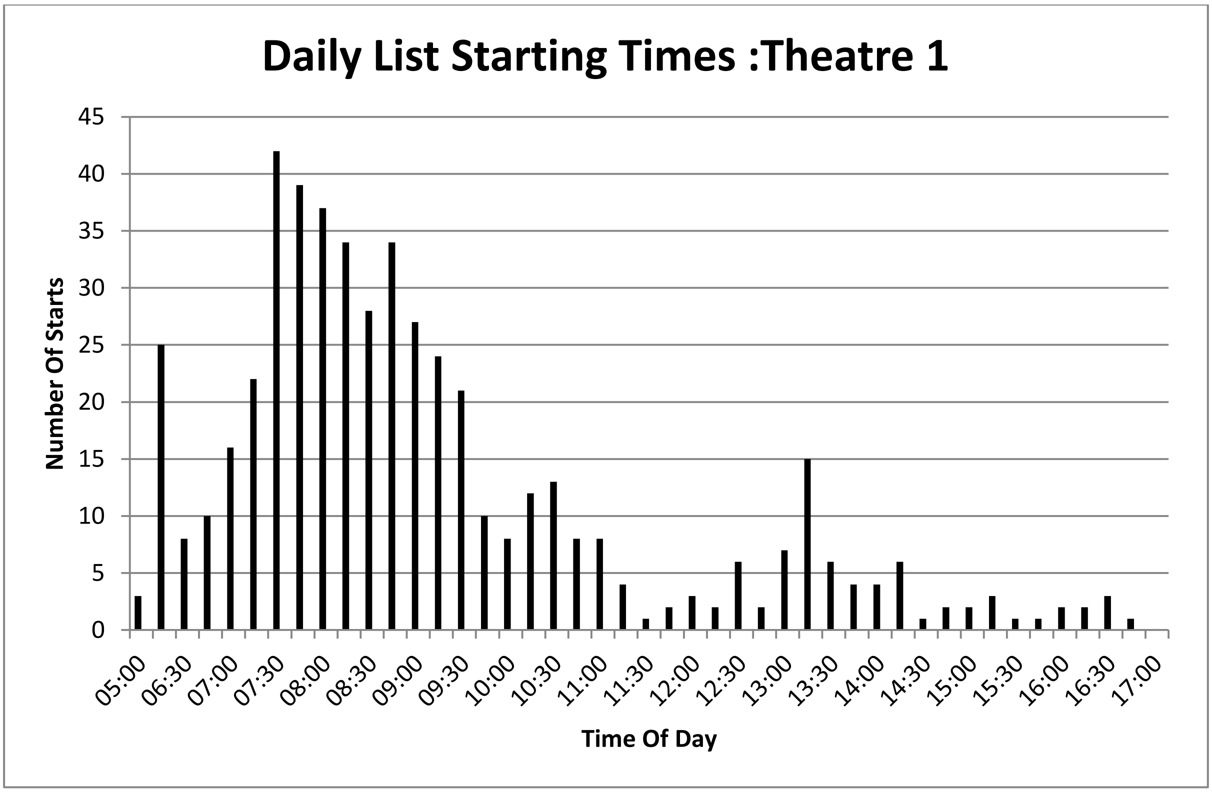


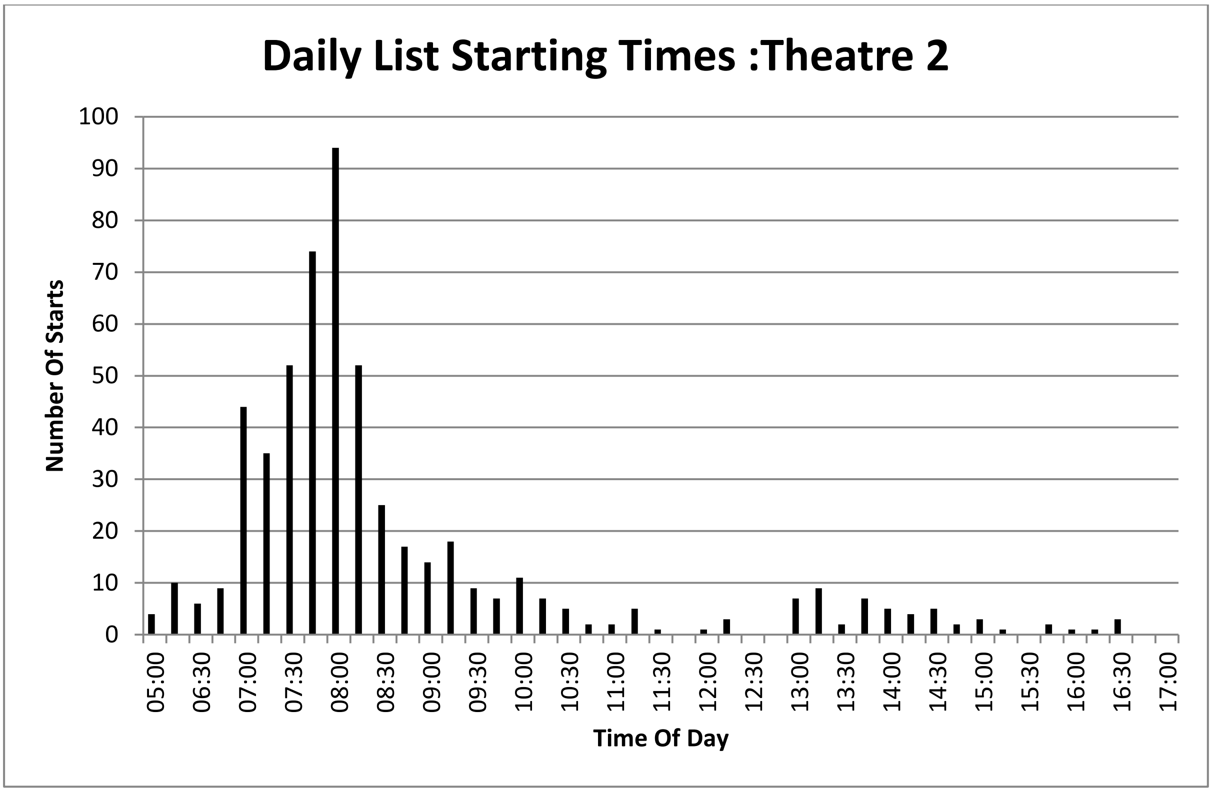
Gastro Theatre



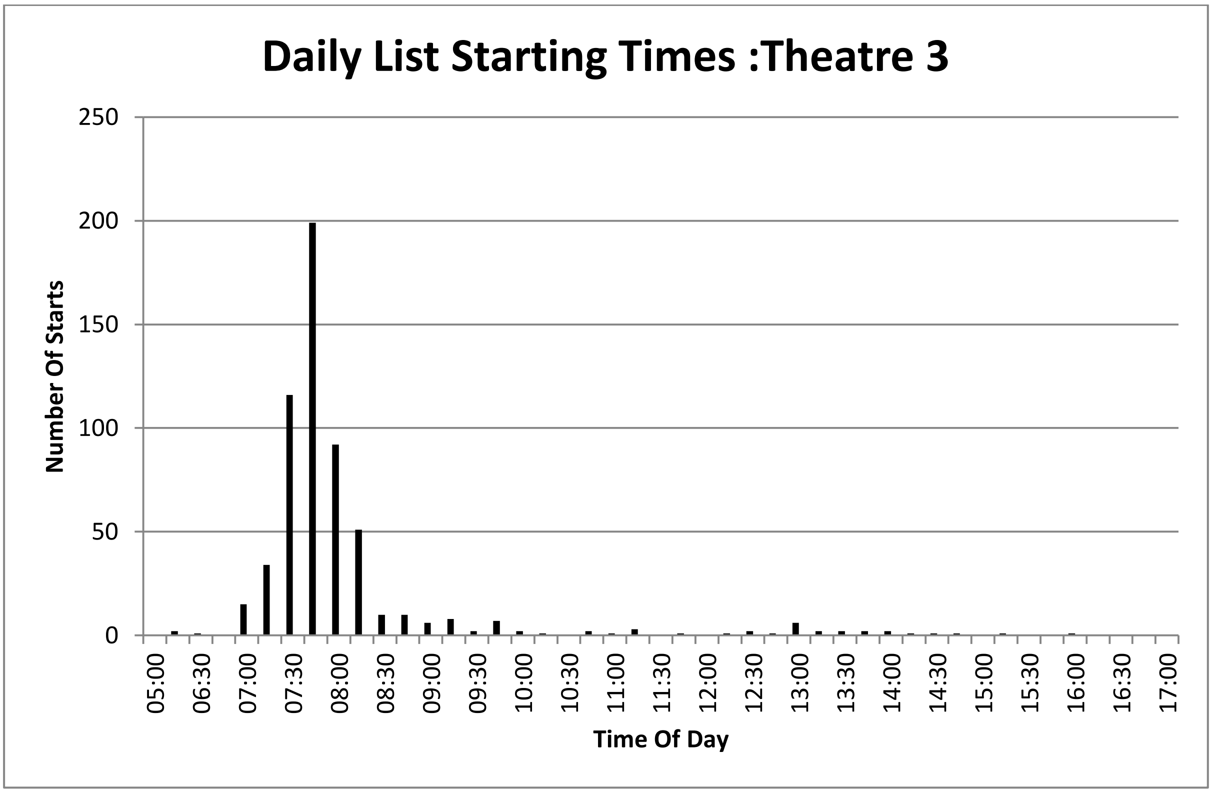
Appendix 9 Starting time analysis for all theatres



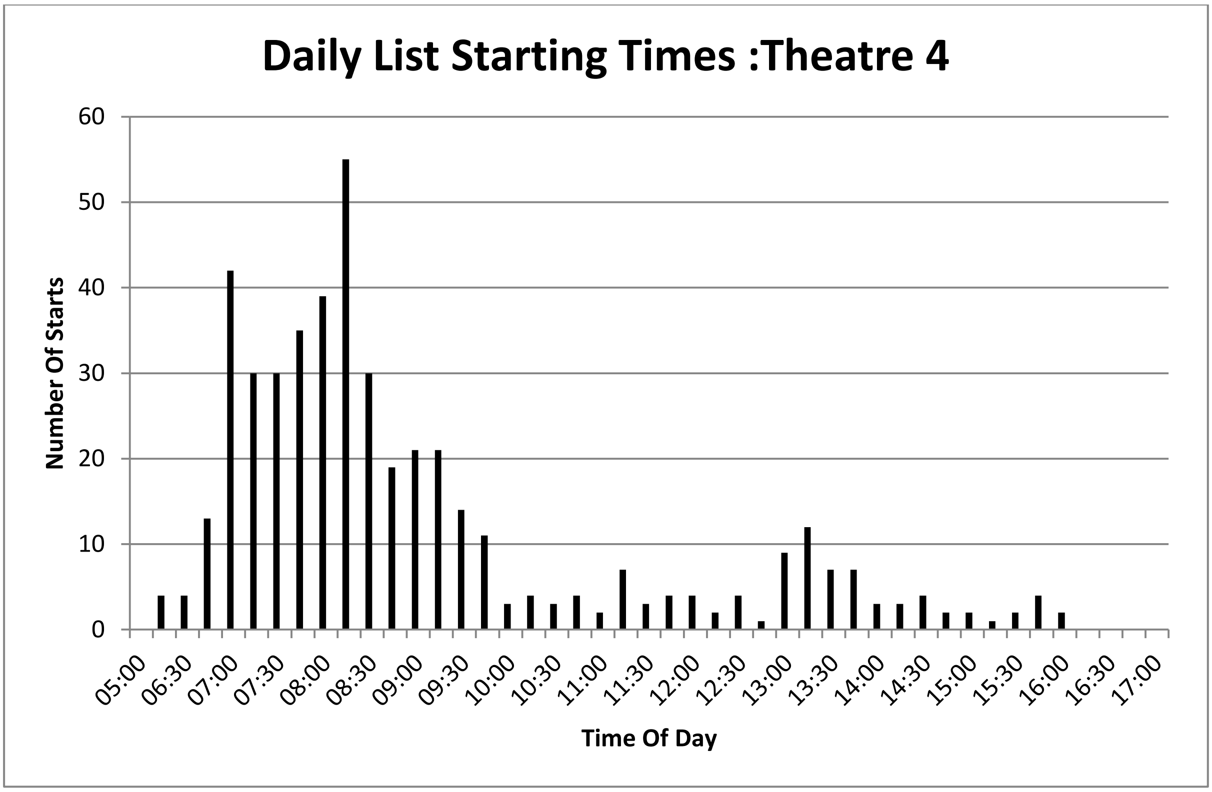


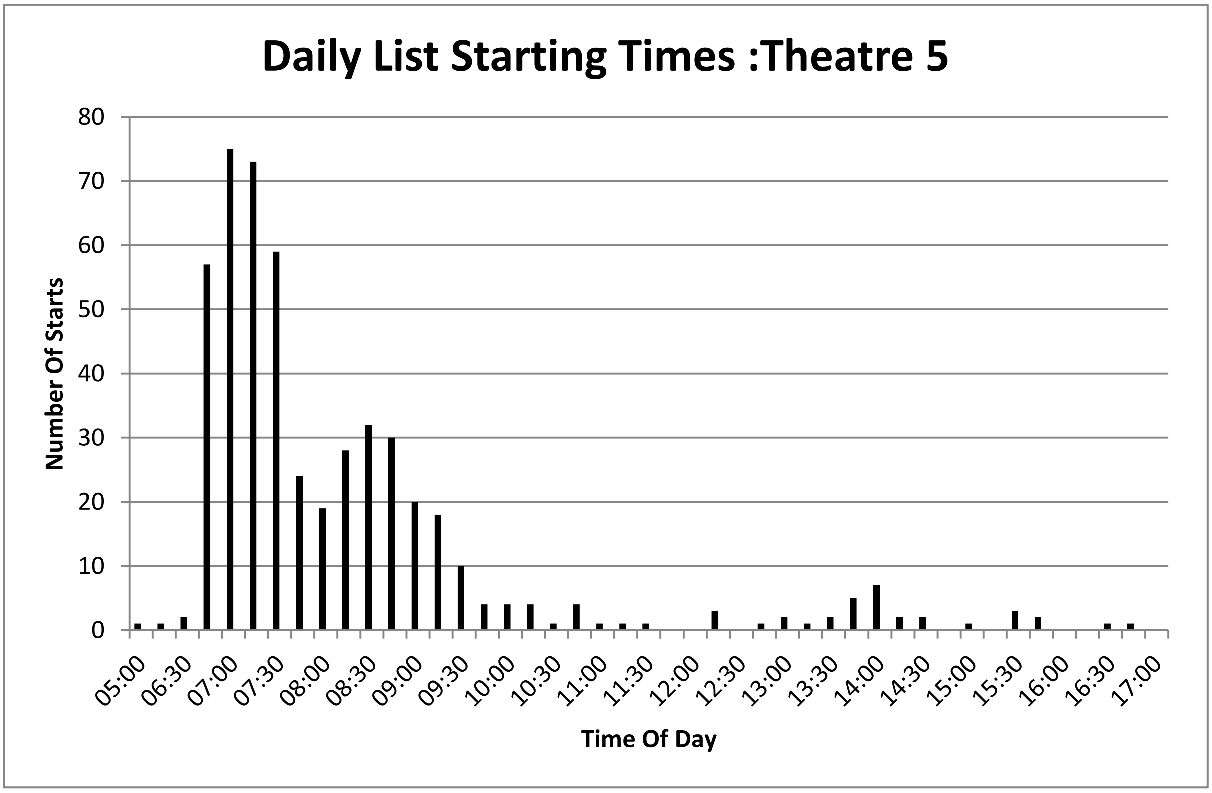


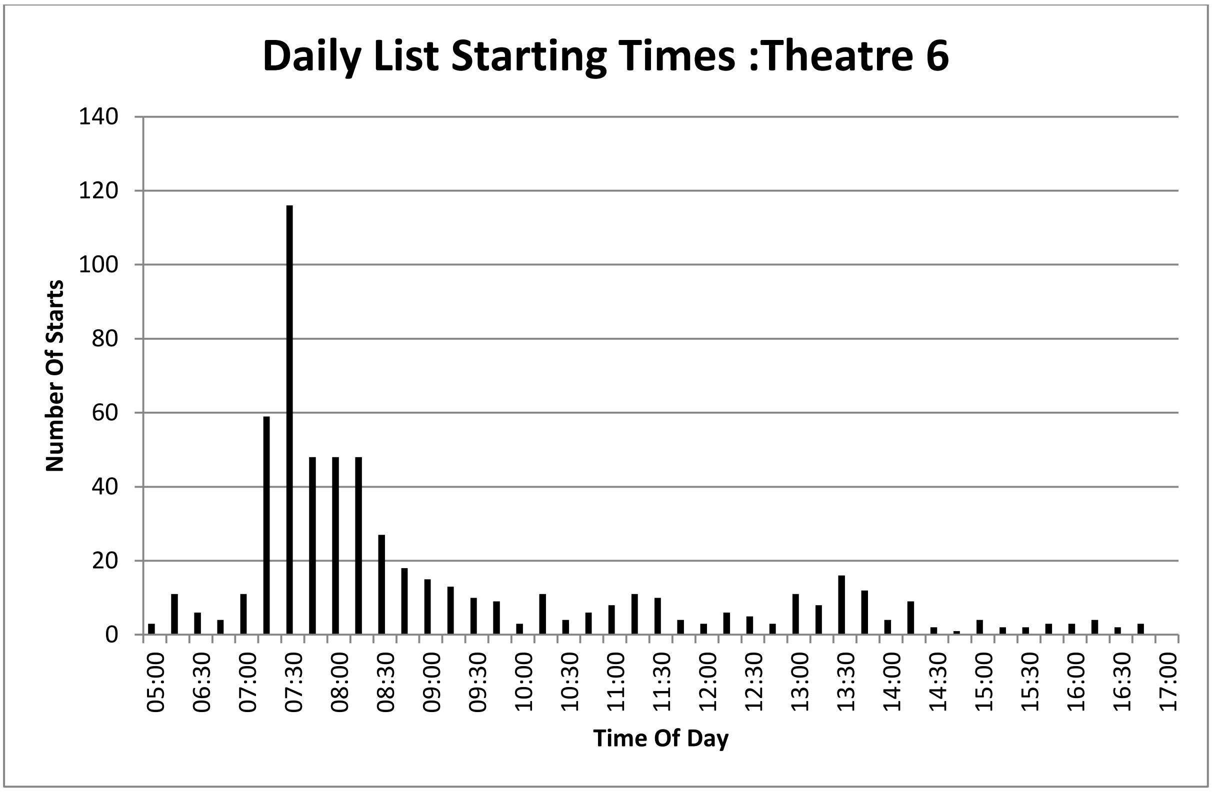
Daily List Starting Times :Theatre 2
100
90
80
70
60
50
40
30
20
10
0
Number Of Starts
05:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
Time Of Day

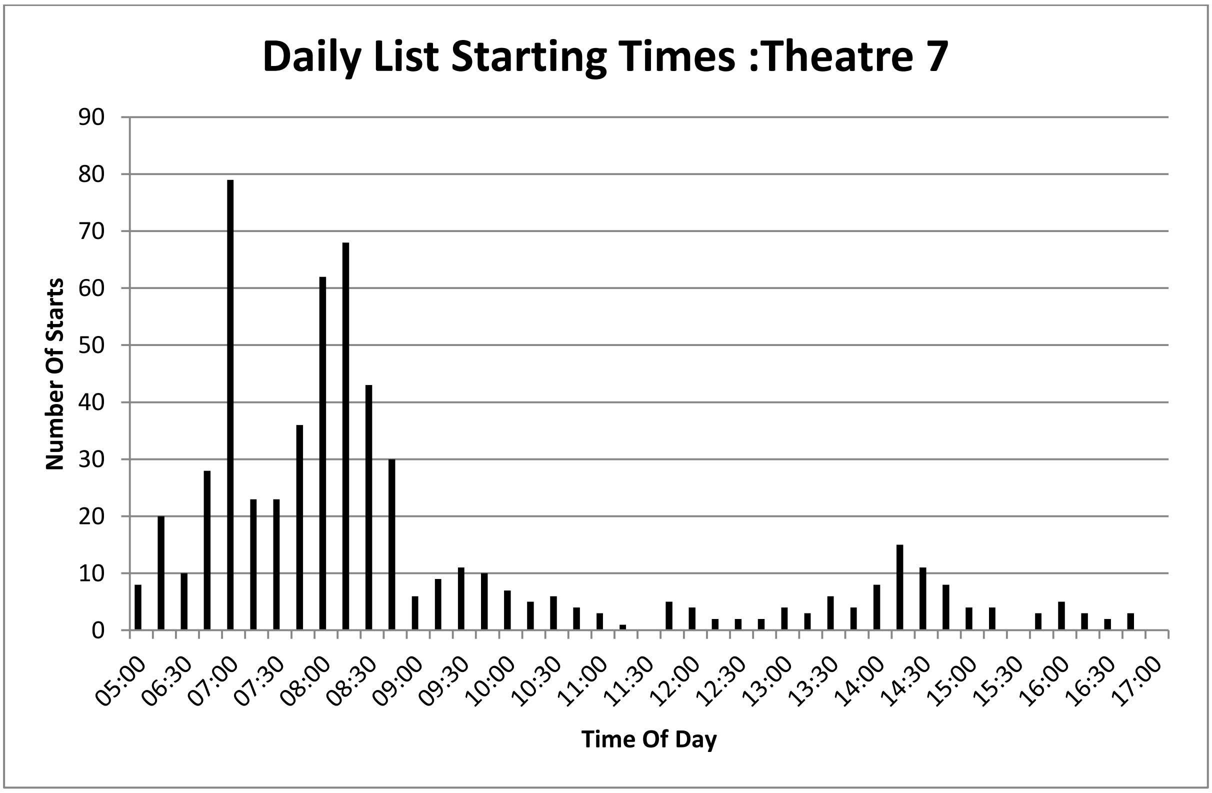


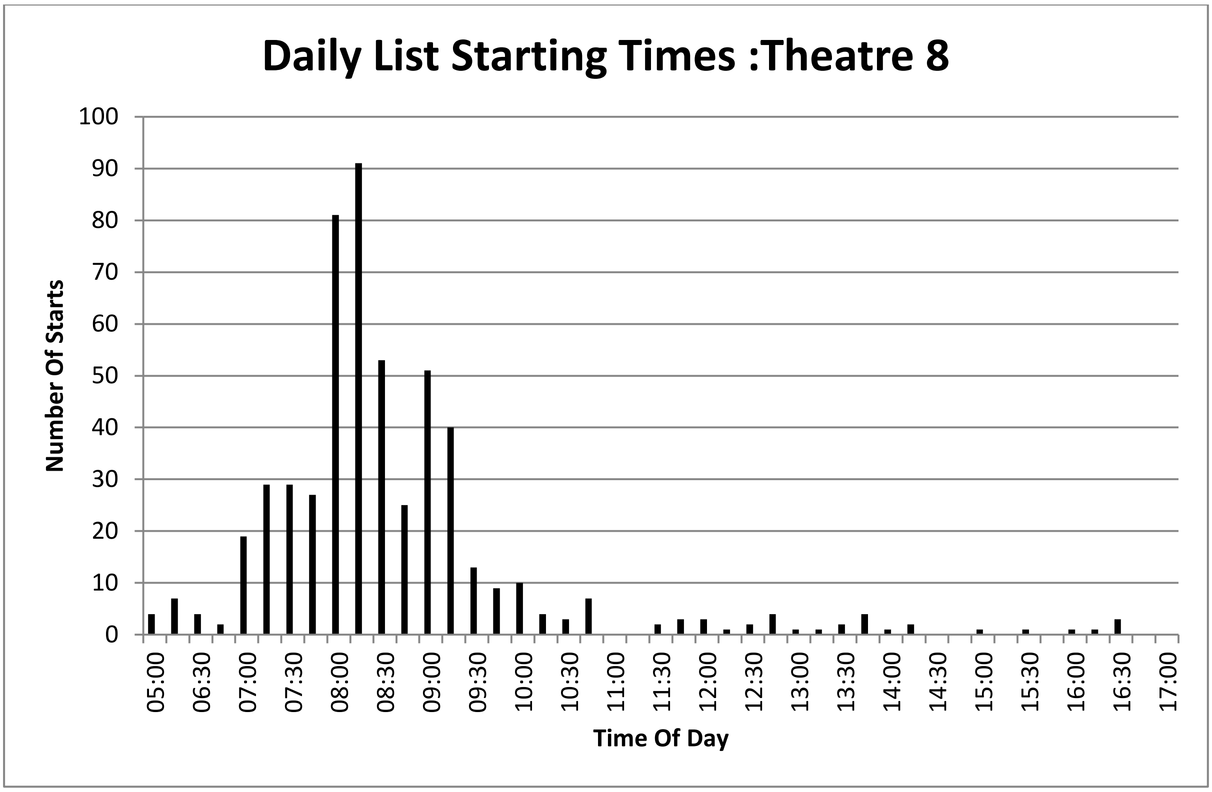
Daily List Starting Times :Theatre 3
250
200
150
100
50
0
Number Of Starts
05:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
Time Of Day

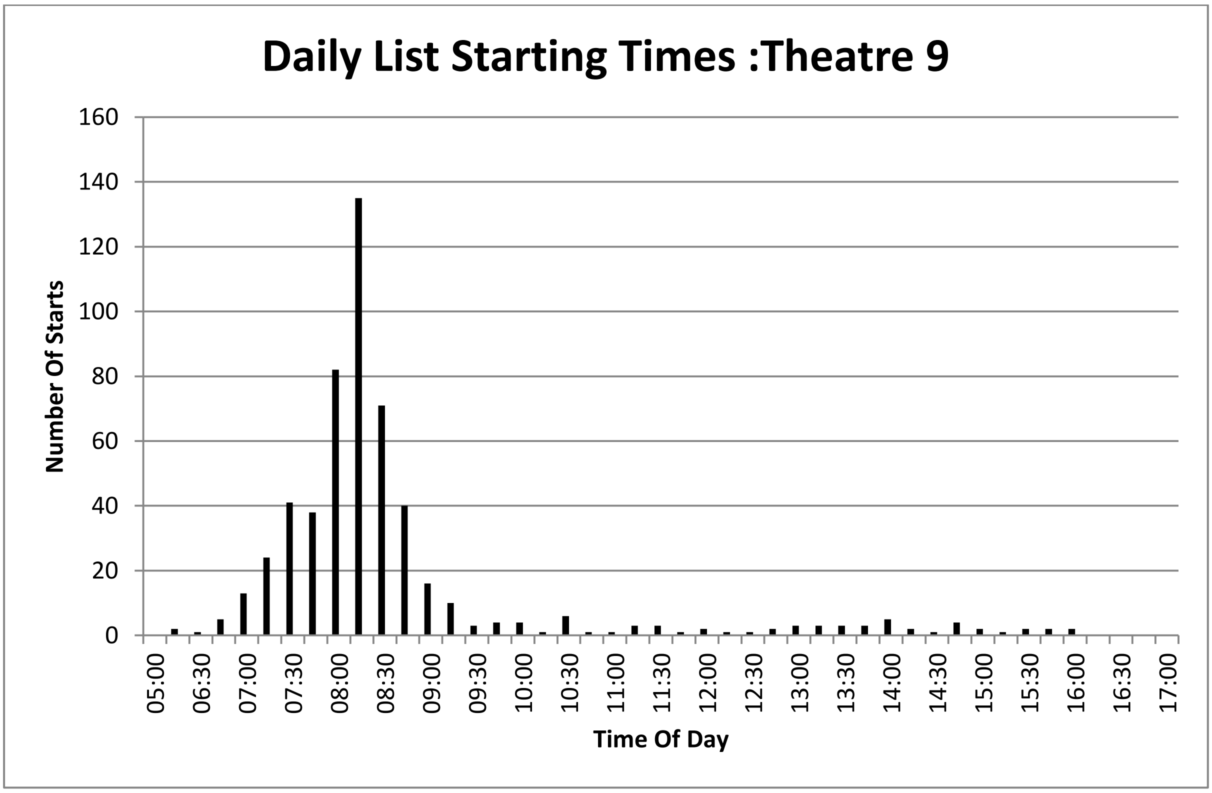

Daily List Starting Times :Theatre 4
Number Of Starts
0
10
20
30
40
50
60
05:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
Time Of Day


Daily List Starting Times :Theatre 5
Number Of Starts
0
10
20
30
40
50
60
70
80
05:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
Time Of Day


Daily List Starting Times :Theatre 6
140
120
100
80
60
40
20
0
Number Of Starts
05:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
Time Of Day


Daily List Starting Times :Theatre 7
90
80
70
60
50
40
30
20
10
0
Number Of Starts
05:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
Time Of Day

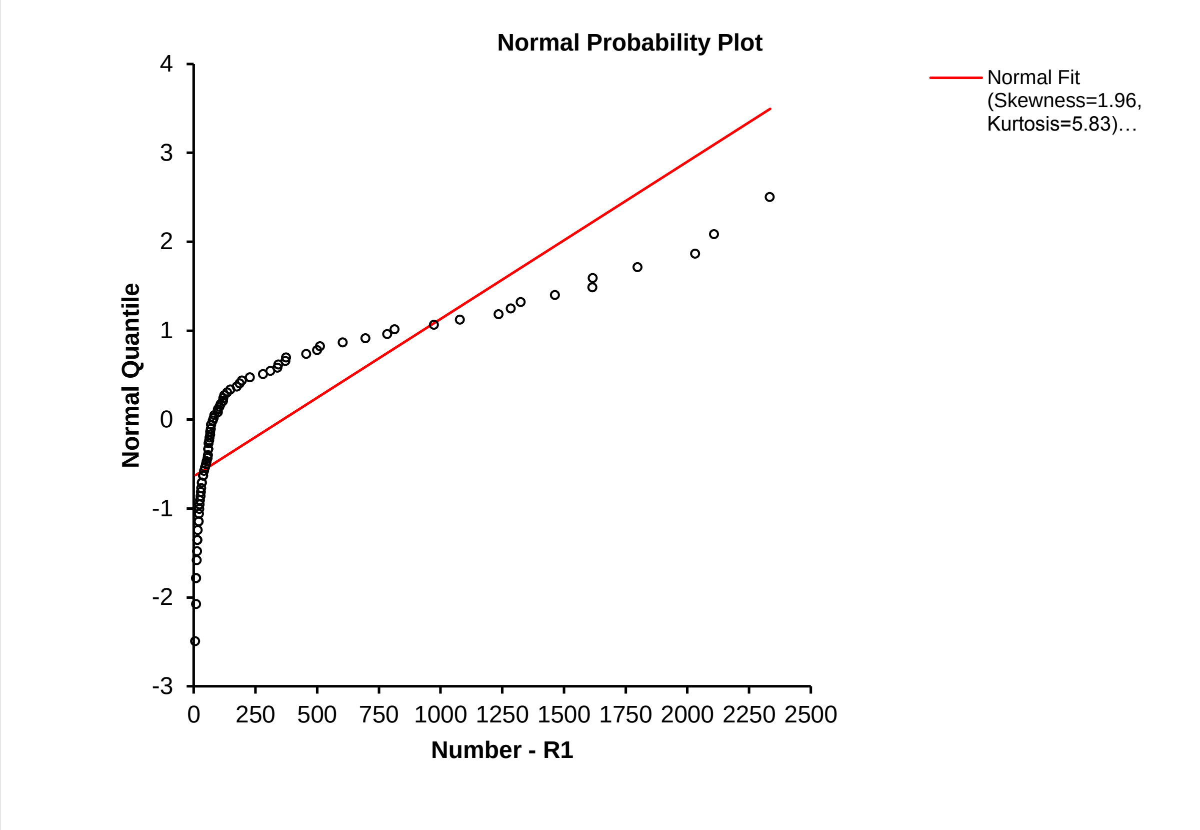

Daily List Starting Times :Theatre 8
Number Of Starts
Time Of Day
0
10
20
30
40
50
60
70
80
90
100
05:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00


Daily List Starting Times :Theatre 9
Number Of Starts
Time Of Day
0
20
40
60
80
100
120
140
160
05:00
06:30
07:00
07:30
08:00
08:30
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00

Appendix 10 - Average late start time calculation

THEATRE	05:00	06:00	06:30	06:45	07:00	07:15	07:30	07:45	08:00	08:15	08:30	08:45	09:00	09:15	09:30	09:45	10:00	1
Theatre 9	0	2	1	5	13	24	41	38	82	135	71	40	16	10	3	4	4	
Theatre 8	4	7	4	2	19	29	29	27	81	91	53	25	51	40	13	9	10	
Theatre 7	8	20	10	28	79	23	23	36	62	68	43	30	6	9	11	10	7	
Theatre 6	3	11	6	4	11	59	116	48	48	48	27	18	15	13	10	9	3	
Theatre 5	1	1	2	57	75	73	59	24	19	28	32	30	20	18	10	4	4	
Theatre 4	0	4	4	13	42	30	30	35	39	55	30	19	21	21	14	11	3	
Theatre 3	0	2	1	0	15	34	116	199	92	51	10	10	6	8	2	7	2	
Theatre 2	4	10	6	9	44	35	52	74	94	52	25	17	14	18	9	7	11	
Theatre 1	3	25	8	10	16	22	42	39	37	34	28	34	27	24	21	10	8	
Gastro Thr	0	0	0	0	0	11	52	11	1	1	0	0	0	0	0	0	0	
	23	82	42	128	314	340	560	531	555	563	319	223	176	161	93	71	52	
	0	0	0	0	0	0	30	45	60	75	90	105	120	135	150	165	180	
	0	0	0	0	0	0	16800	23895	33300	42225	28710	23415	21120	21735	13950	11715	9360	9
							279840											
							63.74487											

Appendix 11: Kolmgorov – Smirnov analysis of list start time distribution: Output from Analyse It ®



n	80	
Range	7.0	to 2335.0
Method	Non-Parametric	
Mean	360.9	
Median	80.0	
SD	564.7	
Skewness	1.96	
Kurtosis	5.83	
Kolmogorov-Smirnov D	0.29	
p	<0.0001	H_0: Sample is from a population with normal distribution. H_1: Sample is non-normal.

	95% Reference limit	90% CI
Lower	10.0	- to -
Upper	2107.1	- to -

Appendix 12: Arena Simulation output

Unnamed Project

Replications: 1 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	28,991

Unnamed Project

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Generic_Patient	72.6321	0.982451553	1.0000	1816.00

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Generic_Patient	0.00	0.000000000	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Generic_Patient	1717.02	193.204	0.00	10978.00

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Generic_Patient	0.00	0.000000000	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Generic_Patient	0.00	0.000000000	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Generic_Patient	1789.65	193.044	15.0000	11067.00

Other

Number In	Value
Generic_Patient	63505.00

Number Out	Value
Generic_Patient	63366.00

WIP	Average	Half Width	Minimum Value	Maximum Value
Generic_Patient	41.0785	(Correlated)	0.00	140.00

Unnamed Project

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Delay_For_Day.Queue	172.71	52.34078	0.00	8655.00
Delay_For_Hour.Queue	1499.86	(Correlated)	0.00	2820.00
Delay_For_Month.Queue	27.5053	15.80701	0.00	2769.00
Delay_For_Year.Queue	4.9662	5.73451	0.00	1420.00
Gastro_OT.Queue	13.5442	3.77670	0.00	333.00
OT_1.Queue	6.7238	1.66638	0.00	310.00
OT_2.Queue	16.0557	5.69931	0.00	1212.00
OT_3.Queue	8.5229	2.99601	0.00	332.00
OT_4.Queue	10.4613	(Correlated)	0.00	1397.00
OT_5.Queue	17.7873	(Correlated)	0.00	820.00
OT_6.Queue	6.0640	1.64587	0.00	525.00
OT_7.Queue	15.8879	(Correlated)	0.00	426.00
OT_8.Queue	9.4509	1.26730	0.00	400.00
OT_9.Queue	9.8528	(Correlated)	0.00	448.00

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Delay_For_Day.Queue	3.9423	1.05269	0.00	104.00
Delay_For_Hour.Queue	34.2360	(Correlated)	0.00	101.00
Delay_For_Minute.Queue	0.00	(Insufficient)	0.00	0.00
Delay_For_Month.Queue	0.6278	0.385503007	0.00	137.00
Delay_For_Year.Queue	0.3410	0.132676849	0.00	139.00
Gastro_OT.Queue	0.02255448	0.007779182	0.00	9.0000
OT_1.Queue	0.01081034	0.002690808	0.00	4.0000
OT_2.Queue	0.05080625	0.018512652	0.00	7.0000
OT_3.Queue	0.00966317	(Insufficient)	0.00	4.0000
OT_4.Queue	0.01555099	(Correlated)	0.00	4.0000
OT_5.Queue	0.04614591	(Correlated)	0.00	7.0000
OT_6.Queue	0.01342593	(Correlated)	0.00	4.0000
OT_7.Queue	0.04577192	0.012487062	0.00	9.0000
OT_8.Queue	0.02676603	0.004147056	0.00	3.0000
OT_9.Queue	0.03199247	0.005531323	0.00	5.0000
Process 11.Queue	0.00	(Insufficient)	0.00	0.00

Unnamed Project

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
R_Theatre_1	0.1480	0.009777197	0.00	1.0000
R_Theatre_2	0.1913	0.014513118	0.00	1.0000
R_Theatre_3	0.2238	0.013423763	0.00	1.0000
R_Theatre_4	0.1288	0.011029113	0.00	1.0000
R_Theatre_5	0.1406	0.013500676	0.00	1.0000
R_Theatre_6	0.1644	(Correlated)	0.00	1.0000
R_Theatre_7	0.1695	0.013205917	0.00	1.0000
R_Theatre_8	0.2155	0.010235273	0.00	1.0000
R_Theatre_9	0.2257	0.012771703	0.00	1.0000
R_Theatre_GT	0.05034250	(Correlated)	0.00	1.0000
Theatre_Sister	0.08289549	0.004128404	0.00	0.5000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
R_Theatre_1	0.1480	0.009777197	0.00	1.0000
R_Theatre_2	0.1913	0.014513118	0.00	1.0000
R_Theatre_3	0.2238	0.013423763	0.00	1.0000
R_Theatre_4	0.1288	0.011029113	0.00	1.0000
R_Theatre_5	0.1406	0.013500676	0.00	1.0000
R_Theatre_6	0.1644	(Correlated)	0.00	1.0000
R_Theatre_7	0.1695	0.013205917	0.00	1.0000
R_Theatre_8	0.2155	0.010235273	0.00	1.0000
R_Theatre_9	0.2257	0.012771703	0.00	1.0000
R_Theatre_GT	0.05034250	(Correlated)	0.00	1.0000
Theatre_Sister	1.6579	0.082568086	0.00	10.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
R_Theatre_1	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_2	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_3	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_4	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_5	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_6	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_7	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_8	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_9	1.0000	(Insufficient)	1.0000	1.0000
R_Theatre_GT	1.0000	(Insufficient)	1.0000	1.0000
Theatre_Sister	20.0000	(Insufficient)	20.0000	20.0000

Unnamed Project

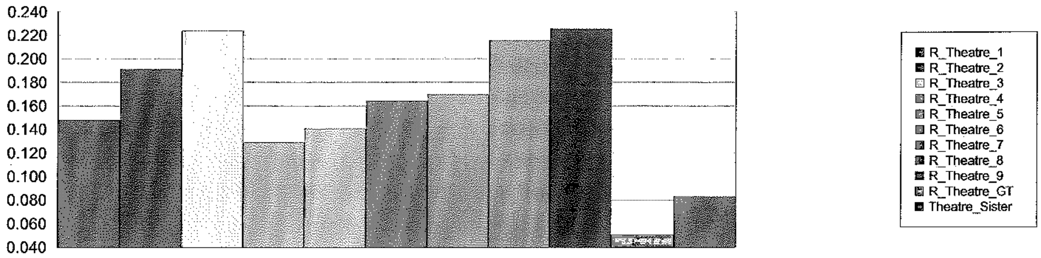
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
R_Theatre_1	0.1480
R_Theatre_2	0.1913
R_Theatre_3	0.2238
R_Theatre_4	0.1288
R_Theatre_5	0.1406
R_Theatre_6	0.1644
R_Theatre_7	0.1695
R_Theatre_8	0.2155
R_Theatre_9	0.2257
R_Theatre_GT	0.05034250
Theatre_Sister	0.08289549



Unnamed Project

Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
R_Theatre_1	2042.00
R_Theatre_2	4019.00
R_Theatre_3	1440.00
R_Theatre_4	1888.00
R_Theatre_5	3295.00
R_Theatre_6	2812.00
R_Theatre_7	3659.00
R_Theatre_8	3597.00
R_Theatre_9	4124.00
R_Theatre_GT	2115.00
Theatre_Sister	28991.00