Providing solutions to improve outpatient flow and turnaround time of outpatient pathology tests at the Campbelltown hospital pathology department

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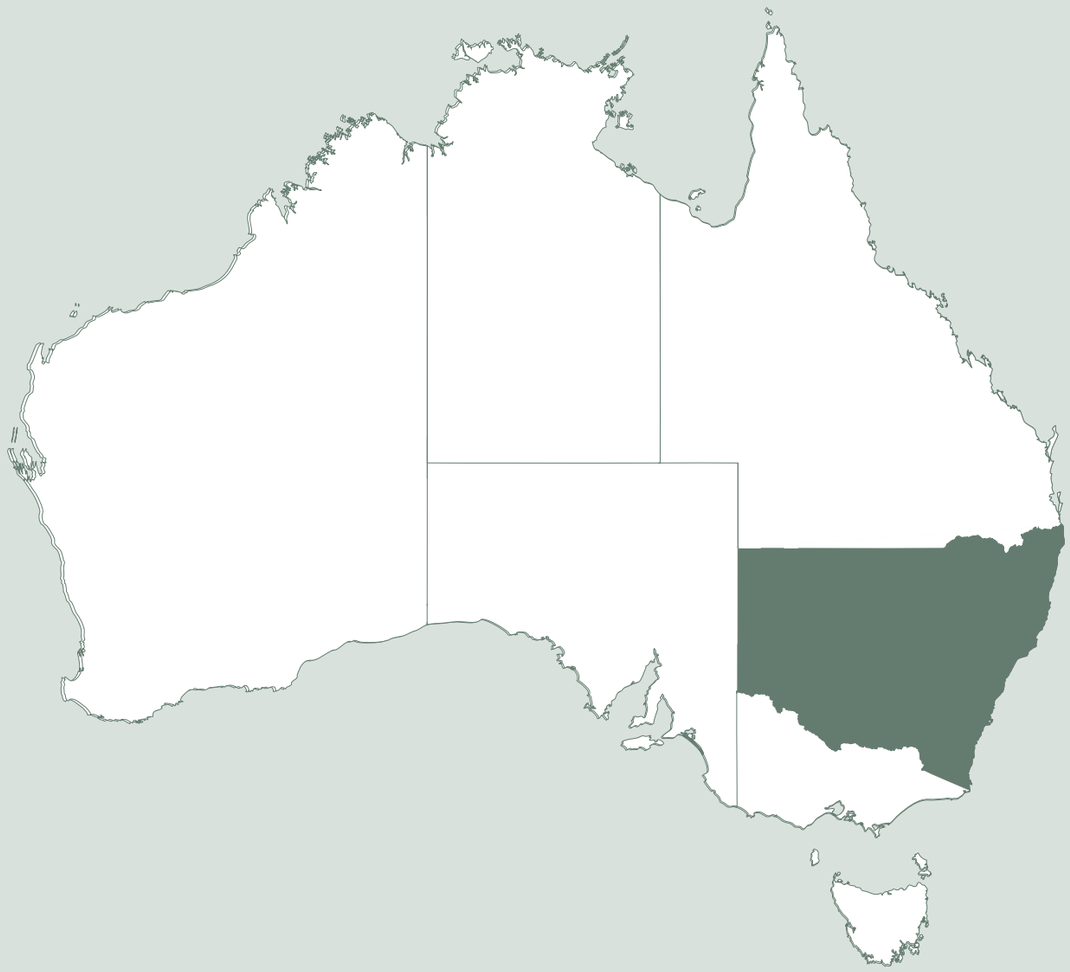

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Preface

This report describes the research I conducted in the Campbelltown public hospital in Sydney Australia, and signifies the final phase of my BSc degree in Industrial Engineering & Management at the University of Twente, Enschede.

Starting to work on your first real thesis is not easy. You feel like you should be prepared after receiving dozens of courses and sweating through nerve-racking last minute study sessions, (and you probably are), but there is always a hint of doubt. Luckily, doubt can quickly be overshadowed by excitement, natural but very pleasant excitement.

Despite months of intensive mail-bombing and reaching out to everybody from direct family to people I vaguely knew from the line at the bakery: no graduation project opportunity surfaced. But finally, through a mutual friend: Sjaak, and a very responsive action from Erwin Hans, I got into contact with Anneke Fitzgerald.

Anneke where do I begin? I want to thank you from the bottom of my heart. Hardly three weeks after our first Skype meeting I was on a plane heading to Sydney, about to have an adventure that would have been impossible without you. And as if that wasn't enough, you offered me the chance to join in on a family, and a fantastic home away from home. The only one happier with the fun you, Kim, Wilma, Chris and Michael have given me, was probably my mother. As you can imagine she wasn't too unhappy about that pair of responsible eyes on this little boy in the big city. I thoroughly enjoyed your hospitality and thinking back on the time I have spent with all of you fills me with joy.

At the University of Western Sydney you introduced me to everyone in the RHOaM group and all the people we cooperated with. Both the experiences of joining all of you in the projects at the hospital, and the workshops in Newcastle have been wonderful, socially and professionally. I would especially like to thank Kate Hayes, Terry Sloan, Ante Prodan and Joanne Curry for giving me the chance and the joy of working with them.

The second group of professionals I had the pleasure of working with is the staff of the pathology department at the Campbelltown public hospital. Although sitting in a waiting area with a laptop logging timestamps isn't the world's most exciting activity, I did not have a dull moment because I was surrounded by all of you. Vicky, Ivo, Karen, Synthia and Lidija, I would like to thank you for giving me the fantastic opportunity to conduct my research in your department, and for putting up with me. I know bombarding you with difficult questions day after day must not have been easy, but your help was invaluable.

A very special thank you for Erwin Hans. Although I was already thrilled about the option of going abroad, you made me even more excited about the prospect of going to this specific location: Australia. Without your seal of approval I wouldn't even have been able to go. Thank you for this opportunity! It truly is like you always say during our extensive and pleasant meetings: this is an experience I will never forget. Furthermore, your constructive and direct feedback has been an excellent guide in reaching this end result.

Finally (and definitely!) I want to thank my family for their support and enthusiasm. And before you are amazed at how wonderful the layout is, thinking: "Since when do industrial engineers have top of the line editing and design skills?" those credits can only go to my sister Nichon. Who knows what the return favour will be?

Arvid Glerum, May 2012

Management summary

Introduction

This research concerns the pathology department of the Campbelltown hospital. Campbelltown and Camden public hospital are the two hospitals that provide networked services for the MacArthur community in South Western Sydney. The provided services include intensive care, cardiology, maternity, gynaecology, oncology, paediatrics, palliative care, respiratory and stroke medicine, surgery and emergency medicine and aged care services (SSWAHS, 2010). A pathology department provides pathology services to a hospital and its patients. The main activities are the collection of human specimens like urine and blood and testing them for deviations for diagnostic purposes. Specimens can come in through internal hospital transportation from inpatients and the emergency department, or through the pathology collection station from outpatients. This research focuses on the outpatient collection process.

Problem description

The Campbelltown hospital has recognized the problem of access block: the situation where patients in the emergency department (ED) requiring inpatient care are unable to gain access to appropriate hospital beds within a reasonable time frame, resulting in ED overcrowding (Fatovich, Nagree, & Sprivuli, 2005). High volume ED presentations can create delays incurred by access block and these delays are exacerbated if ED clinicians do not have access to timely diagnostic information. Collecting the specimens from outpatients takes up a lot of time in the pathology department that could otherwise be used to process specimens from the ED and inpatient wards. The problem the pathology department faces is an inefficient outpatient flow and a long turnaround time of outpatient tests due to a mismatch between capacity and demand in the outpatient collection process.

Research goal

This research aims to provide solutions to improve the outpatient flow and reduce the turnaround time of outpatient pathology tests by focussing on the mismatch between outpatient demand and capacity. In order to attain this goal a picture of the inner workings of the outpatient testing process within the department is constructed and readers will be provided with an understanding of the effects of an altered process parameter e.g. the availability of extra staff. There will be no solution given that solves all the departments problems. Instead this research aims to guide the department towards improving its strategies and practises by providing knowledge about its processes and recommending areas of improvement.

Data analysis

Process parameters influence the rise in or reduction of the number of people waiting in the pathology department throughout the day, with the demand as input. We constructed a spreadsheet model that aims to find the relation between the process parameters and how they influence each other. The spreadsheet model replicates the observed number of patients waiting in the pathology department of the Campbelltown hospital.

When the input and output of the model are the same as observed, the modelled relation between process parameters is assumed to be a realistic representation of their relation on the observation days. If the model is able to replicate the observed output, process parameters can be altered to model their effect on the department's performance. These effects are an indication of the improvement possibilities that a changed parameter can have on the value of the performance measures on the observed days. These comparisons with the observed situation create the opportunity to assess and rank the interventions.

The model uses empirical data gathered during the observational study, requested data and interviews with the pathology staff. A number of parameters are stochastic in nature. We have developed two models and validated these against the observed values to obtain the method with the best fit. In the first (static) model, to simplify it, a deterministic representation of these parameters in the form of a deterministic random variable is used. The second model uses averages and standard deviations derived from the empirically gathered data to create fluctuating values for the service times, arrivals and available capacity. These random variables serve as the basis of a Monte Carlo simulation that uses 10.000 runs.

Conclusion

Three categories of interventions are simulated: (1) an increase of capacity, (2) alignment of demand with existing capacity, and (3) combinations of (1) and (2). Figure M.1 shows the percentage improvement for the interventions compared to the current (unaltered) situation, and gives the standard deviation for the utilization of staff. The results show the potential impact of the interventions in the observed days, to indicate which areas in demand and capacity management are of interest to the department.

	Improvement # patients waiting	Improvement waiting time	Improvement utilization	Standard deviation utilization Monday	Standard deviation utilization Tue-Fri
Increase in capacity					
Extra bench	69.1%	48.9%	15.2%	27%	21%
No absence	77.4%	51.6%	10.7%	29%	24%
Extra collector	85.4%	68.5%	16.7%	24%	19%
Allignment capacity and demand and increase in capacity					
Extra bench morning	62.2%	48.7%	8.9%	26%	17%
Extra collector morning	77.8%	65.6%	10.1%	26%	18%
Allignment capacity and demand					
Dedicated bench	-183.3%	-97.9%	-9.9%	13%	10%
Opening time p2 +30min	1.9%	-0.7%	0.1%	20%	16%
Opening time p2 +60min	14.8%	21.2%	0.8%	20%	16%
Regulate demand	62.8%	63.4%	2.1%	13%	11%

Figure M.1 Simulation results for interventions per category.

These interventions provide the Campbelltown hospital emergency department with an overview of possible directions to improve the service for patients and the workload for collectors by improving the patient flow. Not all interventions will be possible to implement within the restrictions that the department is subject to.

Recommendations & further work

For the spreadsheet model to work accurately the input data needs to be extensive. Extensive data collection will mean better availability of trends throughout the day but also throughout the week and the year. This data can serve to refine the analysis of the daily operations and can serve as input for a number of demand and capacity management techniques that will help the department further align the demand and capacity it faces. Accurate and real-time data collection and processing techniques can serve as the basis for a performance management system that guides and informs the collectors of their achievements and progress.

Table of contents

1. Introduction

This research concerns the pathology department of the Campbelltown hospital. There is pressure on the department to deliver faster test results and reduce the turnaround time of outpatients. Process analysis and optimization techniques are used together with modeling and simulation to assist the department in moving towards these goals. This chapter is structured as follows:

Section 1.1 addresses the background of the research, thereby providing context for the research problem. Section 1.2 describes the research problem whereas section 1.3 states the research goal and research questions. Section 1.4 addresses the research design. Section 1.5 discusses the social, practical and theoretical relevance of the research. Finally, section 1.6 states the structure of the report.

1.1 Background

Australian Healthcare System

Public and private hospital combined admissions in Australia have risen by 16% between 2004 and 2009 and admissions to public hospital emergency departments increased at a faster rate than any other hospital service *(Australian Institute of Health and Welfare, 2010)*. Public hospitals in Australia provided about 7.4 million accident and emergency services in 2009 10, increasing by 4% on average each year between 2005 06 and 2009 10 *(Australian Institute of Health and Welfare, 2011)*.

The organization of healthcare in Australia is known as a two-tier healthcare system. Two-tier healthcare is a form of national healthcare in which a guaranteed public health care system exists, but where a private system operates in parallel. The private system has the benefit of shorter waiting times and more luxurious treatment, but costs far more than the public healthcare system *(McMillan, 2009)*. Australia's public hospital system is jointly funded by the Australian government and state & territory governments and is administered by state and territory health departments. People admitted to public hospitals as public (Medicare) patients receive treatment by doctors and specialists nominated by the hospital. The treating doctor does not charge them for care and treatment or after-care because of Medicare. Medicare is a comprehensive health care system that facilitates access by all eligible Australian residents to free or low-cost medical, optometric and public hospital care, while leaving them free to choose private health services. Individuals' financial contributions to the public health care system are based on their income and are made through a taxation levy known as the Medicare levy. About half of all Australians also have private health insurance. Forty-three per cent of the population (or nine million people) are covered by hospital insurance for treatment as private patients in both public and private hospitals. Private sector expenditure on health accounts for about one-third of total health expenditure. The majority (around 60 per cent) of this is an individuals' out-of-pocket expense and the remainder is expenditure by private health and other insurers *(Department of Foreign Affairs and Trade, 2008)*.

Sydney South West Area Health Services

Sydney South West Area Health Services (SSWAHS) is the provider of health services in Sydney South West, and operates a number of hospitals and facilities amongst which Campbelltown hospital. The Sydney South West (SSW) covers a land area of 6380 square kilometres and in 2009 had a population of approximately 1.38 million, representing just under 20% of the total NSW population *(NSW Health Services, 2010)*. With areas of both substantial new land release for residential development and

medium density urban infill, SSWAHS is one of the fastest growing parts of the State and its population is projected to climb above 1.63 million people by 2030, an 18% increase *(SSWAHS, 2005)*.

The area is characterized by its multicultural character due to a high proportion of new migrants settling in Sydney South West. In addition to the influx of new migrants to the area, the population grows by around 19,000 newborns per annum. Birth rates are considerably above the State average and this trend is projected to continue with young families expected to comprise a large proportion of new residential developments. There are 266,000 children under the age of 15 representing 20% of the total population *(SSWAHS, 2005)*.

At the other end of the age range, there are 180,000 people over the age of 65, representing 17% of the population. Hospital data indicates that people over the age of 65 years are responsible for 45% of all acute hospital bed days. The number of people aged over 65 years is projected to increase by 45% by 2016 at which time they will represent 13% of the total population *(SSWAHS, 2005)*.

A total of 3958 beds are available and 17.792 full time employees are employed by Sydney South West Area Health Service *(NSW Health Services, 2010)*.

Campbelltown hospital

Campbelltown and Camden public hospital are the two hospitals that provide networked services for the MacArthur community in South Western Sydney, co-ordinated by the Campbelltown facility. The provided services include intensive care, cardiology, maternity, gynaecology, oncology, paediatrics, palliative care, respiratory and stroke medicine, surgery and emergency medicine and aged care services. In the fiscal year 2008/2009 the Campbelltown hospital had an equivalent of 1238 full time employees, 360 beds and 28.373 separations (patients leaving the hospital) *(SSWAHS, 2010)*.
The following sections describe the two departments involved in the multidisciplinary research, the emergency and pathology department.

-Emergency department

Of the two hospitals serving the Macarthur community Campbelltown hospital is the only facility with an emergency department (ED). The emergency department had 48.868 attendances in 2008/09, a high number of attendances compared to others in the Sydney South West region, and by far the highest number of attendances compared to other facilities in its peer group. While the total number of ED attendances in the Sydney South West area increased by just under 2.4% from 342.787 in 07/08 to 350.957 in 08/09, the attendances at Campbelltown's ED increased well over 3.5% in the same period *(NSW Health Services, 2009) (NSW Health Services, 2010)*.

To assess the performance of an ED the NSW Health Services use quality of care indicators. These indicators assess the performance of the ED for 5 different triage categories. A patient entering the ED is assessed during triage and categorised according to urgency. Each of the 5 categories has a target, a time in which a doctor must have seen the patient. The percentage of time this target is met gives a performance indicator and all the 5 indicators combined make up the Emergency Admission Performance (EAP), which is measured on a 0-100 scale. The EAP for the Sydney South West region declined from 72 in 07/08 to 69 in 08/09 while Campbelltown's EAP dropped from 66 in 07/08 to 60 in 08/09 *(NSW Health Services, 2009) (NSW Health Services, 2010)*.

-Pathology department

A pathology department provides pathology services to a hospital and its patients. The main activities are the collection of human specimens like urine and blood and testing them for deviations for diagnostic purposes. Specimens can come in through internal hospital transportation from inpatients and the emergency department, or through the pathology collection station from outpatients. Pathology departments differ in capacity and equipment but are usually capable of providing at least basic test results needed for diagnostic purposes.

The pathology department of Campbelltown hospital is part of a regional network servicing the needs of hospitals in the Sydney South West Area called the Sydney South West Pathology Services (SSWPS). The need for a pathology network arose because not all the facilities in the area can sustain a pathology department. The Campbelltown pathology department services the needs of both Campbelltown patients as well as Camden patients, and some specialised tests and overflow get processed in Liverpool. This is the largest and most comprehensive SSWPS facility around 35 km from Campbelltown.

1.2 Research problem

The Campbelltown hospital has recognized the problem of access block: the situation where patients in the emergency department requiring inpatient care are unable to gain access to appropriate hospital beds within a reasonable time frame, resulting in ED overcrowding (Fatovich, Nagree, & Sprivuli, 2005). Overcrowding can lead to a number of problems, including prolonged waiting times, increased suffering for those in pain, unpleasant therapeutic environments, and, in some cases, poor clinical outcomes (Derlet, 2002). Hospital and ED overcrowding is even associated with increased mortality (Sprivulis, Da Silva, Jacobs, Frazer, & Jelinek, 2006). High volume ED presentations can create delays incurred by access block and these delays are exacerbated if ED clinicians do not have access to timely diagnostic information. Key stakeholders in the ED identified the turnaround time of a test that's sent off to the pathology department as a crucial factor of the time a patient spends in the ED. The dependence of the ED to get a timely result back from the pathology department is a determining factor in the time a patient spends in the ED. A lean event showed a number of interruptions contributing to the long turnaround time of an ED test. The two longest interruptions occur in the specimen reception and logging area of the pathology department, which is separated from the laboratory part of the department. The first interrupting factor is the amount of specimens entering the pathology department from wards other than the ED. These specimens enter pathology at the exact same point as the ED specimens: the chute for the in-hospital air tube transportation system. Because other wards can also request high priority tests every specimen coming through the chute must be treated the same. The second interrupting factor is the outpatient section of the pathology department where patients come in to get their blood collected. Collecting the specimens from outpatients takes up a lot of time that could otherwise be used to process specimens from the ED and inpatient wards. A floor plan of the pathology department with the different areas of interest can be seen in Appendix A.

The problem the pathology department faces is an inefficient outpatient flow and a long turnaround time of outpatient tests due to a mismatch between capacity and demand.

This research aims to provide solutions to improve the outpatient flow and reduce the turnaround time of outpatient pathology tests by focussing on the mismatch between outpatient demand and capacity. The problem bundle constructed for the pathology department is shown in Figure 1.2.

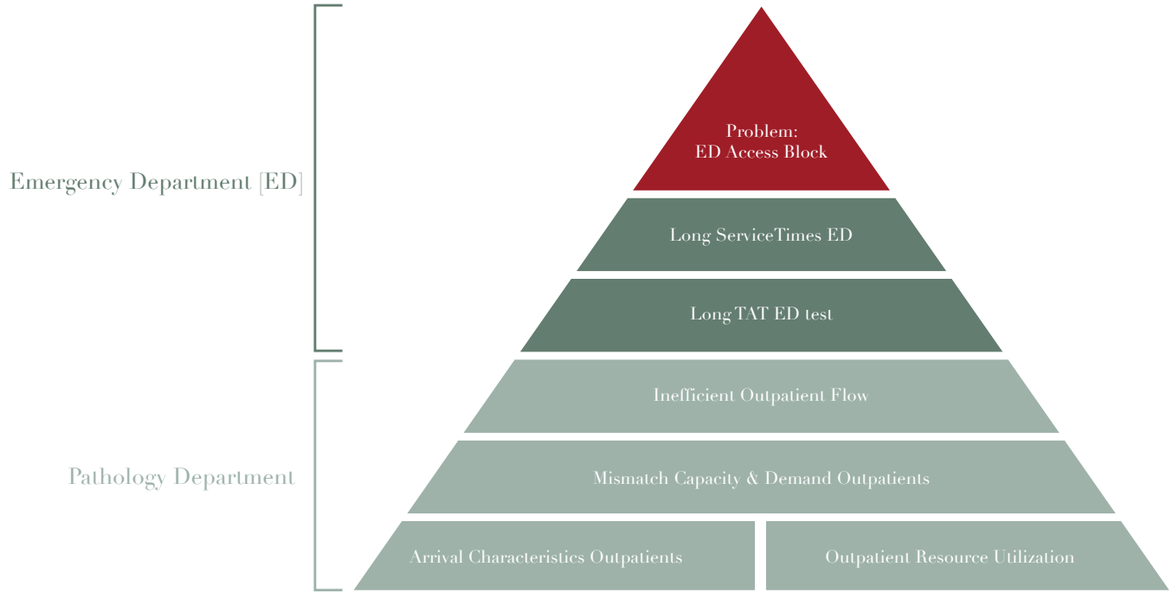


Figure 1.2 Pathology Problem Bundle

1.3 Research goal & questions

The research goal is: To provide solutions to improve outpatient flow and turnaround time of outpatient pathology tests at the Campbelltown hospital pathology department.

In order to provide an answer to the research goal stated above the following research questions need to be answered:

1 **What are the activities performed by the blood collectors?**

In order to provide solutions for the department there needs to be a thorough understanding of the different steps and tasks involved in obtaining and processing a specimen, as well as the secondary tasks of the collectors.

2 **What is the demand for outpatient testing?**

In order to assess the outpatient demand outpatient arrival characteristics are gathered and analysed.

3 **What is the available capacity for outpatient testing?**

In order to assess the departments capacity for outpatient testing, data is gathered regarding service times at the different stations and the availability of required hospital resources. Data regarding variability in service times and availability of resources is gathered as well.

4 **A. What are relevant performance measures in the outpatient testing process? B. What is the department's current performance on the relevant performance measures?**

Queuing theory literature and interviews with staff provide relevant performance measures. We construct a spreadsheet model that is used to model the outpatient testing process and analyse the department's current performance.

5 **What are possible solutions to improve the turnaround time of outpatient testing?**

Capacity and demand management literature is used to provide solutions to improve patient flow. The general effects of these solutions on the department's outpatient testing process performance is analysed using the spreadsheet model to give an approximation of their impact.

1.4 Research model

This research is practise oriented and based on an adapted version of the action research model where the implementation and evaluation phases are not executed. Action research is chosen because its strength lies in its focus on generating solutions to practical problems (Coghlan & Coughlan, 2002). For more information on action research see paragraph 2.2.2. Capacity and demand data is gathered using an observational study, historical data and a series of interviews. We construct an overview of current performance by analysing this data. A literature study is used to identify possibilities to close the gap between capacity and demand.

1.5 Relevance of the research

1.5.1 Social and practical relevance

Campbelltown hospital is an important healthcare hub in the area. As mentioned in paragraph 1.1 there are a number of issues threatening the ability of the Campbelltown hospital to deliver quality care in a timely manner. The performance of the Campbelltown emergency department is already behind compared to similar EDs and it lies in an area with a rapidly expanding population and a growing elderly community *(SSWAHS, 2005) (NSW Health Services, 2009) (NSW Health Services, 2010)*. Increasing the capacity of the pathology department to assist the ED in meeting their goals is an important step forward. Furthermore, like in every hospital, departments at Campbelltown are connected and research improving interdepartmental collaboration cannot only benefit the departments involved in this research but also the entire hospital.

1.5.2 Theoretical relevance

When using action research, Coughlan *(2002)* suggests, the following fundamental methodological question arises: how can operations managers and researchers learn from the applied activity that characterises the practice of operations management (OM)? As the name suggests, action research is an approach to research that aims both at taking action and creating knowledge or theory about that action *(Coghlan & Coughlan, 2002)*. In general, the development of the field of operations management will be enhanced by empirical work. All types of empirical research are needed. Empirical research can provide a strong foundation for making realistic assumptions in mathematical and simulation modelling research in operations management. Too often, it is forgotten that the results of mathematical modeling are only as valid as the assumptions upon

which the model is based. It is vital that mathematical models be based on realistic, rather than simply convenient, assumptions. Using empirically based distributions as inputs to simulation models can yield findings with greater external validity *(Flynn, Sakakibara, Schroeder, Bates, & Flynn, 1990)*.

1.6 Structure of the report

The report contains five chapters. Starting with an introduction in chapter 1 followed by the problem analysis in chapter 2. The problem analysis chapter provides an overview of the process as well as a literature review, followed by an elaboration on the research methodology and methods of data gathering and analysis. In chapter 3 the results of the data gathering and analysis are given, whereas chapter 4 applies the data analysis techniques to rank recognised improvement possibilities. Finally chapter 5 contains the conclusions and recommendations.

2. Problem analysis

Chapter 2 is structured as follows:

Section 2.1 provides an analysis of the processes relevant for the research questions. The different parts of the process, concepts, are explained and the relation between them is shown. Section 2.2 describes the theoretical framework. The theoretical framework encompasses a literature review and states the methodology used in this research. Section 2.3 addresses the methods used in data collection. Section 2.4 states the method of data analysis. In this paragraph the spreadsheet model used in data analysis is explained and an overview of the performance measures used is given. Finally section 2.5 discusses the limitations of the methodology and ethics.

2.1 Process analysis

In order to get an understanding of the outpatient flow and outpatient specimen processing in the pathology department we construct a timeline of outpatient testing, shown in Figure 2.1.1. Two distinct sets of activities can be identified within the pathology department: laboratory services and Specimen reception and collection. Laboratory services perform the testing of the specimens and communicate the result to the physician. Specimen reception and collection performs every action needed to get a specimen with the correct administration to the laboratory services. In the case of outpatients the blood needs to be collected first, a procedure known as phlebotomy. Upon arrival at the pathology department the patient needs to register at the counter (the registration process) before the patient is eligible to enter the collection process where the specimen is collected. The collection process starts with the phlebotomy after which the patient leaves and the collector enters the specimen collection area with the specimens. This is the same area where specimens from other parts of the hospital enter the pathology department via the chute of the in hospital vacuum transportation system. Every specimen needs to be logged in to the system and prepared in a spinner before being handed over to the lab via the handover bench. Once the outpatient's specimen has been handed over to the lab the collector starts the collection process from the beginning for a new outpatient. Thus the outpatient flow is relevant in the period from patient entering the waiting room up to his specimen entering the lab signalling the start of a new cycle.

Figure 2.1.1 Timeline of Outpatient testing

2.1.1 Concepts

-Outpatient

Outpatients are patients coming in the pathology department to get their blood collected. Any medical professional with permission to order diagnostic tests can forward a patient to pathology as an outpatient to get their blood collected. An outpatient is free to choose when to get their blood collected as long as it between 08:00 and 17:00 on a workday, when the pathology department is operating. Three outpatient classes are identified: normal, 1-hour glucose and 3-hour glucose. Normal outpatients register and are instantly eligible for phlebotomy. One-hour glucose patients get a glucose drink after the registration and have to wait for 65 minutes before their blood can be collected. Three-hour glucose outpatients have to rest for 30 minutes after registration before their blood is collected. Afterwards they get a glucose drink and have to wait for 145 minutes before their blood is collected for the second time. The outpatient collection process per class is illustrated in Figure 2.1.2. To get a better understanding of the current demand the concept of 'outpatient' is defined as the number of outpatients per class arriving per time period and their arrival times.

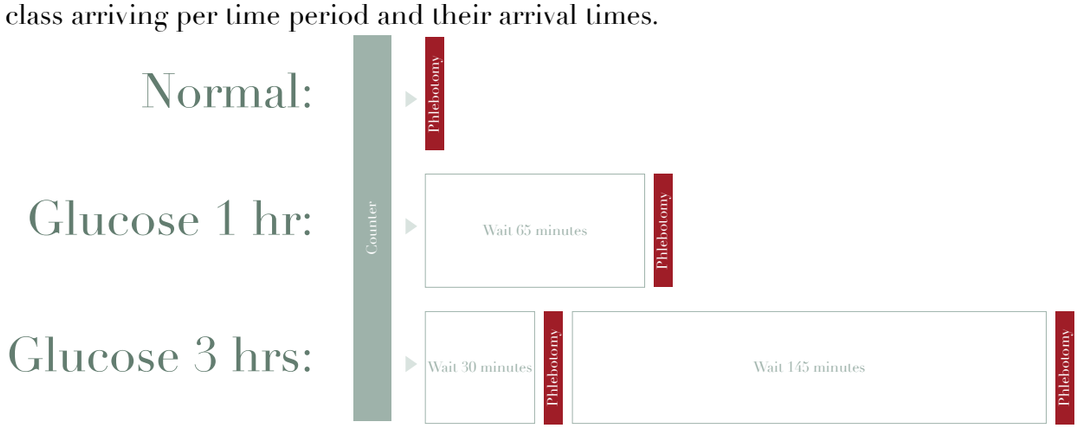


Figure 2.1.2 Outpatient collection process per class

-Turnaround time (Total)

Different interpretations are given to turnaround time (TAT) depending on perspective. For diagnostic purposes a TAT (total) is the time period starting at a referring doctor needing additional information to give a diagnosis, the moment of ordering a test, until the moment results becomes available. The time between ordering of the test and the outpatient entering the pathology department however is not relevant to the performance of the pathology department, since this is solely a choice of the patient himself and outside the sphere of control of the department. The TAT (total) for the pathology department therefore is the time between two timestamps: the outpatient arriving at the waiting room and results becoming available for the referring doctor in the hospital information system.

-Turnaround time (Patient Length of Stay)

The Patient Length of Stay, TAT (PLOS), is the part of the TAT (total) where the patient is physically involved and represents the first part of the outpatient testing process. The patient length of stay consists of two processes and the waiting time before them: the registration process and the phlebotomy process. The TAT (PLOS) is thus the time period between the outpatient arriving at the waiting room and the end of the phlebotomy. Registering these two timestamps and calculating the difference operationalizes this concept.

Registration process:

- **Patient wait time counter**
  Patient wait time counter is the time between two timestamps: the outpatient arriving at the waiting room and the start of the service period at the counter.
- **Service time counter**
  Service time counter is the time between two timestamps: the start of the service period at the counter and the end of the service period. This service period ends when the patient can take a seat in the waiting room.

Phlebotomy process:

- **Patient wait time phlebotomy**
  Patient wait time phlebotomy represents the time between two timestamps: the end of the service period at the counter to the patient entering the phlebotomy room, the start of the specimen collection.
- **Phlebotomy time** (time from entry to exit phlebotomy room)
  The second part of the TAT (PLOS) is the phlebotomy time. This is the part of the patient length of stay that is of value for the outpatient. It is comprised of the time between two timestamps: entering the phlebotomy room and exiting the phlebotomy room, or patient collection start and patient collection end.

-Turnaround time (Log)

The turnaround time (Log), together with the phlebotomy process, constitutes the collection process. TAT (Log), is the time it takes to process an outpatient specimen and get it ready for testing by the laboratory service. In this time the specimen is logged, spun and handed over to the lab. TAT (Log) is the time between two timestamps: the end of patient collection and the specimen entering the lab.

-Turnaround time (Lab)

The turnaround time of the laboratory, TAT (Lab), consists of the time between two timestamps: a specimen entering the lab and the results becoming available for the referring doctor. A specimen enters the laboratory services part of the pathology department when it is digitally logged into the lab by specimen collection and reception and is physically handed over.

-Resources

Resources are the tangible requirements to execute the outpatient testing process. Smith-Daniels et al. (1988) show that capacity management in health care involves decisions relating to acquisition and allocation of three types of resources: workforce, equipment, and facilities *(Smith-Daniels, Schweikhart, & Smith-Daniels, 1988)*. Resources for the pathology department are shown below.

Staff

The resource workforce is defined as the number of staff available to do work at a given moment in time. The number of staff members that are able to work can differ from the department's number of FTEs stated on the roster on a day-to-day base because of absences. Planned and even unplanned absences can influence the number of staff per day because a substitute is not always available.

Phlebotomy rooms

The resource facility is defined as number of phlebotomy rooms available for collection purposes at a given moment in time.

Equipment

The resource equipment is defined as the availability of equipment needed to successfully process patients. It is assumed that there is no constraint on the availability of this resource.

2.1.2 Relationship between concepts

The definition of concepts gives an outline of the relationship between concepts. The turnaround time (Total) is divided in 3 areas: the TAT (PLOS), the TAT (LOG) and the TAT (Lab). Patient flow focuses on the TAT (PLOS) with the TAT (LOG). This time period consists of the registration process and the collection process, which consists of the phlebotomy process and the logging process. These time periods are shown in Figure 2.1.3.

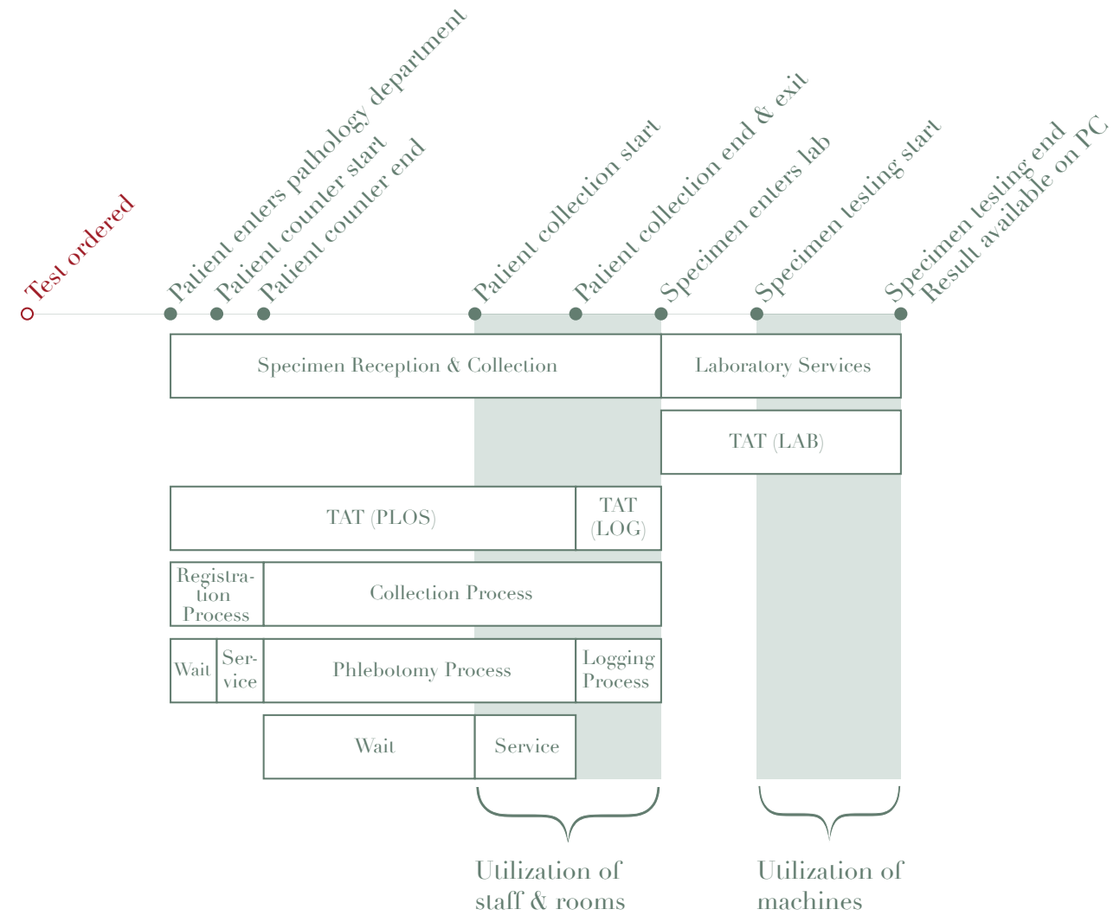


Figure 2.1.3 Relationship between concepts

2.2 Theoretical framework

The literature review in paragraph 2.2.1 focuses on capacity and demand management literature in the healthcare and outpatient context. The first objective of the review is identifying possible areas of process improvement provided by capacity and demand management literature. The second objective is recognizing strategies the department can use to realize those improvements. Paragraph 2.2.2 states the methodology used in this research.

2.2.1 Literature review

An important feature of healthcare processes (or services in general) is that the demand for resources is to a large extent unscheduled *(Creemers & Lambrecht, Modeling a hospital queueing network, 2010)*. As a consequence, there is a permanent mismatch between the demand for a treatment and the available capacity *(Creemers & Lambrecht, Modeling a hospital queueing network, 2010)*. Service practitioners have always been challenged with balancing demand and capacity due to this mismatch. This area of study is referred to as "demand and capacity management". Demand management is an attempt to shift demand, while capacity management is a response to demand *(Klassen & Rohleder, 2002)*. When speaking of capacity management, the aim is to minimize patient waiting time and to avoid idle capacity, with the goal of attending to demand in time and in the most efficient way possible *(Adenso-Diaz, Gonzalez-Torre, & Garcia, 2002)*. Lovelock *(1992)* defines the capacity of a service as the highest possible amount of output that may be obtained in a specific period of time with a predefined level of staff, installations and equipment. Both long and short-term decisions are required to fully manage demand and capacity *(Klassen & Rohleder, 2002)*.

To understand demand and capacity in healthcare the concept of patient flow is used. Patient flow represents the ability of the healthcare system to serve patients quickly, reliably and efficiently as they move through stages of care *(Hall, 2006)*. Queue and delay analysis can produce dramatic improvements in medical performance, patient satisfaction and cost efficiency of healthcare *(Creemers & Lambrecht, Modeling a hospital queueing network, 2010)*. There is a demand side (the patient mix and the associated variability in the arrival stream) and a supply side (the hospital resources such as surgeons, nurses, operating rooms, waiting rooms, recovery, imaging machines, laboratories) in any healthcare process. Moreover, both demand and supply are inherently stochastic. This stochastic nature creates disturbances and outages during the process *(Creemers & Lambrecht, Modeling a hospital queueing network, 2010)*.

-Variability

An important determinant of the flow time is variability. It is well known that variability induces waiting time. Two types of variability can be distinguished. Natural variability is variability that is inherent to the system process. Natural variability is much more substantial in healthcare as compared to manufacturing environments. Second, we have variability that can be related or assigned to a specific external cause. This variability is caused by unplanned absences of medical staff or interruptions during service operations, also known as outages. There is a consensus on the harmful effects of outages on patient flow times as well as on the quality of service *(Creemers & Lambrecht, Modeling a hospital queueing network, 2010)*.

Outages can be divided into unplanned absences of medical staff and interruptions during service operations. Unplanned absences and interruptions during service activities have a major impact on flow times. Medical staff faces various obligations that they have to attend to. These phenomena may cause a variable arrival pattern at the hospital *(Liu & Liu, 1998)* and may lead to interruptions during the treatment process *(Chisholm, Collison, Nelson, & Cordell, 2000) (Chisholm, Dornfeld, Nelson, & Cordell, 2001) and (Easton & Goodale, 2005; Dudewicz & Mishra, 1988)*. It is clear that hospital environments are characterized by substantial amounts of variability. As is argued in the literature *(Hopp, 2008)* variability induces waiting times. While in service industries variability cannot be countered by means of inventory in the traditional sense, patients will have to wait until capacity becomes available *(Sethuraman & Tirupati, 2005)*. Besides the time buffer, hospitals often have to rely on a capacity buffer to mitigate the impact of variability and to maintain required service levels *(Creemers & Lambrecht, Modeling a hospital queueing network, 2010)*.

-Demand management strategies

In manufacturing, production planning and control comprises work order scheduling and inventory management. In professional service organizations, planning and control systems comprise workforce practice guidelines, and protocols and mechanisms for controlling demand. Managing the flow of work though the system in professional services means managing the flow of customers *(Heineke, 1995)*. Demand management attempts to control when or where demand occurs, in order to match it efficiently with available capacity. Demand management is also used to smooth the flow of demand in order to avoid large differences between peak and non-peak periods *(Jack & Powers, 2008)*. Demand management strategies have been shown to be critical to health-care organizations in dramatically improving health-care delivery *(Jack & Powers, 2008)*. Two factors are important when looking at demand management in the healthcare environment. One is the ability to pre-schedule customers. Another is the ability of patients to control the timing of their demand *(Klassen & Rohleder, 2002)*.

Outpatient appointment scheduling has been the subject of scientific investigation since the beginning of the fifties of the previous century. The objective of appointment scheduling is trading off the interests of physicians and patients: the patients prefer to have a short waiting time, the physician likes to have as little idle time as possible, and to finish on time *(Kaandorp & Koole, 2007)*.

Improving outpatient resource utilization significantly enhances the efficiency of healthcare organizations. Due to substantial number of walk-in patients to outpatient services scheduling becomes extremely complicated and important. Selecting the right scheduling alternative, a healthcare organization can markedly improve operating efficiency of outpatient resources *(Su & Shih, 2003)*.

It is not always possible for a patient to control timing of demand, but the use of a cross-over or mixed-registration type can spread outpatient arrival time to produce a more even workload *(Su & Shih, 2003)*. The goal of such a scheduling method is to lower the total throughput time, especially for patients with an appointment as an incentive for registering. The following two possibilities are identified for preregistering patients, if possible, thereby attempting to spread the workload:

- Outpatient management system with both walk-in patients and an appointment system.
- Priority queuing system, where a walk in outpatient observes the queue and has the option to registers for a timeslot later in the day. The patient is consequently free to visit to for instance another department of the hospital knowing the exact time of phlebotomy.

-Capacity management strategies

Research on capacity management covers a wide scope of resource management issues relative to how internal delivery systems can efficiently and effectively leverage scarce resources to meet the fluctuating demand for health-care services *(Jack & Powers, 2008)*. Unlike the reliance on slack capacity and inventory buffers in other industries, it is not possible in health- care delivery to produce the complete service package in advance of demand and hold it as inventory. This real-time element of service co-production and patient consumption makes the matching of supply and demand very important *(Jack & Powers, 2008)* and limits the system to buffering by capacity.

The demand management approaches used on the operational level constitute ways for administrators and other decision-makers to make the best possible use of their resources by simultaneously considering the large number of variables that are found in these complex health-care service environments *(Jack & Powers, 2008)*.

The major barrier for capacity in the short term is to be able to deal with unexpected demands. To overcome these barriers the following workforce management strategies are identified:

- Volume flexibility strategies *(Bloom, Alexander, & Nuchols, 1997)*
  - Deployment of overtime and temporary employees
  - Innovative shift schedules
  - Creative use existing employees through cross training
- Capacity planning models for minimum staff calculation that balance the workload of staff *(Adenso-Diaz, Gonzalez-Torre, & Garcia, 2002)*

2.2.2 Action research methodology

The goal of this research is to provide a picture of the inner workings of the outpatient testing process within the department and provide readers with an understanding of what happens in the system when a parameter changes. There will be no solution given that solves all the departments problems. Instead this research aims to guide the department towards improving its strategies and practises by providing knowledge about its processes and recommending areas of improvement. In order to do this insight needs to be gained into the workings of the department. The model used to structure this research is an adapted version of the Action Research (AR) model. AR is not easily defined. It is a style of research rather than a specific method. The term is now identified with research in which the researchers work explicitly with and for people rather than undertake research on them *(Meyer, 2000)*. AR is an approach to research that aims both at taking action and creating knowledge or theory about that action by working through a cyclical four-step process of consciously and deliberately: planning, taking action and evaluating the action, leading to further planning and so on *(Coghlan & Coughlan, 2002)*. Action research is chosen because its strength lies in its focus on generating solutions to practical problems and its ability to empower practitioners getting them to engage with research and subsequent "development" or implementation activities *(Meyer, 2000)*. This model is visualized in Figure 2.2 and differs from the generic Action Research Model in that it is not a complete cycle, the research does not progress into the implementation and reflection phase of the action research model.

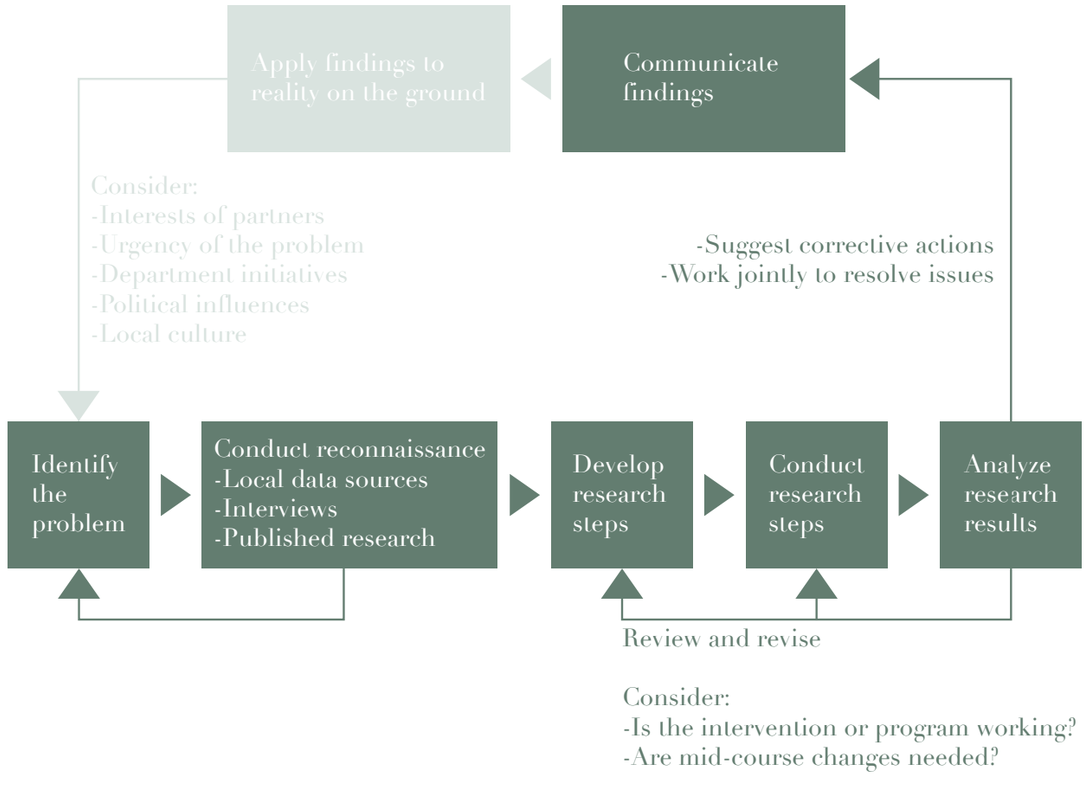


Figure 2.2 Adaptation of the Action Research Model, (Source: http://www.nij.gov/topics/crime/gun-violence/prevention/action-research-model.htm)

To map the current situation in the department information is gathered on both the capacity and the demand side. This research consists of the following components:

- An observational study to map the process layout and acquire timestamps necessary to analyse arrival rate, service times and variability.
- Interviews with collectors to assess their activities, workload, interruptions and to answer questions that arise during the observational study.
- Requested data provides necessary background information for the outpatient testing process.
- A spreadsheet model linking the different process parameters in order to describe the patient flow throughout the system. Monte Carlo Simulation will be used in the spreadsheet model as a method to incorporate the stochastic nature of empirically gathered process parameters.
- A literature review was conducted to identify possibilities to close the gap between capacity and demand.

2.3 Data gathering method

The data gathering is done in a mixed approach, a numerical observational study to gather relevant timestamps and a number of qualitative interviews to construct a better view of the situation. Additional department data is requested as background information and to supplement the observational data and interviews

2.3.1 Observational study

A non-participative observational study is conducted. The first part is a morning session following and observing a collector from opening at 08:00 to 12:00. This serves the purpose of gaining insight in the process layout as well as confirming details about activities and numerical estimates mentioned in interviews.

The second part is a 6 day gathering of timestamps from opening at 08:00 to 14:00 when there are very little or no outpatient arrivals to be logged. The timestamps cover all the points in time relevant to the TAT (PLOS) as seen in paragraph 2.1 and are logged to the second in an Excel spread sheet using macros.

The third part is a gathering of timestamps in the specimen reception area, where specimens come in via the chute and collection rooms. The timestamps allows for identification of the natural service times and the pre-emptive outages in the specimen reception part of the process. Timestamps are logged for a total of 133 cycles during 2 days of observation between 08:00 and 16:00.

2.3.2 Interview

Interviews can be used as a primary data gathering method to collect information from individuals about their own practices, beliefs, or opinions. They can be used to gather information on past or present behaviours or experiences. Interviews can further be used to gather background information or to tap into the expert knowledge of factual material and data, such as descriptions of processes *(Harrell & Bradle, 2009)*. A semi-structured interview method is chosen because semi-structured interviews give the interviewer a certain amount of freedom and provide to interviewee with the possibility to diverge, possibly steering the interview into an area the interviewer had not thought of. Also, semi-structured interviews are often used when the researcher wants to delve deeply into a topic and to understand thoroughly the answers provided *(Harrell & Bradle, 2009)*.

The daily interview sessions with the collectors consist of questions that arise before and during observations, and are posed after each observational session when the

collectors are available. The interviews are held in the work area of interest for possible clarification purposes. Open-ended questions are answered in a group setting (n=3) as to allow collectors to bounce of each other's ideas. Questions regarding estimates of percentages and best practise times are asked individually. Numerical estimates are confirmed by interviewing at least 2 other collectors, without them knowing previous answers.

2.3.3 Requested data

The requested data contains:

- Historical total number of walk in outpatients per day (n=36)
- Official time schedule for number of collectors per time per day including breaks
- Number of collectors available for work per time per day for the observed days
- Official number of leave days
- FTEs available for specimen reception & collection

2.4 Method of data analysis

On the observation days process data is gathered. Not only is the demand during the day known, also the resulting number of patients waiting is known. Process parameters like service times, interruptions, secondary activities and the number of collectors available throughout the day are, if possible, observed otherwise requested. A graphical representation of the phlebotomy process and its parameters can be seen in Figure 2.4.1.

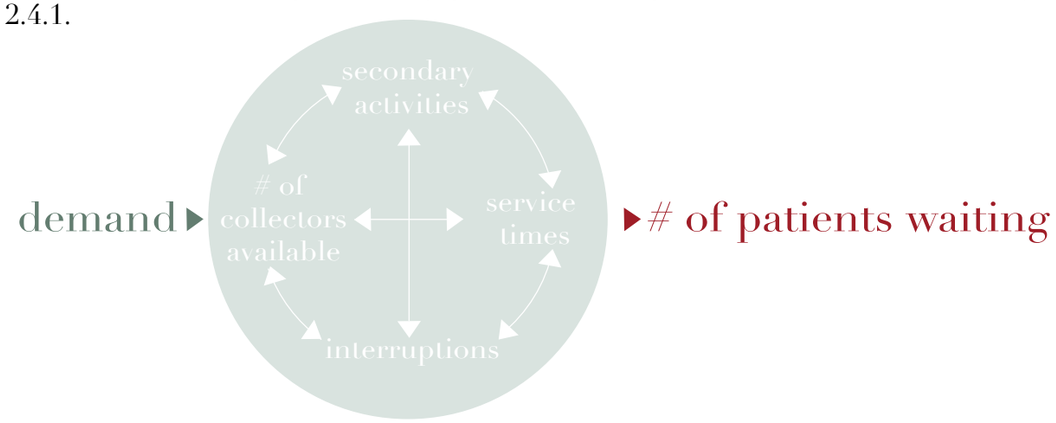


Figure 2.4.1 A graphical representation of the phlebotomy process and its parameters

Process parameters influence the rise in or reduction of the number of people waiting throughout the day, with the observed demand as input. We construct a spreadsheet model that aims to provide the same process output as observed, by finding the relation between the process parameters and how they influence each other. When the input (demand) and output (number of patients waiting throughout the day) are the same as observed, the modelled relation between process parameters is assumed to be a realistic representation of their relation on the observation days.

The speed at which patients can be processed depends on the value of the process parameters. These values change every interval with a corresponding change in number of patients waiting at the end of each time interval t. Figure 2.4.2 provides an overview of the different activities of the collectors that limit the time available for phlebotomy. Because this available time for phlebotomy changes every interval, a steady state cannot be found using queuing theory. Instead a spreadsheet model is used because of its ability to determine the behaviour of the system by varying the process parameters in each time interval t according to the observed situation. The spreadsheet model uses the output of the last time interval t as an input for the new interval, as to reflect the situation where a patient isn't served within the current interval and therefore will still be waiting at the beginning of the next interval. If the model is able to replicate the observed output and relation between process parameters, these parameters can be altered to see how those changes affect the value of the performance measures. These changed values are an indication of the improvement possibilities that a changed parameter can have on the value of the performance measures on the observed days. These comparisons with the observed situation create the opportunity to assess and rank interventions.

Figure 2.4.2 Activities limiting the available time for phlebotomy

2.4.1 Spreadsheet model

The spreadsheet model attempts to replicate the observed number of patients waiting in the pathology department of the Campbelltown hospital. The model uses 108 5-minute intervals for the period between 08:00 and 17:00 and gives a prediction $W(t)$ of the number of patients waiting at the end of each interval as output. To give the prediction $W(t)$ the model is divided in two parts: the demand and the capacity side. On the demand side there are the number of patients present in the system and the new arrivals at each interval. On the capacity side there is the speed at which the system can process patients. Factors influencing the processing speed are explained below.

The model uses empirical data gathered during the observational study, requested data and interviews with the pathology staff. A number of parameters are stochastic in nature. Two models are created and tested against the observed values to obtain the method with the best fit. In the first (static) model, to simplify it, a deterministic representation of these parameters in the form of a deterministic random variable is used. The second model uses averages and standard deviations derived from the empirically gathered data to create fluctuating values for the service times, arrivals and available capacity. These random variables serve as the basis of a Monte Carlo simulation that uses 10.000 iterations. In a Monte Carlo simulation pseudo-random numbers are generated that are normally distributed using empirically gathered means and standard deviations. The Monte Carlo method simulates the observed situation by using a multitude of iterations, where the situation varies each iteration due to the pseudo-random variables. The following parameters are represented using pseudo-random numbers in the Monte Carlo simulation:

- # Of arrivals at the counter per time period t
- # Of arrivals at the phlebotomy process per time period t
- Available number of collectors per time period t
- Service time at the counter
- Service time phlebotomy
- Service time processing

-Demand

The demand side of the model in each 5-minute interval consists of the arrivals in this interval plus all the patients that are still waiting from the previous 5-minute interval. In order to give an accurate representation of arrivals at the phlebotomy process, we aggregate the arrivals for all 3 patients classes (p_0, p_1, p_2). As seen in Figure 2.1.2, the glucose patients (p_1, p_2) require a fixed and exact waiting time before being allowed to enter the phlebotomy process. 3-hour glucose patients (p_2) require 2 collections, for the purpose of this model these are represented as two separate arrivals in two separate time intervals. The aggregation of demand is represented in Figure 2.4.3. The assumption is made that all arrivals occur at the beginning of the period.

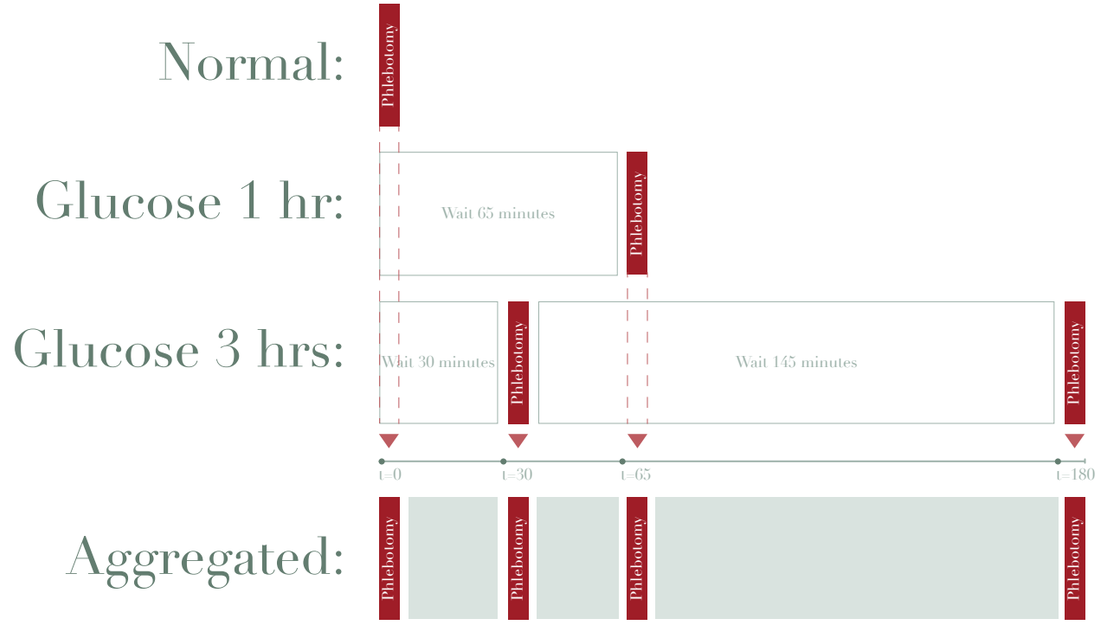


Figure 2.4.3 Demand aggregation

The demand aggregation can be seen in Figure 3.3.1 and is defined as:

$$\lambda(t) = \lambda_0(t) + \lambda_1(t-13) + \lambda_2(t-6) + \lambda_2(t-36), \forall t \in \{1,2,\dots,108\}, \lambda_{1,2,3} \in \mathbb{N}$$

This aggregation leads to the following demand per interval (t):

$$D(t) = \lambda(t) + D(t-1) - TH_{Total}(t-1), \forall t \in \{1,2,\dots,108\}$$

Where $D(t\text{-}1)$ is the demand in the previous time interval and $TH_{Total}(t-1)$ is the throughput (process rate) of patients in the previous time interval. In effect the demand in period t depends on the number of patients waiting at the end of the previous period plus the new arrivals at the beginning period t.
The patient demand for services at the counter does not need to be aggregated because all patients require service at the counter directly after entering the Pathology Department and only attend the counter once. The demand for services at the counter is denoted as $\lambda_c(t)$.

-Capacity

The capacity is the ability of the system to process patients. The capacity originates from the time available to collectors to collect blood coupled with the time it takes to collect a patients blood (μ_2), provided the 3 phlebotomy rooms are sufficient for the maximum possible throughput (processing rate). The number of collectors available for each interval varies due to a specific roster, unexpected absence and responsibilities outside of the pathology department. Also, there must be a collector present at the administration counter whenever arriving patients require service with service time μ_1. The time available per collector to collect blood is influenced by secondary activities and interruptions during and between services. The secondary activities are activities done when the demand for collection is low; the interruptions are divided in chute and non-chute interruptions. Chute interruptions occur whenever there are specimens arriving from other wards at the chute of the in hospital vacuum transportation system. Non-chute interruptions are all other interruptions, e.g. phone calls and consults. We use the following parameters when determining the throughput:

$TH_{total}(t) = Process\ Rate\ at\ time\ t$

$\mu_i = Service\ time\ at\ station\ i, i = 1\ (counter), i = 2\ (phlebotomy), i = 3(processing)$

$R_c(t) = Roster\ for\ Collectors, planned\ \#\ collectors\ at\ time\ t$

$A_r = Absentee\ rate$

$C_{emp} = Empirically\ gathered\ \#\ collectors\ at\ time\ t$

$C_{cntr} = \#\ collectors\ needed\ to\ process\ patients\ at\ the\ counter\ at\ time\ t$

$C_{cntr} = \lambda_c(t) * \mu_1 / \Delta t$

$WE_{total} = Total\ amount\ of\ extra\ work\ (secondary\ activities)\ in\ minutes$

$WE_f(t) = Fraction\ of\ extra\ work\ done\ at\ time\ t$

$IRR_{total} = Total\ amount\ of\ interruptions\ in\ minutes$

$IRR_{cp} = Percentage\ of\ total\ interrupts\ originating\ from\ incoming\ chute\ specimens$

$IRR_{ncp} = Percentage\ of\ total\ interrupts\ originating\ from\ non-chute\ interruptions$

$IRR_{cf} = Fraction\ of\ chute\ interrupts\ occurring\ at\ time\ t$

$IRR_{ncf} = Fraction\ of\ non-chute\ interrupts\ occurring\ at\ time\ t$

These parameters are used to determine the following useful parameters.
Minutes available for collection purposes at time *t*:

$$M_c(t) = (R_c(t) * (1 - A_r) - C_{cntr}) * \Delta t$$

Or, alternatively, using empirically gathered data on the number of collectors present:

$$M_c(t) = (C_{emp} - C_{cntr}) * \Delta t$$

Minutes of extra work to be performed at time *t*:

$$M_{ew}(t) = WE_{total} * WE_f(t)$$

Minutes of interruptions occurring at time *t*:

$$M_{irr}(t) = (IRR_{total} * IRR_{cp} * IRR_{cf}) + (IRR_{total} * IRR_{ncp} * IRR_{ncf})$$

Service time for one patient:

$$\mu_{Phleb} = \mu_2 + \mu_3$$

Using these times we determine the throughput with the following equation:

$$TH_{total}(t) = \frac{(M_c(t) - M_{ew}(t) - M_{irr}(t))}{\mu_{Phleb}}$$

-Combination of capacity and demand

By combining the throughput with the demand in period *t* we can determine the number of patients waiting at the end of each interval . For this we use the following equation:

$$W(t) = D(t) - TH_{total}(t)$$

2.4.2 Performance measures

We use the following performance measures, coined by Hopp and Spearman *(2008)* and *(Creemers & Lambrecht, Modeling a healthcare system as a queueing network, 2007)* to assess the performance of the outpatient testing process:

u	Utilization of phlebotomy staff
u (max)	Maximum utilization of phlebotomy staff

The utilization of the phlebotomy staff is useful to determine to what extend the resources of the department are being used. The utilization consists of 2 parts: the total time available to the phlebotomy staff per time period t and the time used by phlebotomy staff per time period t. The total time available consists of the number of collectors available times the number of minutes in time period t. The time used is determined by adding the minutes of work required at the counter, the minutes extra work required, the minutes interruptions in time t and the time used for collecting and processing specimens, so the utilization is determined by:

$$u(t) = \frac{C_{cntr} * \Delta t + M_{ew}(t) + M_{irr}(t) + TH_{total}(t) * (\mu_1 + \mu_2)}{C_{emp} * \Delta t}$$

CT_q Expected waiting time for phlebotomy

$CT_q(\max)$ Maximum expected waiting time for phlebotomy

Determining the waiting time is useful to ensure that patients are helped within a reasonable timeframe and can serve as a tool to monitor the collection process. The method to determine the length of time patients are waiting needs to encompass the fact that a patient is usually waiting longer than the length of period t. Also, the model is not capable of following specific patients, so the value of this parameter gives an indication of the total amount of minutes in waiting time left in the waiting area at the end of time period t. The waiting time for patients still waiting at the end of each period t is determined by:

$$CT_q(t) = \Big((W(t) * 5) - (\mu_1 * \lambda(t))\Big) + \left(\frac{CT_q(t-1)}{W(t-1)} * \big(W(t-1) - TH_{total}(t)\big)\right)$$

WIP_q Expected number of patients in phlebotomy queue

$WIP_q(\max)$ Maximum expected number of patients waiting in phlebotomy queue

The number of patients waiting at the end of each interval t is an important and visual performance measure. If the number of new arrivals outweigh the rate in which patients can be processed the number of patients waiting will grow and the waiting area will fill up. The number of patients waiting is empirically gathered or can be determined by using the model described in paragraph 2.4.1.

2.5 Discussion

2.5.1 Limitations of the methodology

Both the observational study and the interview have their shortcomings. Interviews are not neutral tools; data is based on personal interactions, which lead to negotiated and contextually based results *(Fontana & Frey, 2000)*. Also, due to the interpersonal nature of the interview context, participants may be more likely to respond in ways they deem socially desirable *(Richman, 1999) (Yin, 2009)*. Finally the qualitative interview has a small sample size, which prevents generalisation.

The observational study also has its limitations. The 8 days of observations might not represent a 'normal' situation, if there even is one. Therefore, in the model, assumptions have to be made. It also affects the predictive capability of the model negatively.

To improve usability of the process metrics that are observed in the observational study estimates from staff are also requested in interviews. Information on past experiences gathered in the interviews together with additional requested historical data is used to supplement and reinforce the data collected in the observational study. Outcomes of the model and simulation will only give a relatively accurate fit of the current situation if the parameters are still valid. E.g. if the situation in the department changes the historical service times will no longer provide a correct basis for the model. Because of the scope of this research and the context specific parameters the results will only be applicable to the Campbelltown pathology department and may not be representative if generalized.

2.5.2 Ethics

Traditionally, ethics in research relies on considerations such as not doing harm, not breaching confidentiality, not distorting data, informed consent, honesty, and the right to withdraw *(Williamson & Prosser, 2002)*. In this research there is a close collaboration between the researcher and the staff of the pathology department. Before interviews are conducted and questions are asked the purpose of the research is discussed and any questions from the department are answered. Since the pathology department requested this research aligning the goals is of mutual benefit. During the gathering of empirical data there is no contact with patients and only anonymous timestamps are gathered. This research reflects only on the performance of the department as a whole and no staff members are mentioned

3. Results

Chapter 3 provides the results for the analysis of the gathered data and is structured as follows:

Section 3.1 starts with an overview of the inputs used in the analysis followed by an overview of the observed situation in section 3.2. Finally section 3.3 gives a comparison of the observed situation and the result obtained from data analysis. This assessment determines if the spreadsheet model provides an accurate representation of the observed situation.

3.1 Model inputs

To determine the modelled number of patients waiting in each time period t we operationalize the input parameters specified in paragraph 2.4.1 according to the methods specified in paragraph 2.3.

Demand

An overview of the observed demand per time period t is given in Appendix B. The demand is split up in two sections: an un-aggregated (raw) demand at the counter and an aggregated demand for the phlebotomy process, as explained in 2.4.1. We use this data to determine the demand side of the model. Figure 3.1.1 and 3.1.2 provide a visual representation of the 2 sections for both the Monday and the Tuesday-Friday demand for each half hour time period. Mondays differ from Tuesday-Friday, mainly because of the difference in demand pattern. As can be seen in the figures below, the demand is higher on Mondays, especially in the morning period 08:00-13:00. This trend is, amongst others, caused by:

- Mental health patients can come in during the entire week but for unknown reasons prefer Monday and usually arrive very early.
- Cancer therapy patients come in on Monday because they get chemotherapy later in the week and the results need to be in before the chemicals are ordered.
- Patients that had non-life threatening events occur during the weekend are asked by the Emergency Department staff to get their bloods drawn first thing next Monday.

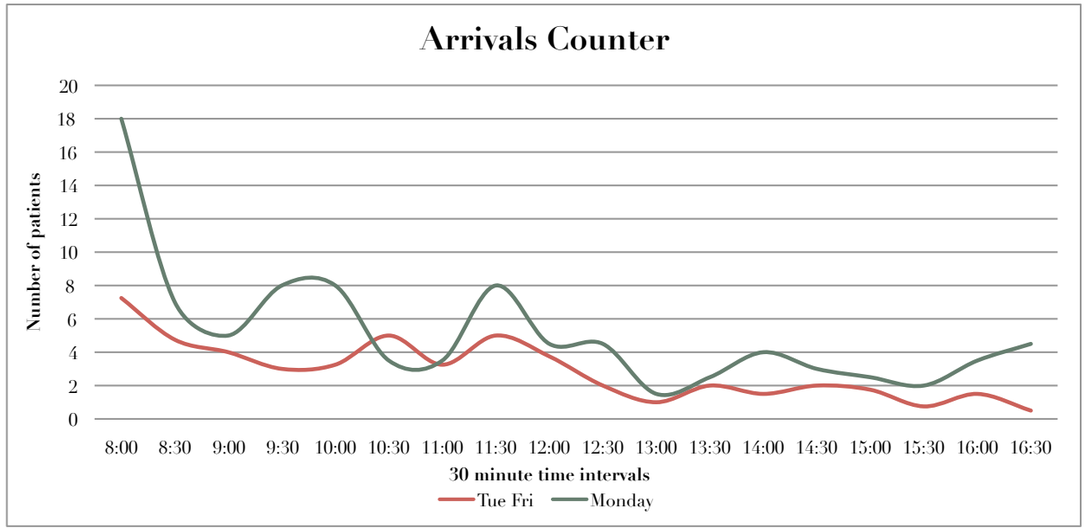


Figure 3.1.1 Observed demand at the counter (n=396,11-24 October 2011, empirically gathered at the Campbelltown hospital pathology department)

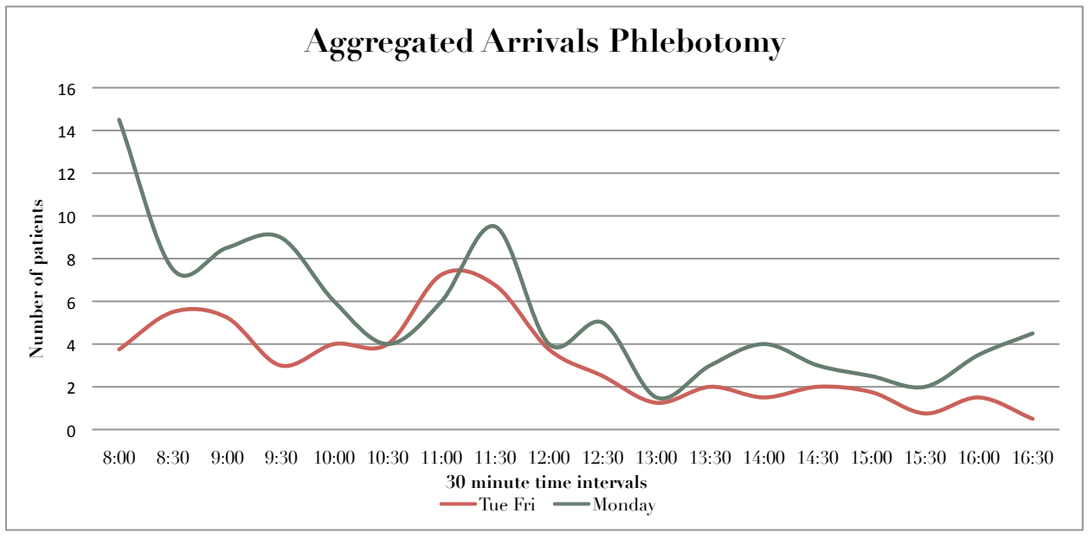


Figure 3.1.2 Aggregated observed demand for the Phlebotomy process (n=424,11-24 October 2011, empirically gathered at the Campbelltown hospital pathology department)

Capacity

The capacity represents the number of collectors available for work at each time period t. Appendix C gives an overview of the roster for collectors and the empirically gathered number of collectors at each time period *t*. The observed average number of collectors available on Tuesday till Friday is adjusted by subtracting extra collectors present for training purposes during the data collection. We determine the absence rate from the difference between the observed number of collectors present and the number of collectors stated on the roster. The overall empirically found absence rate amongst collectors is 9,69%, 12,73% on Monday and 8,22% on Tuesday-Friday. Figure 3.1.3 provides a visual representation of the number of collectors available gathered empirically and stated on the roster.

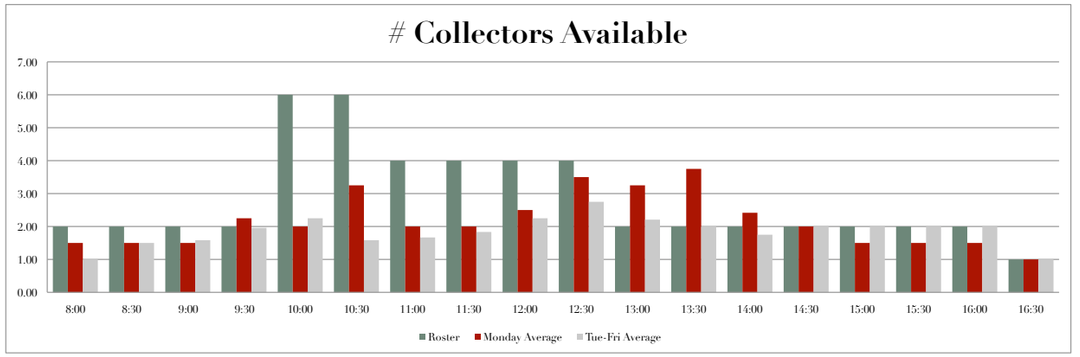


Figure 3.1.3 Number of collectors available on roster and observed (data received from Campbelltown hospital pathology department for the period of 11-24 October 2011)

Service times

As seen in 2.4.1 the model uses 3 different empirically gathered service times for service at the counter, the phlebotomy process and the specimen processing. We obtain the mean service times and standard deviations from the empirically gathered raw data. Outliers can lead to a misrepresentation of the average value; to correct this situation the outliers are determined through a boxplot and are not represented in the average service times. An overview of the raw service times, the boxplots and the refined service times can be found in Appendix D. The service times in minutes are given in table 3.1.1.

	Service Times			
	Counter	Phlebotomy Monday	Phlebotomy Tue-Fri	Processing
Average	0.91	3.14	4.23	2.04
Standard Deviation	0.3	0.99	1.57	1.24
n	241	118	125	121

Table 3.1.1 Service times and standard deviation in minutes with the number of observations on which they are based (empirically gathered between 11-24 October 2011 at the Campbelltown hospital pathology department)

Secondary activities

Appendix E gives an overview of the secondary activities, the extra work, which the collectors have to do. Because the secondary activities are not time dependant the collectors can choose at what time during the day to perform them. For this purpose an overview of the fraction of extra work done at time *t* $WE_f(t)$ is also given. Secondary activities are performed between 13:00 and 17:00 because of low demand in this timeframe. On Monday the secondary activities take 105 minutes, on the other days 80 minutes per day.

Interruptions

The empirically gathered interruptions are split up in interruptions due to incoming specimens via the chute and other interruptions. As with the service times, the outliers are not taken into account. The interruptions observed in the time periods *t* are extrapolated to get a total interruption time for both chute and non-chute interruptions. Non-chute interruptions are presumed to occur evenly throughout the day whereas the chute interruptions follow a pattern during the day. This fraction of chute interrupts occurring at time *t* IRR_{cf} is given in Appendix F, together with the data to determine the total minutes of interruptions. The total interruptions and the fraction of chute and non-chute work are given in table 3.1.2 below.

	Mon	Tue-Fri
Total IRR	169	215
Chute	81%	70%
Non chute	19%	30%

Table 3.1.2 Total interruptions in minutes and percentage of chute and non-chute interruptions (n=71, 21-22 October 2011, empirically gathered at the Campbelltown hospital pathology department)

3.2 Observed situation

We have shown the observed arrival and capacity in paragraph 3.1. The observed number of patients waiting is shown in Figure 3.2.1, together with the waiting time in 3.2.2, which are determined using the methods described in 2.4.2. The utilization cannot be determined using the method described in 2.4.2 because not all data needed could be collected simultaneously for each time period t. The simulated result for the performance measure utilization in the unaltered situation can be seen in table 4.2.2. Table 3.2 shows the exact performance measure for the observed situation.

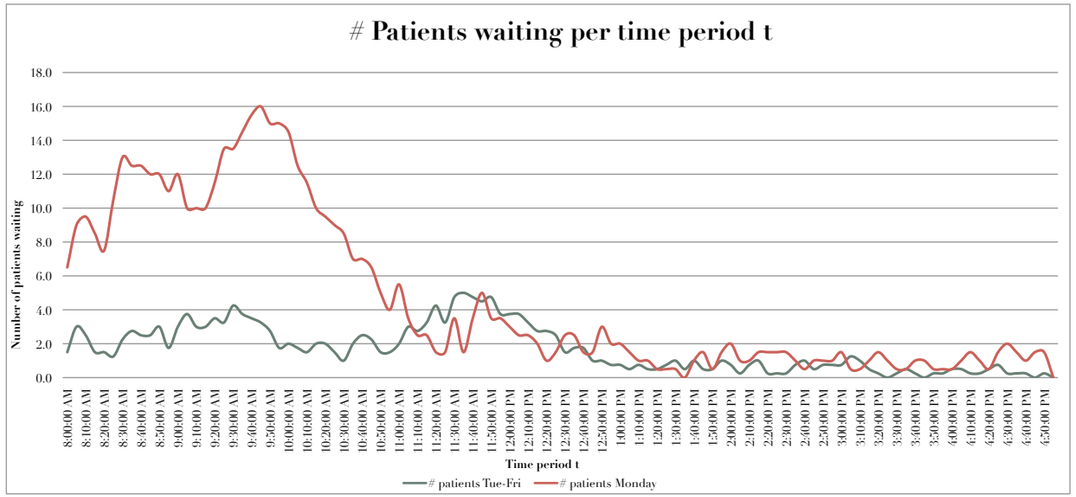


Figure 3.2.1 Observed number of patients waiting per time period t

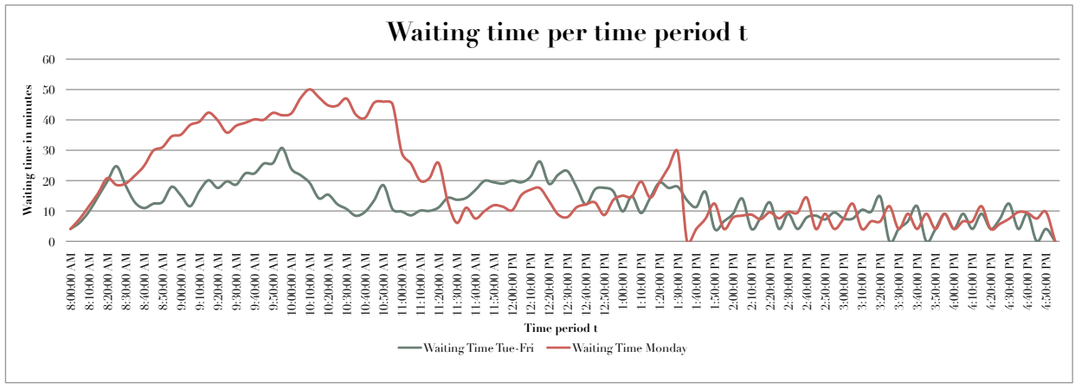


Figure 3.2.2 Observed waiting time per time period t

		Observed		
		Utilization	Waiting time	# Patients
Monday	Average	n.a.	18.8	4.6
	Max	n.a.	50.1	16.0
	St. Deviation	n.a.	14.3	4.7
Tue-Fri	Average	n.a.	12.9	1.7
	Max	n.a.	30.8	5.0
	St. Deviation	n.a.	6.5	1.3

Table 3.2 Observed results performance measures

3.3 Model performance & outcome

Results for both the static and the simulation model are obtained and the comparison between observed and the two models for both Monday and Tuesday-Friday can be seen in Figure 3.3.1 and 3.3.2.

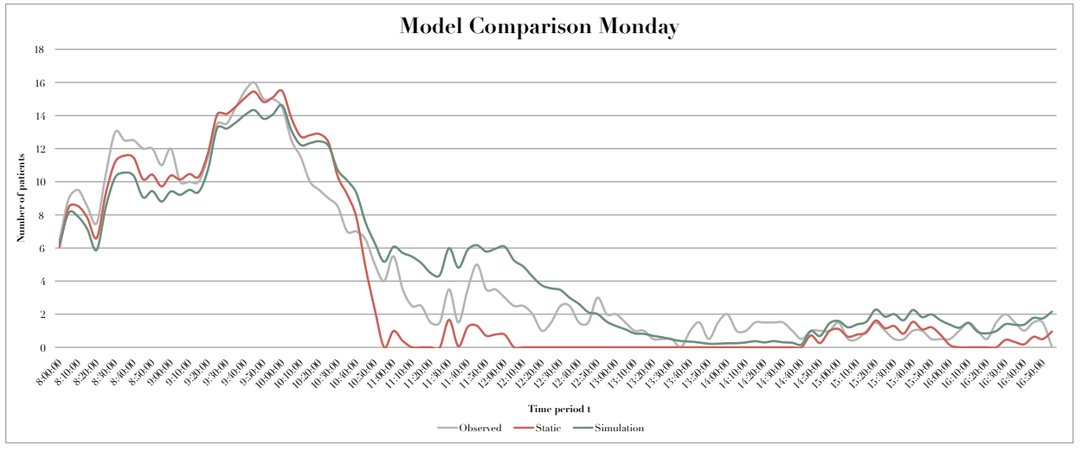


Figure 3.3.1 Comparison of models with observed situation for number of patients waiting at the end of each time interval t on Mondays

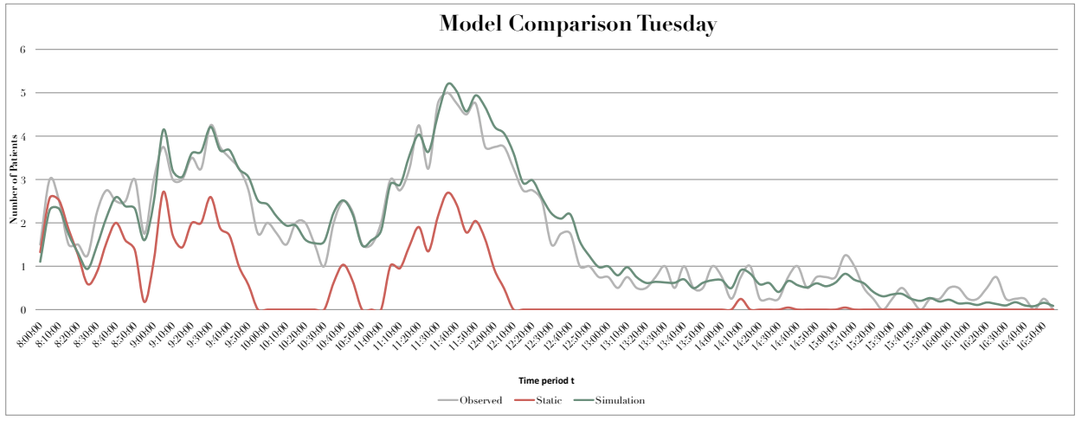


Figure 3.3.2 Comparison of models with observed situation for number of patients waiting at the end of each time interval t on Tuesday-Friday

The models are validated using 2 criteria: whether they follow the same distribution as the observed values and whether the 2 samples are the same. For this purpose we use the following tests:

- Mann-Whitney test (sample comparison)
- Two-sample Kolmogorov-Smirnov test (distribution)
- Sign test (distribution)
- Wilcoxon signed-rank test (distribution)

All 4 statistical tests are executed using a significance level of alpha=0,05. The hypotheses for sample comparison:

- H_0: The two samples follow the same distribution
- H_a: The distributions of the two samples are different

The hypotheses for distribution comparison:

- H_0: The difference of location between the samples is equal to 0
- H_a: The difference of location between the samples is different from 0

The resulting p-values can be seen in table 3.3.

		KS	MW	SIGN	WILCOX
Monday	Static	<0,000001	<0,000001	<0,000001	<0,000001
	Simulation	0.125	0.611	0.631	0.092
Tuesday	Static	<0,000001	<0,000001	<0,000001	<0,000001
	Simulation	0.607	0.892	0.387	0.187

Table 3.3 P-values resulting from the statistical tests

The results show that the static test never reaches a p-value greater than the significance level, thereby rejecting both H_0. The p-values resulting from the simulation are higher than the significance level for all four statistical tests thereby not rejecting the hypotheses H_0. The simulation provides an accurate representation of the observed situation when looking at the number of patients waiting at the end of each interval.

4. Application

This chapter is structured as follows:

Section 4.1 describes interventions that follow from the literature review, and the observed situation. In section 4.2 these interventions are used as an input for the spreadsheet model, with the performance indicators as outcome. In section 4.3 the interventions are ranked according to the performance indicators as to provide the hospital with possible areas of improvement.

4.1 Interventions

Several interventions are identified through the capacity and demand literature regarding staffing, work distribution, demand planning and variability.

Demand management

We identify two interventions in the area of demand management. The first is adjusting the demand to the available capacity in each time period *t*. This way the available capacity can be used optimally. The model represents this intervention by altering the arrival times of the total amount of patients to follow the same distribution as the collector's capacity throughout the day.

The second intervention is to change the scheduling timeframe for the 3-hour glucose patients. These patients are requested to arrive between 08:00 and 09:00, when there is also a high arrival rate for walk in outpatients. Simulation results are given for postponing the scheduled timeframe for 2-hour glucose patients with 30 and 60 minutes. The model represents this intervention by postponing all 2-hour glucose patient arrivals (both phlebotomy arrivals and the counter arrival) with 30 and 60 minutes.

Capacity Management

We identify several interventions in the context of capacity management. The first three have to do with the availability of staff without altering the distribution of work between collectors. Gathered data about staff availability shows that the available number of collectors varies substantially and that there are usually fewer collectors available than stated on the roster. The first intervention is reducing the absence and ensuring that the capacity stated on the roster is available. The model represents the full potential of this intervention by using the roster without absence as capacity. The second two interventions represent the extra availability of a collector, for half a day (08:00-12:30) and an entire day. The model represents these interventions by adding an extra collector to the average number of collectors available per time period t. The variability in the number of collectors available remains unaltered.

The second three interventions have to do with reducing variability. If there is a dedicated staff member responsible for the incoming chute specimens and the specimen reception and processing, chute interruptions and processing times are reduced for collectors. It is also assumed that this staff member can reduce the non-chute interruptions by half by taking up secondary tasks e.g. answering phones and assisting in requests for stocks. Not all non-chute interruptions can be handled by this staff member, for instance handling a consult, so half the interruptions remain.

There is the possibility of assigning one of the collectors a permanent position at the chute, or adding a staff member to do this job. Two interventions of adding a dedicated bench worker are: half a day (08:00-12:30) or an entire day. The model represents these interventions by reducing the chute interruptions to zero and reducing the non-chute interruptions and processing time by half for the time periods where there is a dedicated bench staff member present.

4.2 Simulation results

The simulated results for the proposed interventions can be found below in table 4.2.1 and in Figures 4.2.1 and 4.2.2. We show the simulated results for the days Monday and Tuesday-Friday and show both the average and maximum values for the number of patients waiting and the waiting time per patient. An overview of the simulation results including the standard deviations is given in appendix G.

	# Patients waiting				Waiting time in minutes			
	Avg		Max		Avg		Max	
	Monday	Tuesday	Monday	Tuesday	Monday	Tuesday	Monday	Tuesday
Observed	4.6	1.7	16.0	5.0	18.8	12.9	50.1	30.8
MC	4.9	1.7	14.6	5.2	18.5	9.9	41.4	20.8
Ded bench	12.1	5.0	25.5	10.3	48.1	33.4	74.8	49.4
Open 30	4.7	1.8	14.9	5.3	17.5	9.9	38.9	21.8
Open 60	4.3	1.4	14.1	3.5	16.4	8.1	34.3	14.1
xtr .5 bench	2.0	0.7	8.5	2.7	7.3	3.2	21.6	9.0
Extra bench	1.7	0.6	8.5	2.6	5.3	2.6	21.6	9.0
Reg Demand	1.2	0.8	4.3	1.4	6.2	4.6	22.8	7.2
No absence	1.7	0.2	9.4	2.0	5.2	1.3	21.3	8.3
Extra .5 coll	1.2	0.4	6.4	1.6	4.6	2.0	17.6	4.3
Extra coll	0.8	0.3	6.4	1.6	2.3	1.2	12.7	4.2

Table 4.2.1 Simulation results for each intervention

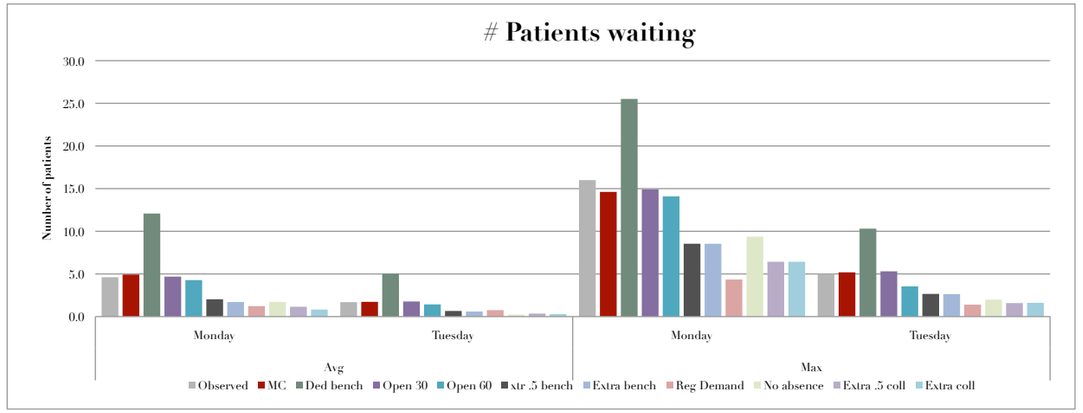


Figure 4.2.1 Simulation results number of patients waiting for each intervention

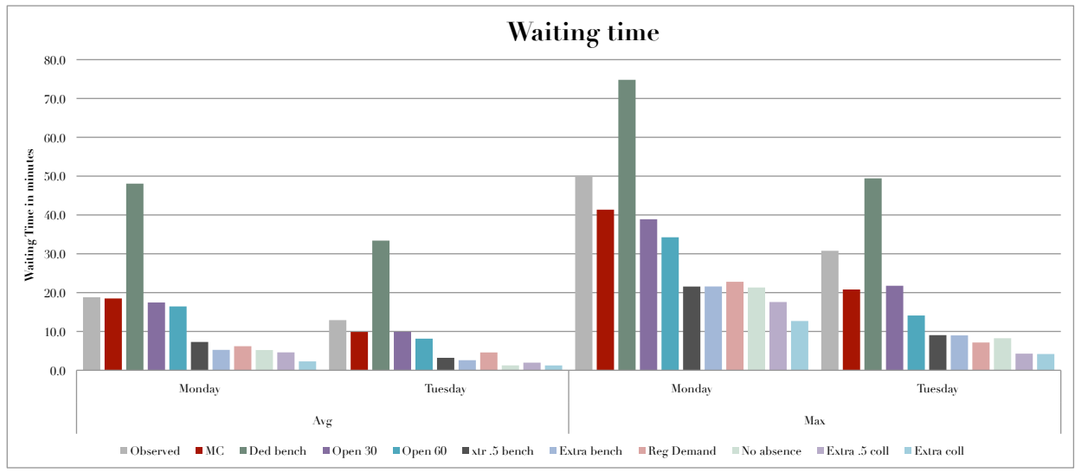


Figure 4.2.2 Simulation results waiting time in minutes for each intervention

The simulation also shows the utilization of phlebotomy staff for each intervention. Table 4.2.2 shows the average and maximum utilization and standard deviation per intervention for Monday and Tuesday-Friday.

	Utilization					Utilization	
	Avg		Max			stdev	
	Monday	Tuesday	Monday	Tuesday		Monday	Tuesday
MC	81%	72%	100%	99%	MC	21%	16%
Ded bench	92%	90%	100%	100%	Ded bench	13%	10%
Open 30	81%	72%	100%	99%	Open 30	20%	16%
Open 60	81%	71%	100%	97%	Open 60	20%	16%
xtr .5 bench	71%	62%	100%	90%	xtr .5 bench	26%	17%
Extra bench	62%	52%	100%	90%	Extra bench	27%	21%
Reg Demand	79%	74%	99%	91%	Reg Demand	13%	11%
No absence	67%	55%	100%	96%	No absence	29%	24%
Extra .5 coll	68%	61%	100%	90%	Extra .5 coll	26%	18%
Extra coll	57%	52%	100%	90%	Extra coll	24%	19%

Table 4.2.2 Simulation results per intervention for the performance measure utilization

4.3 Ranking of interventions

We rank the interventions using a score for each column. The worst score on the column gets the lowest rank and the best score on the row gets the highest rank. These sub rankings are added up to obtain a final ranking. This ranking can be seen in table 4.3.1.

	# Patients waiting		Waiting time		# Patients waiting		Waiting time			
	Avg Monday	Max Monday	Avg Monday	Max Monday	Avg Tuesday	Max Tuesday	Avg Tuesday	Max Tuesday	**Score**	**Rank**
Ded bench	9	9	9	9	9	9	9	9	**72**	**9**
Open 30	8	8	8	8	8	8	8	8	**64**	**8**
Open 60	7	7	7	7	7	7	7	7	**56**	**7**
xtr .5 bench	6	5	5	6	6	5	4	6	**43**	**6**
Extra bench	4	4	4	5	4	4	5	5	**35**	**5**
Reg Demand	3	6	1	1	5	6	6	3	**31**	**4**
No absence	5	1	6	4	3	2	3	4	**28**	**3**
Extra .5 coll	2	3	3	2	2	3	2	2	**19**	**2**
Extra coll	1	2	2	3	1	1	1	1	**12**	**1**

Table 4.3.1 Ranking of the interventions by column

Besides that the interventions are ranked according to their average percentage of improvement compared to the baseline simulation result. These are the percentage improvement for both Monday and Tuesday-Friday and the average and maximum of the number of patients waiting and the waiting times per patient. The intervention with the highest average reduction is ranked the highest. This ranking can be seen in table 4.3.2.

	# patients waiting		Waiting Time		# patients waiting		Waiting Time			
	Avg Monday	Max Monday	Avg Monday	Max Monday	Avg Tuesday	Max Tuesday	Avg Tuesday	Max Tuesday	**Avg**	**Rank**
Ded bench	-145.2%	-189.9%	-74.5%	-98.6%	-159.9%	-238.3%	-80.8%	-137.6%	**-140.6%**	**9**
Open 30	4.8%	-2.4%	-2.0%	-2.3%	5.6%	-0.4%	6.0%	-4.6%	**0.6%**	**8**
Open 60	13.2%	17.4%	3.6%	31.8%	11.1%	17.5%	17.2%	32.2%	**18.0%**	**7**
xtr .5 bench	58.8%	61.8%	41.6%	48.7%	60.6%	67.5%	47.9%	56.5%	**55.4%**	**6**
Extra bench	65.3%	65.7%	41.6%	49.2%	71.6%	73.7%	47.8%	56.8%	**59.0%**	**5**
Reg Demand	75.1%	56.3%	70.3%	73.0%	66.5%	53.5%	44.9%	65.6%	**63.1%**	**4**
No absence	65.0%	85.7%	35.9%	61.6%	71.8%	87.2%	48.5%	60.3%	**64.5%**	**3**
Extra .5 coll	76.5%	79.5%	56.0%	69.4%	75.1%	80.1%	57.5%	79.4%	**71.7%**	**2**
Extra coll	83.3%	83.3%	56.0%	68.9%	87.6%	87.4%	69.3%	79.9%	**77.0%**	**1**

Table 4.3.2 Ranking of the interventions by their average improvement over the baseline

Table 4.3.3 shows the ranking of the interventions on the performance measure utilization, again based on a ranking per column as well as a ranking by average improvement over the baseline.

			Utilization					Utilization				
			Avg		Max			Avg		Max		
	Rank col	Rank perc	Monday	Tuesday	Monday	Tuesday	Average	Monday	Tuesday	Monday	Tuesday	**Score**
MC	-	-	-	-	-	-	-	-	-	-	-	-
Ded bench	9	9	-13.5%	-25.1%	-0.1%	-1.2%	-9.9%	9	9	9	9	**36**
Open 30	8	8	0.0%	0.2%	0.0%	0.3%	0.1%	8	7	5	8	**28**
Open 60	7	7	0.4%	0.5%	0.0%	2.2%	0.8%	7	6	3	7	**23**
xtr .5 bench	3	5	12.7%	14.2%	0.0%	8.8%	8.9%	5	5	4	2	**16**
Extra bench	1	2	23.5%	28.1%	0.1%	9.0%	15.2%	2	1	2	1	**6**
Reg Demand	5/6	6	2.4%	-2.6%	0.8%	7.6%	2.1%	6	8	1	5	**20**
No absence	5/6	3	16.9%	22.9%	-0.1%	3.0%	10.7%	3	3	8	6	**20**
Extra .5 coll	4	4	16.4%	15.4%	0.0%	8.6%	10.1%	4	4	6	4	**18**
Extra coll	2	1	30.2%	28.1%	-0.1%	8.7%	16.7%	1	2	7	3	**13**

Table 4.3.3 Ranking of the interventions by column and by the average improvement over the baseline on the performance measure utilization

5. Conclusion & recommendations

5.1 Conclusions

The main research goal was to “Provide solutions to improve outpatient flow and turnaround time of outpatient pathology tests at the Campbelltown hospital pathology department”.

Alternatives on the tactical and operational level are generated from demand and capacity management literature. Three categories of interventions are simulated: (1) an increase of capacity, (2) alignment of demand with existing capacity, and (3) combinations of (1) and (2). Figure M.1 shows the percentage improvement for the interventions compared to the current (unaltered) situation, and gives the standard deviation for the utilization of staff. The results show the potential impact of the interventions in the observed days, to indicate which areas in demand and capacity management are of interest to the department.

	Improvement # patients waiting	*Improvement waiting time*	*Improvement utilization*	*Standard deviation utilization*		*Standard deviation utilization*	
Increase in capacity				**Monday**		**Tue-Fri**	
Extra bench	69.1%	48.9%	15.2%	27%		21%	
No absence	77.4%	51.6%	10.7%	29%		24%	
Extra collector	85.4%	68.5%	16.7%	24%		19%	
Allignment capacity and demand and increase in capacity							
Extra bench morning	62.2%	48.7%	8.9%	26%		17%	
Extra collector morning	77.8%	65.6%	10.1%	26%		18%	
Allignment capacity and demand							
Dedicated bench	-183.3%	-97.9%	-9.9%	13%		10%	
Opening time p2 +30min	1.9%	-0.7%	0.1%	20%		16%	
Opening time p2 +60min	14.8%	21.2%	0.8%	20%		16%	
Regulate demand	62.8%	63.4%	2.1%	13%		11%	

Figure 5.1 Simulation results for alternatives per solution category.

The first category is an increase in capacity. Here the situation remains completely unaltered for every variable except for the number of available staff members. The availability of staff members is in no way adjusted to the distribution of demand. The interventions given in this category will require organizational and monetary input but reward those inputs with the highest relative return in improvements over the simulated baseline. Hiring an extra Full Time Employee (FTE) will increase the department's expenses and that might not be a viable option for the department. Lowering the absence rate will require organizational effort and can also add to the departments expenses. Although these interventions reduce the workload of the collectors they do not lower the variation in workload during the day. This is explained by the fact that there is no alignment between demand and capacity, simply an enlargement of the capacity.

The second category is a selective increase in capacity with the goal of improving the alignment of demand and capacity as well as providing extra capacity. Both interventions require attaining additional staff but just in the busy morning periods, so both interventions require only 0.5 additional FTE's. The improvements in number of patients waiting and the improvement in utilization drops compared to the first category, but the improvements in waiting time remain in the same region. There is a slight decrease in the variation in workload during the day, which can indicate that these interventions account for a better alignment between demand and capacity. This corresponds with the observation of under capacity in the unaltered situation.

The third category is based on aligning the capacity and demand without adding additional staff. These interventions require organizational effort to change current practice. The first intervention, where one collector is permanently stationed at the handover bench to process samples, is simulated to see whether this change in practise and resulting lowering of variation for the remaining collectors can represent a viable option. Clearly this dedicated bench-processor does not improve the process under the assumptions of the model. The lowering of the variability and decrease in processing time does not make up for the loss of a collector. Because this intervention, in effect reduces the number of available collectors occupied with processing patients it effects the utilization negatively. The other extreme intervention is the regulating of demand to the point where demand follows the same distribution during the day as the availability of collectors. This intervention is simulated to show the potential of demand management strategies for the department. As can be expected this intervention provides a substantial improvement on both waiting times and the number of patients waiting compared to the baseline. The utilization for this, and the following two, intervention is comparable to the baseline since there is no change in total capacity. The variation in workload during the day however is noticeably lower for these interventions indicating that these interventions smooth the capacity utilization. The final two interventions are based on shifting the timeframe in which 3-hour glucose patients may arrive. This allows the system to process the bulk of the regular rush hour patients before attending to these patients. Shifting the timeframe forwards in time by 30 minutes does not provide the collectors with enough time to process the bulk of the regular patients waiting resulting in a virtually unchanged situation. Shifting the timeframe forwards in time by 60 minutes relieves the system long enough to account for an improvement over the baseline. Although the improvements are minor compared to the other interventions it offers a relatively effortless improvement on the performance measures, since it does not impact the departments expenses and requires no change in current practise. The inconvenience to 3-hour glucose patients is thought to be negligible.

These interventions provide the Campbelltown hospital emergency department with an overview of possible directions to improve the service for patients and the workload for collectors by improving the patient flow. Not all given alternatives will be possible to implement within the restrictions that the department is subject to.

5.2 Limitations

The results shown represent the improvements that would have been possible on the observed days to indicate which areas of demand and capacity management are of interest to the department. The model with its current inputs is not suitable for forecasting demand or capacity or predicting the impact of alternatives in the future. The basic working of the model is suitable to provide a prediction of the impact of interventions on the long run but that will require a detailed and accurate forecast of demand and capacity data as input. Assumptions made in the model also limit the practical accuracy of the model. The assumptions made in modelling the effect of deploying a dedicated bench worker include the reduction of variation and processing times that may prove to be different in practise. The same reasoning holds for the assumptions made regarding the interruptions. Finally, this model is only suitable to describe situations comparable to that of the Campbelltown hospitals pathology department. Similar departmental structures can possibly also be simulated with this model but the model is in essence non transferrable.

5.3 Recommendations

For the spreadsheet model to work accurately the input data needs to be extensive. Extensive data collection will mean better availability of trends throughout the day but also throughout the week and the year. This data can serve to refine the analysis of the daily operations and can serve as input for a number of demand and capacity management techniques that will help the department further align the demand and capacity it faces. Accurate and real-time data collection and processing techniques can serve as the basis for a performance management system that guides and informs the collectors of their achievements and progress.

Bibliography

Adenso-Diaz, B., Gonzalez-Torre, P., & Garcia, V. *(2002)*. A Capacity Management Model in Service Industries. International Journal of Service Industry Management , 13 (3), 286-302.

Australian Institute of Health and Welfare. *(2011)*. Australian hospital statistics 2009-10. Australian Institute of Health and Welfare. Canberra: Australian Institute of Health and Welfare.

Australian Institute of Health and Welfare. *(2010, June 17)*. Hospital admissions rise, signs that elective surgery queues falling. Opgeroepen op Oktober 18, 2011, van AIHW: http://www.aihw.gov.au/media-release-detail/?id=6442464882

Bloom, J., Alexander, J., & Nuchols, B. *(1997)*. Nurse Staffing Patterns and Hospital Efficiency in the United States. Social Science & Medicine , 44 (2), 147-155.

Chisholm, C., Collison, E., Nelson, D., & Cordell, W. *(2000)*. Emergency department workplace interruptions: are emergency physicians "interrupt-driven" and "multitasking". Academic Emergency Medicine , 7 (12), 1239-1243.

Chisholm, C., Dornfeld, A., Nelson, D., & Cordell, W. *(2001)*. Work interrupted: a comparison of workplace interruptions in emergency departments and primary care offices. Annals of Emergency Medicine , 38 (2), 146-151.

Coghlan, P., & Coughlan, D. *(2002)*. Action research for operations management. International Journal of Operations & Production management , 22 (2), 220-240.

Creemers, S., & Lambrecht, M. *(2007)*. Modeling a healthcare system as a queueing network. 55. Leuven: K.U.Leuven.

Creemers, S., & Lambrecht, M. *(2010)*. Modeling a hospital queueing network. In R. J. Nico M. van Dijk, Queueing Networks: A Fundamental Approach (Vol. 1, p. 798). Springer.

Department of Foreign Affairs and Trade. *(2008, April 1)*. Health care in Australia. Opgeroepen op Oktober 19, 2011, van http://www.dfat.gov.au: http://www.dfat.gov.au/facts/healthcare.html

Derlet, R. W. *(2002)*. Overcrowding in Emergency Departments: Increased Demand and Decreased Capacity. Annals of Emergency Medicine , 39 (4).

Dudewicz, E., & Mishra, S. *(1988)*. Modern mathematical statistics. New York: John Wiley Sons.

Easton, F., & Goodale, J. *(2005)*. Schedule recovery: unplanned absences in service operations. Decision Sciences , 36 (3), 459-488.

Fatovich, D. M., Nagree, Y., & Sprivuli, P. *(2005)*. Access block causes emergency department overcrowding and ambulance diversion in Perth, Western Australia. Emergency Medical Journal , 22 (5), 351-354.

Flynn, B., Sakakibara, S., Schroeder, G., Bates, K., & Flynn, E. *(1990)*. Empirical Research Methods in Operations Management. Journal of Operations Management , 9 (2), 250-284.

Fontana, A., & Frey, J. H. *(2000)*. The interview: From structured questions to negotiated text. In N. D. Lincoln, Handbook of qualitative resarch (pp. 645-672). London: Sage.

Hall, R. W. *(2006)*. Patient flow: reducing delay in healthcare delivery. Springer.

Harrell, M., & Bradle, M. *(2009)*. Data Collection Methods: Semi-Structured Interviews and Focus Groups. National Defence Research Institute (RAND). Santa Monica: RAND.

Heineke, J. *(1995)*. Strategic operations management decisions and professional performance in U.S. HMOs. Journal of Operations Management , 13 (4), 255-272.

Hopp, W. J. *(2008)*. Factory Physics (3rd ed.). New York: McGraw-Hill.

Jack, E. P., & Powers, T. L. *(2008)*. A review and synthesis of demand management, capacity management and performance in health-care services. International Journal of Management Reviews , 11 (2), 149-174.

Kaandorp, G. C., & Koole, G. *(2007)*. Outpatient Appointment Scheduling. Health Care Manage Sci , 10 (3), 217-229.

Klassen, K. J., & Rohleder, T. R. *(2002)*. Demand and capacity management decisions in services: How they impact on one another. International Journal of Operations & Production Management , 22 (5), 527-548.

Liu, L., & Liu, X. *(1998)*. Block appointment systems for outpatient clinics with multiple doctors. Journal of the Operational Research Society , 49 (12), 1254-1259.

Lovelock, C. *(1992)*. Seeking Synergy in Service Operations: Seven Things Marketers Need To Know about Service Operations. European Management Journal , 10 (1), 22-29.

McMillan. *(2009, July 9)*. Two-tier Health care. Opgeroepen op Oktober 19, 2011, van Articlebase.com: http://www.articlesbase.com/health-articles/twotier-health-care-1020480.html

Meyer, J. *(2000)*. Using qualitative methods in health related action research. BMJ , 320, 178-81.

NSW Health Services. *(2009)*. Comparison Data Book 2007/08 Volume 1. New South Wales Health Services, Demand and Performance Evaluation Branch. Sydney: NSW Health Services.

NSW Health Services. *(2010)*. Comparison Data Book 2008/2009. NSW Health Services, Demand and Performance Evaluation Branch. Sydney: NSW Health Services.

Richman, W. K. *(1999)*. A meta-analytical study of social desirability distortion in computer-administered questionnaires, traditional questionnaires, and interviews. Journal of Applied Psychology , 84 (5), 754-775.

Sethuraman, K., & Tirupati, D. *(2005)*. Evidence of bullwhip effect in healthcare sector: causes, consequences and cures. International Journal of Services and Operations Management , 1 (4), 372-394.

Smith-Daniels, V., Schweikhart, S., & Smith-Daniels, D. *(1988)*. Capacity management in health care services: review and future research directions. Decision Sciences , 19 (4), 889-919.

Sprivulis, P. C., Da Silva, J.-A., Jacobs, I. G., Frazer, A. R., & Jelinek, G. A. *(2006)*. The association between hospital overcrowding and mortality among patients admitted via Western Australian emergency departments. MJA , 184 (5), 208-212.

SSWAHS. *(2005)*. A Health Profile of Sydney South West. Sydney South West Area Health Services. Sydney South West Area Health Services.

SSWAHS. *(2010)*. Year in review 2008/09. Sydney South West Area Health Services. Liverpool: Media & Communication Unit.

Su, S., & Shih, C.-L. *(2003)*. Managing a mixed-registration-type appointment system in outpatient clinics. International Journal of Medical Informatics , 70 (1), 31-40.

Williamson, G., & Prosser, S. *(2002)*. Action research: politics, ethics and participation. Journal of Advanced Nursing , 40 (5), 587-593.

Yin, R. *(2009)*. Case study research: Design and methods . (4th, Red.) Los Angeles: Sage.

Appendix A: Floor plan

- waiting room
- counter
- phlebotomy
- specimen processing
- handover bench
- chute
- laboratory services

Appendix B: Demand

	11-10-11	12-10-11	13-10-11	14-10-11	17-10-11	24-10-11	Mondays	Tue_Fri
	n = 59	n = 51	n = 42	n = 57	n = 91	n = 96	avg	avg
	11	12	13	14	17	24	Monday	Tuesday
8:00:00	4	2	3	6	8	11	9,5	3,75
8:05:00	0	1	2	2	1	3	2	1,25
8:10:00	3	1	0	0	2	0	1	1
8:15:00	0	1	0	0	2	0	1	0,25
8:20:00	1	1	0	1	0	2	1	0,75
8:25:00	1	0	0	0	5	2	3,5	0,25
8:30:00	2	0	1	2	1	2	1,5	1,25
8:35:00	0	1	0	1	2	1	1,5	0,5
8:40:00	1	2	0	0	1	2	1,5	0,75
8:45:00	1	2	0	1	1	0	0,5	1
8:50:00	1	0	1	0	1	1	1	0,5
8:55:00	1	1	0	1	2	0	1	0,75
9:00:00	0	1	0	2	0	0	0	0,75
9:05:00	0	1	2	2	0	1	0,5	1,25
9:10:00	0	0	0	0	1	1	1	0
9:15:00	0	0	0	2	0	2	1	0,5
9:20:00	1	2	0	0	1	2	1,5	0,75
9:25:00	0	1	1	1	0	2	1	0,75
9:30:00	1	0	2	1	1	3	2	1
9:35:00	0	0	1	0	1	2	1,5	0,25
9:40:00	0	1	1	0	2	2	2	0,5
9:45:00	0	0	1	0	1	1	1	0,25
9:50:00	1	1	0	0	0	2	1	0,5
9:55:00	0	1	0	1	0	1	0,5	0,5
10:00:00	1	0	0	0	1	6	3,5	0,25
10:05:00	1	0	0	0	0	0	0	0,25
10:10:00	0	1	2	0	0	1	0,5	0,75
10:15:00	0	1	1	1	2	1	1,5	0,75
10:20:00	1	0	1	1	2	1	1,5	0,75
10:25:00	0	0	0	2	2	0	1	0,5
10:30:00	0	1	1	2	0	1	0,5	1
10:35:00	1	2	0	0	1	0	0,5	0,75
10:40:00	2	1	1	0	1	2	1,5	1
10:45:00	1	0	1	1	1	0	0,5	0,75
10:50:00	0	0	1	1	1	0	0,5	0,5
10:55:00	1	0	1	2	0	0	0	1
11:00:00	1	0	0	2	1	1	1	0,75
11:05:00	0	0	0	0	0	1	0,5	0
11:10:00	1	0	1	0	1	0	0,5	0,5
11:15:00	3	0	0	1	0	1	0,5	1
11:20:00	0	1	0	1	1	0	0,5	0,5
11:25:00	0	2	0	0	1	0	0,5	0,5
11:30:00	1	3	0	1	4	0	2	1,25
11:35:00	0	4	0	1	0	1	0,5	1,25
11:40:00	0	2	0	1	3	1	2	0,75
11:45:00	0	0	0	0	2	1	1,5	0
11:50:00	1	1	2	0	1	0	0,5	1
11:55:00	0	2	0	1	1	2	1,5	0,75
12:00:00	1	1	0	0	2	0	1	0,5
12:05:00	1	1	1	0	0	1	0,5	0,75
12:10:00	0	1	1	1	0	1	0,5	0,75
12:15:00	1	0	0	1	0	1	0,5	0,5
12:20:00	0	1	1	0	1	0	0,5	0,5
12:25:00	3	0	0	0	1	2	1,5	0,75
12:30:00	0	0	1	0	2	0	1	0,25
12:35:00	1	1	0	1	0	1	0,5	0,75
12:40:00	2	0	0	0	0	1	0,5	0,5
12:45:00	0	1	0	1	1	0	0,5	0,5
12:50:00	0	0	0	0	1	1	1	0
12:55:00	0	0	0	0	1	1	1	0
13:00:00	0	0	0	1	0	0	0	0,25
13:05:00	1	2	0	0	2	0	1	0,75
13:10:00	0	0	0	0	0	0	0	0
13:15:00	0	0	0	0	0	1	0,5	0
13:20:00	0	0	0	0	0	0	0	0
13:25:00	0	0	0	0	0	0	0	0
13:30:00	0	0	0	0	0	0	0	0
13:35:00	1	1	0	0	0	0	0	0,5
13:40:00	0	0	1	0	0	0	0	0,25
13:45:00	1	0	0	0	1	1	1	0,25
13:50:00	1	0	1	0	0	0	0	0,5
13:55:00	0	0	1	1	1	2	1,5	0,5
14:00:00	0	0	0	1	1	0	0,5	0,25
14:05:00	0	0	0	0	0	1	0,5	0
14:10:00	0	0	2	1	1	0	0,5	0,75
14:15:00	1	0	0	0	1	1	1	0,25
14:20:00	0	0	0	0	0	1	0,5	0
14:25:00	1	0	0	0	1	1	1	0,25
14:30:00	0	0	0	0	1	0	0,5	0
14:35:00	1	1	0	1	0	1	0,5	0,75
14:40:00	1	0	0	0	0	0	0	0,25
14:45:00	1	0	0	0	0	2	1	0,25
14:50:00	0	0	1	1	0	0	0	0,5
14:55:00	1	0	0	0	0	2	1	0,25
15:00:00	1	0	0	1	1	0	0,5	0,5
15:05:00	1	0	1	1	0	0	0	0,75
15:10:00	0	0	0	1	1	0	0,5	0,25
15:15:00	0	0	1	0	1	0	0,5	0,25
15:20:00	0	0	0	0	0	2	1	0
15:25:00	0	0	0	0	0	0	0	0
15:30:00	1	0	0	0	1	0	0,5	0,25
15:35:00	0	0	1	0	0	0	0	0,25
15:40:00	0	0	0	0	1	1	1	0
15:45:00	0	0	0	0	0	0	0	0
15:50:00	1	0	0	0	0	1	0,5	0,25
15:55:00	0	0	0	0	0	0	0	0
16:00:00	0	0	1	1	1	0	0,5	0,5
16:05:00	0	0	0	0	0	1	0,5	0
16:10:00	1	0	0	0	0	2	1	0,25
16:15:00	0	0	0	0	0	0	0	0
16:20:00	1	0	0	1	1	0	0,5	0,5
16:25:00	0	0	0	1	1	1	1	0,25
16:30:00	0	0	0	0	1	1	1	0
16:35:00	0	0	1	0	1	0	0,5	0,25
16:40:00	0	0	0	0	1	0	0,5	0
16:45:00	0	0	0	0	1	1	1	0
16:50:00	1	0	0	0	1	0	0,5	0,25
16:55:00	0	0	0	0	1	1	1	0

Figure B.1 Arrivals at counter per time period t, all patient classes

	11-okt	12-okt	13-okt	14-okt	17-okt	24-okt	Mon		Tue-fri	
	n = 64 Arrivals all P	n = 55 Arrivals all P	n = 46 Arrivals all P	n = 63 Arrivals all P	n = 95 Arrivals all P	n = 101 Arrivals all P	n = 196 Together	Avg	n = 228 Together	Avg
	11-10-11	12-10-11	13-10-11	14-10-11	17-10-11	24-10-11	Monday	Monday	Tuesday	Tuesday
08:00	2	2	1	1	5	8	13	6,5	6	1,5
08:05	0	1	2	4	3	3	6	3	7	1,75
08:10	2	0	0	0	2	0	2	1	2	0,5
08:15	0	0	0	0	1	0	1	0,5	0	0
08:20	0	0	0	0	0	0	0	0	0	0
08:25	0	0	0	0	5	2	7	3,5	0	0
08:30	3	0	0	1	2	4	6	3	4	1
08:35	1	1	2	2	2	1	3	1,5	6	1,5
08:40	2	2	0	1	1	1	2	1	5	1,25
08:45	2	1	0	0	0	0	0	0	3	0,75
08:50	1	1	0	2	3	0	3	1,5	4	1
08:55	0	0	0	0	0	1	1	0,5	0	0
09:00	1	1	1	2	1	2	3	1,5	5	1,25
09:05	0	1	2	5	0	1	1	0,5	8	2
09:10	0	0	0	0	1	1	2	1	0	0
09:15	0	1	0	0	0	1	1	0,5	1	0,25
09:20	1	1	1	2	2	2	4	2	5	1,25
09:25	0	1	1	0	0	6	6	3	2	0,5
09:30	1	0	2	2	1	1	2	1	5	1,25
09:35	0	0	1	0	1	2	3	1,5	1	0,25
09:40	0	2	1	0	1	2	3	1,5	3	0,75
09:45	0	0	1	0	2	2	4	2	1	0,25
09:50	1	1	0	0	0	2	2	1	2	0,5
09:55	0	0	0	0	1	3	4	2	0	0
10:00	2	0	0	1	0	3	3	1,5	3	0,75
10:05	1	1	0	0	0	0	0	0	2	0,5
10:10	0	1	1	0	0	1	1	0,5	2	0,5
10:15	0	1	2	1	2	1	3	1,5	4	1
10:20	1	0	1	0	2	1	3	1,5	2	0,5
10:25	0	1	0	2	2	0	2	1	3	0,75
10:30	1	0	1	0	0	1	1	0,5	2	0,5
10:35	0	3	0	2	1	2	3	1,5	5	1,25
10:40	1	1	2	0	2	0	2	1	4	1
10:45	1	0	0	0	0	0	0	0	1	0,25
10:50	0	0	0	0	0	1	1	0,5	0	0
10:55	1	0	1	2	0	1	1	0,5	4	1
11:00	1	2	0	1	2	3	5	2,5	4	1
11:05	1	0	2	4	1	1	2	1	7	1,75
11:10	1	1	1	1	1	1	2	1	4	1
11:15	4	1	0	1	1	0	1	0,5	6	1,5
11:20	1	3	0	2	0	0	0	0	6	1,5
11:25	1	1	0	0	1	1	2	1	2	0,5
11:30	1	4	1	1	4	2	6	3	7	1,75
11:35	0	2	0	4	0	0	0	0	6	1,5
11:40	0	2	0	1	3	2	5	2,5	3	0,75
11:45	1	1	0	0	3	0	3	1,5	2	0,5
11:50	1	1	3	0	1	1	2	1	5	1,25
11:55	1	1	1	1	1	2	3	1,5	4	1
12:00	1	1	0	1	2	1	3	1,5	3	0,75
12:05	1	1	2	0	0	0	0	0	4	1
12:10	0	1	0	1	0	1	1	0,5	2	0,5
12:15	0	0	0	0	0	1	1	0,5	0	0
12:20	2	1	1	1	1	0	1	0,5	5	1,25
12:25	1	0	0	0	2	0	2	1	1	0,25
12:30	0	0	0	1	2	1	3	1,5	1	0,25
12:35	1	1	0	1	1	0	1	0,5	3	0,75
12:40	2	2	0	0	0	1	1	0,5	4	1
12:45	0	0	0	0	1	0	1	0,5	0	0
12:50	0	0	0	1	2	2	4	2	1	0,25
12:55	0	1	0	0	0	0	0	0	1	0,25
13:00	1	0	0	1	1	0	1	0,5	2	0,5
13:05	0	0	0	0	1	0	1	0,5	0	0
13:10	0	2	0	0	0	0	0	0	2	0,5
13:15	0	0	0	0	0	1	1	0,5	0	0
13:20	0	0	0	0	0	0	0	0	0	0
13:25	1	0	0	0	0	0	0	0	1	0,25
13:30	1	0	0	0	0	0	0	0	1	0,25
13:35	0	1	0	0	0	0	0	0	1	0,25
13:40	1	0	1	0	1	1	2	1	2	0,5
13:45	0	0	0	0	0	1	1	0,5	0	0
13:50	1	0	1	0	0	0	0	0	2	0,5
13:55	0	0	1	1	1	2	3	1,5	2	0,5
14:00	0	0	0	1	1	0	1	0,5	1	0,25
14:05	0	0	0	0	0	1	1	0,5	0	0
14:10	0	0	2	1	1	0	1	0,5	3	0,75
14:15	1	0	0	0	1	1	2	1	1	0,25
14:20	0	0	0	0	0	1	1	0,5	0	0
14:25	1	0	0	0	0	1	2	1	1	0,25
14:30	0	0	0	0	1	0	1	0,5	0	0
14:35	1	1	0	1	0	1	1	0,5	3	0,75
14:40	1	0	0	0	0	0	0	0	1	0,25
14:45	1	0	0	0	0	2	2	1	1	0,25
14:50	0	0	1	1	0	0	0	0	2	0,5
14:55	1	0	0	0	0	2	2	1	1	0,25
15:00	1	0	0	1	1	0	1	0,5	2	0,5
15:05	1	0	1	1	0	0	0	0	3	0,75
15:10	0	0	0	1	1	0	1	0,5	1	0,25
15:15	0	0	1	0	1	0	1	0,5	1	0,25
15:20	0	0	0	0	0	2	2	1	0	0
15:25	0	0	0	0	0	0	0	0	0	0
15:30	1	0	0	0	1	0	1	0,5	1	0,25
15:35	0	0	1	0	0	0	0	0	1	0,25
15:40	0	0	0	0	1	1	2	1	0	0
15:45	0	0	0	0	0	0	0	0	0	0
15:50	1	0	0	0	0	1	1	0,5	1	0,25
15:55	0	0	0	0	0	0	0	0	0	0
16:00	0	0	1	1	1	0	1	0,5	2	0,5
16:05	0	0	0	0	0	1	1	0,5	0	0
16:10	1	0	0	0	0	2	2	1	1	0,25
16:15	0	0	0	0	0	0	0	0	0	0
16:20	1	0	0	1	1	0	1	0,5	2	0,5
16:25	0	0	0	1	1	1	2	1	1	0,25
16:30	0	0	0	0	1	1	2	1	0	0
16:35	0	0	1	0	1	0	1	0,5	1	0,25
16:40	0	0	0	0	1	0	1	0,5	0	0
16:45	0	0	0	0	1	1	2	1	0	0
16:50	1	0	0	0	1	0	1	0,5	1	0,25
16:55	0	0	0	0	1	1	2	1	0	0

Figure B.2 Aggregated arrivals at phlebotomy station per time period t

Appendix C: Collector availability

	roster	Observed						Average	Average Corrected
	All days	11-10-11	12-10-11	13-10-11	14-10-11	17-10-11	24-10-11	Mondays	Tue_Fri
08:00	2	3	1	3	1	2	1	1,50	1,00
08:05	2	3	1	3	1	2	1	1,50	1,00
08:10	2	3	1	3	1	2	1	1,50	1,00
08:15	2	3	1	3	1	2	1	1,50	1,00
08:20	2	3	1	3	1	2	1	1,50	1,00
08:25	2	3	1	3	1	2	1	1,50	1,00
08:30	2	3	2	3	1	2	1	1,50	1,25
08:35	2	3	2	3	1	2	1	1,50	1,25
08:40	2	3	2	3	1	2	1	1,50	1,25
08:45	2	3	2	1	1	2	1	1,50	1,75
08:50	2	3	2	1	1	2	1	1,50	1,75
08:55	2	3	2	1	1	2	1	1,50	1,75
09:00	2	2	2	1	1	2	1	1,50	1,25
09:05	2	2	2	1	1	2	1	1,50	1,50
09:10	2	2	2	1	1	2	1	1,50	2,00
09:15	2	2	2	1	1	2	1	1,50	1,50
09:20	2	2	2	1	1	2	1	1,50	1,75
09:25	2	2	2	1	1	2	1	1,50	1,50
09:30	2	2	1	3	1	2	2	2,00	1,75
09:35	2	2	1	3	1	2	2	2,00	2,00
09:40	2	2	1	3	1	2	2	2,00	2,00
09:45	2	1	1	3	1	2	3	2,50	2,00
09:50	2	1	1	3	1	2	3	2,50	2,00
09:55	2	1	1	3	1	2	3	2,50	2,00
10:00	6	1	1	3	1	2	2	2,00	2,00
10:05	6	1	1	3	1	2	2	2,00	2,00
10:10	6	1	1	3	1	2	2	2,00	2,00
10:15	6	1	1	7	1	2	2	2,00	2,50
10:20	6	1	1	7	1	2	2	2,00	2,50
10:25	6	1	1	7	1	2	2	2,00	2,50
10:30	6	6	6	7	2	4	2	3,00	1,25
10:35	6	6	6	7	2	4	2	3,00	1,25
10:40	6	6	6	7	2	4	2	3,00	1,25
10:45	6	6	6	7	2	4	3	3,50	1,25
10:50	6	6	6	7	2	4	3	3,50	2,25
10:55	6	6	6	7	2	4	3	3,50	2,25
11:00	4	4	4	5	2	2	2	2,00	1,75
11:05	4	4	4	5	2	2	2	2,00	1,25
11:10	4	4	4	5	2	2	2	2,00	1,75
11:15	4	4	4	5	2	2	2	2,00	1,75
11:20	4	4	4	5	2	2	2	2,00	1,75
11:25	4	4	4	5	2	2	2	2,00	1,75
11:30	4	4	4	5	2	2	2	2,00	1,75
11:35	4	4	4	5	2	2	2	2,00	1,75
11:40	4	4	4	5	2	2	2	2,00	1,75
11:45	4	4	4	5	2	2	2	2,00	1,75
11:50	4	4	4	5	2	2	2	2,00	1,75
11:55	4	4	4	5	2	2	2	2,00	2,25
12:00	4	1	1	1	2	2	2	2,00	2,25
12:05	4	1	1	1	2	2	2	2,00	2,25
12:10	4	1	1	1	2	2	2	2,00	2,25
12:15	4	1	1	1	2	2	4	3,00	2,25
12:20	4	1	1	1	2	2	4	3,00	2,25
12:25	4	1	1	1	2	2	4	3,00	2,25
12:30	4	1	1	1	2	2	4	3,00	2,25
12:35	4	1	1	1	2	2	4	3,00	2,25
12:40	4	1	1	1	2	2	4	3,00	2,25
12:45	4	2	2	5	4	4	4	4,00	3,25
12:50	4	2	2	5	4	4	4	4,00	3,25
12:55	4	2	2	5	4	4	4	4,00	3,25
13:00	2	2	2	5	2	4	4	4,00	2,75
13:05	2	2	2	5	2	4	4	4,00	2,50
13:10	2	2	2	5	2	4	4	4,00	2,00
13:15	2	2	2	5	2	3	2	2,50	2,00
13:20	2	2	2	5	2	3	2	2,50	2,00
13:25	2	2	2	5	2	3	2	2,50	2,00
13:30	2	2	2	5	2	3	4	3,50	2,00
13:35	2	2	2	5	2	3	4	3,50	2,00
13:40	2	2	2	5	2	3	4	3,50	2,00
13:45	2	2	2	5	2	4	4	4,00	2,00
13:50	2	2	2	5	2	4	4	4,00	2,00
13:55	2	2	2	5	2	4	4	4,00	2,00
14:00	2	2	2	5	1	2	3	2,50	1,75
14:05	2	2	2	5	1	2	3	2,50	1,75
14:10	2	2	2	5	1	2		2,00	1,75
14:15	2	2	2	5	1	2	3	2,50	1,75
14:20	2	2	2	5	1	2	3	2,50	1,75
14:25	2	2	2	5	1	2	3	2,50	1,75
14:30	2	2	2	3	1	2	3	2,50	2,00
14:35	2	2	2	3	1	2	3	2,50	2,00
14:40	2	2	2	3	1	2	3	2,50	2,00
14:45	2	2	2	3	1	2	1	1,50	2,00
14:50	2	2	2	3	1	2	1	1,50	2,00
14:55	2	2	2	3	1	2	1	1,50	2,00
15:00	2	2	2	3	1	2	1	1,50	2,00
15:05	2	2	2	3	1	2	1	1,50	2,00
15:10	2	2	2	3	1	2	1	1,50	2,00
15:15	2	2	2	3	1	2	1	1,50	2,00
15:20	2	2	2	3	1	2	1	1,50	2,00
15:25	2	2	2	3	1	2	1	1,50	2,00
15:30	2	2	2	3	1	2	1	1,50	2,00
15:35	2	2	2	3	1	2	1	1,50	2,00
15:40	2	2	2	3	1	2	1	1,50	2,00
15:45	2	2	2	3	1	2	1	1,50	2,00
15:50	2	2	2	3	1	2	1	1,50	2,00
15:55	2	2	2	3	1	2	1	1,50	2,00
16:00	2	2	2	3	1	2	1	1,50	2,00
16:05	2	2	2	3	1	2	1	1,50	2,00
16:10	2	2	2	3	1	2	1	1,50	2,00
16:15	2	2	2	3	1	2	1	1,50	2,00
16:20	2	2	2	3	1	2	1	1,50	2,00
16:25	2	2	2	3	1	2	1	1,50	2,00
16:30	1	1	1	1	1	1	1	1,00	1,00
16:35	1	1	1	1	1	1	1	1,00	1,00
16:40	1	1	1	1	1	1	1	1,00	1,00
16:45	1	1	1	1	1	1	1	1,00	1,00
16:50	1	1	1	1	1	1	1	1,00	1,00
16:55	1	1	1	1	1	1	1	1,00	1,00

Figure C.1 Collector availability, roster & observed. Tuesday average corrected for extra collectors in training, see paragraph 4.1

Appendix D: Service times

Descriptive statistics (Quantitative data):

Statistic	X1
No. of observations	314
Minimum	0,233
Maximum	61,067
1st Quartile	0,800
Median	1,067
3rd Quartile	1,463
Mean	1,489
Variance (n-1)	12,511
Standard deviation (n	3,537

Box plots:

Figure D.1 Raw service times for service at the counter & boxplot for raw counter service times, identifying outliers.

Tue	Wed	Thu	Fri	Mon	Mon
11-10-11	12-10-11	13-10-11	14-10-11	17-10-11	24-10-11
n = 45	n = 49	n = 30	n = 46	n = 71	n = 73
0:01:50	0:01:08	0:01:08	0:01:08	0:01:57	0:01:03
0:00:40	0:01:02	0:01:07	0:01:15	0:00:36	0:00:40
0:01:04	0:01:00	0:00:35	0:01:18	0:00:44	0:00:48
0:02:36	0:01:09	0:00:21	0:01:13	0:00:48	0:00:32
0:00:53	0:02:16	0:00:15	0:00:42	0:00:16	0:01:08
0:01:33	0:01:47	0:01:50	0:00:34	0:00:29	0:00:36
0:01:40	0:01:29	0:02:04	0:00:37	0:00:37	0:00:31
0:01:56	0:00:53	0:07:01	0:00:53	0:00:20	0:00:28
0:01:11	0:02:02	0:00:42	0:00:54	0:00:34	0:00:48
0:00:39	0:01:27	0:01:13	0:00:34	0:01:10	0:00:19
0:01:00	0:01:21	0:00:45	0:00:48	0:00:33	0:00:44
0:00:52	0:10:00	0:01:23	0:01:18	0:00:35	0:00:48
0:01:06	0:02:03	0:02:11	0:03:19	0:00:58	0:00:51
0:00:37	0:01:44	0:00:58	0:01:38	0:02:15	0:00:24
0:01:50	0:01:06	0:01:45	0:01:06	0:00:36	0:02:09
0:01:32	0:02:34	0:01:54	0:00:56	0:00:19	0:01:28
0:00:58	0:00:51	0:04:23	0:01:30	0:00:59	0:01:22
0:01:37	0:01:58	0:01:06	0:00:44	0:00:33	0:00:46
0:02:16	0:02:49	0:00:59	0:02:19	0:00:56	0:01:37
0:01:42	0:01:08	0:00:39	0:01:25	0:00:50	0:00:50
0:01:57	0:01:08	0:01:00	0:00:47	0:00:32	0:00:45
0:01:13	0:00:57	0:01:21	0:01:15	0:00:30	0:00:54
0:01:41	0:03:22	0:01:04	0:01:27	0:00:47	0:00:48
0:01:06	0:01:51	0:01:33	0:01:05	0:01:50	0:01:06
0:01:03	0:00:38	0:01:07	0:00:59	0:00:24	0:00:58
0:00:46	0:01:15	0:01:09	0:01:09	0:00:58	0:00:16
0:01:15	0:01:15	0:01:06	0:01:14	0:01:02	0:01:22
0:01:30	0:01:04	0:03:34	0:03:52	0:02:40	0:01:06
0:00:46	0:01:13	0:00:58	0:01:00	0:01:06	0:00:25
0:00:26	0:02:20	0:00:49	0:00:27	0:01:05	0:00:30
0:00:57	0:00:38		0:03:01	0:05:18	0:01:13
0:00:55	0:00:55		0:01:02	0:00:56	0:00:23
0:01:00	0:01:00		0:01:07	0:00:22	0:01:09
0:00:24	0:01:04		0:01:09	0:00:28	0:00:43
0:01:33	0:01:00		0:01:00	0:01:59	0:00:49
0:02:32	0:01:24		0:01:28	0:01:04	0:01:27
0:01:00	0:01:01		0:01:11	0:01:19	0:00:22
0:00:29	0:00:50		0:02:43	0:03:20	0:02:06
0:01:25	0:01:54		0:01:13	0:00:42	0:00:48
0:01:40	0:00:50		0:01:05	0:01:09	0:01:11
0:01:29	0:01:52		0:00:53	0:01:08	0:00:45
0:00:50	0:01:09		0:01:25	0:01:35	0:00:30
0:00:56	0:01:46		0:01:35	0:00:30	0:01:01
0:00:56	0:01:29		0:01:01	0:02:32	0:00:24
0:00:58	1:01:04		0:01:28	0:01:22	0:00:42
	0:01:06		0:01:06	0:00:46	0:00:59
	0:00:55			0:00:27	0:01:49
	0:06:27			0:01:21	0:01:09
	0:06:27			0:01:05	0:01:02
				0:01:09	0:01:57
				0:00:36	0:01:53
				0:00:33	0:01:04
				0:00:34	0:00:42
				0:00:48	0:01:27
				0:00:51	0:00:54
				0:00:49	0:00:53
				0:00:55	0:00:49
				0:00:38	0:01:11
				0:00:49	0:00:54
				0:00:17	0:00:15
				0:00:14	0:00:57
				0:01:04	0:02:08
				0:03:10	0:00:40
				0:00:23	0:01:07
				0:01:02	0:00:48
				0:01:06	0:01:54
				0:01:04	0:07:10
				0:01:18	0:01:10
				0:00:58	0:01:50
				0:01:21	0:01:02
				0:00:42	0:01:35
					0:01:00
					0:05:05

ABS ST	ABS ST
21-11-11	22-11-11
n = 83	n = 50
0:11:23	0:00:24
0:02:09	0:00:24
0:00:35	0:00:19
0:02:23	0:02:17
0:02:52	0:02:11
0:02:46	0:02:22
0:02:40	0:01:56
0:02:21	0:02:17
0:01:16	0:02:24
0:00:59	0:01:57
0:00:57	0:09:22
0:01:22	0:08:36
0:04:51	0:04:41
0:03:00	0:02:17
0:09:53	0:05:18
0:04:29	0:01:29
0:01:36	0:02:56
0:27:03	0:02:24
0:02:43	0:05:03
0:01:56	0:14:09
0:01:03	0:00:20
0:10:59	0:00:34
0:02:04	0:00:58
0:05:30	0:00:34
0:03:17	0:00:47
0:00:52	0:01:29
0:02:33	0:02:14
0:00:57	0:02:39
0:00:55	0:01:18
0:03:51	0:03:00
0:02:19	0:01:41
0:02:03	0:01:03
0:00:41	0:03:23
0:01:49	0:02:14
0:03:13	0:01:20
0:03:05	0:00:55
0:02:35	0:03:49
0:01:04	0:08:00
0:01:07	0:00:47
0:01:10	0:02:20
0:03:38	0:03:05
0:00:52	0:01:36
0:01:19	0:02:47
0:00:52	0:01:40
0:01:59	0:01:28
0:01:10	0:00:40
0:01:21	0:03:53
0:01:37	0:01:34
0:04:10	0:01:11
0:03:51	0:01:06
0:01:47	
0:01:42	
0:01:32	
0:01:49	
0:00:52	
0:01:27	
0:00:24	
0:00:57	
0:00:43	
0:05:50	
0:02:50	
0:00:45	
0:01:27	
0:01:37	
0:01:24	
0:06:57	
0:00:36	
0:06:51	
0:01:32	
0:00:50	
0:00:49	
0:02:54	
0:07:34	
0:01:03	
0:02:16	
0:02:40	
0:01:49	
0:02:29	
0:04:53	
0:02:14	
0:05:39	
0:05:23	
0:01:48	

Descriptive statistics (Quantitative data):

Statistic	X1
No. of observations	133
Minimum	0,317
Maximum	27,050
1st Quartile	1,117
Median	1,950
3rd Quartile	3,000
Mean	2,810
Variance (n-1)	10,094
Standard deviation (n-1)	3,177

Box plots:

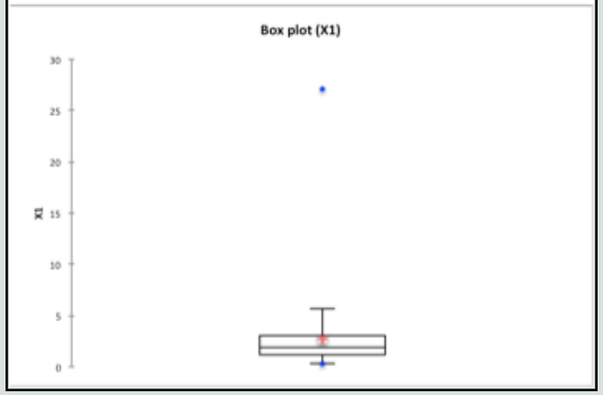


Figure D.2 Raw service times for specimen processing & boxplot for specimen processing service times, identifying outliers.

Tue	Wed	Thu	Fri	Mon	Mon
11-10-11	12-10-11	13-10-11	14-10-11	17-10-11	24-10-11
n = 35	n = 37	n = 25	n = 38	n = 66	n = 65
0:04:17	0:05:14	0:03:46	0:05:55	0:02:58	0:01:42
0:05:39	0:04:07	0:02:57	0:12:18	0:02:14	0:02:09
0:04:41	0:02:38	0:05:41	0:03:13	0:02:20	0:02:35
0:02:32	0:03:46	0:20:23	0:04:42	0:04:27	0:06:14
0:06:45	0:14:59	0:03:11	0:02:51	0:03:13	0:04:25
0:04:20	0:05:41	0:03:10	0:02:22	0:03:27	0:02:20
0:07:06	0:05:37	0:04:12	0:03:00	0:03:00	0:02:12
0:03:19	0:06:02	0:03:22	0:03:02	0:03:39	0:03:04
0:06:57	0:03:13	0:03:30	0:03:53	0:02:25	0:02:08
0:03:23	0:05:49	0:05:10	0:02:46	0:02:41	0:02:04
0:03:25	0:05:40	0:05:05	0:04:25	0:03:07	0:03:01
0:02:34	0:03:31	0:02:31	0:02:55	0:19:38	0:01:58
0:04:02	0:05:40	0:12:28	0:04:41	0:02:16	0:04:41
0:09:55	0:04:07	0:02:23	0:02:50	0:03:54	0:02:07
0:04:40	0:02:20	0:03:42	0:03:54	0:06:46	0:02:41
0:06:44	0:05:07	0:01:54	0:02:34	0:03:33	0:02:57
0:01:54	0:03:48	0:06:07	0:02:35	0:02:19	0:02:11
0:02:30	0:08:30	0:03:54	0:04:18	0:03:13	0:03:35
0:09:41	0:04:12	0:04:06	0:02:50	0:03:17	0:02:20
0:05:42	0:02:21	0:03:49	0:02:31	0:03:55	0:02:24
0:08:35	0:02:04	0:04:09	0:04:21	0:02:44	0:02:03
0:07:38	0:11:15	0:02:30	0:20:43	0:02:40	0:02:11
0:04:43	0:08:15	0:02:11	0:05:36	0:02:19	0:02:43
0:02:45	0:02:00	0:04:09	0:06:21	0:02:26	0:02:29
0:06:40	0:03:09	0:03:11	0:03:54	0:03:44	0:02:08
0:03:56	0:02:59		0:05:20	0:06:44	0:07:41
0:04:27	0:05:33		0:04:39	0:02:41	0:03:53
0:03:19	0:02:53		0:04:48	0:03:43	0:02:45
0:02:41	0:06:30		0:03:07	0:02:29	0:04:05
0:03:00	0:04:56		0:02:16	0:03:10	0:02:14
0:04:15	0:08:29		0:03:23	0:03:55	0:04:02
0:08:26	0:03:47		0:02:58	0:03:32	0:02:18
0:04:18	0:05:40		0:02:32	0:04:44	0:01:59
0:03:16	0:05:14		0:03:32	0:06:45	0:02:53
0:06:25	0:05:39		0:05:49	0:02:27	0:02:17
	0:15:25		0:04:22	0:04:44	0:02:13
	0:15:00		0:03:15	0:03:02	0:04:58
			0:03:27	0:02:33	0:02:27
				0:02:21	0:05:34
				0:02:55	0:02:39
				0:04:43	0:05:51
				0:09:40	0:02:47
				0:03:17	0:06:36
				0:06:04	0:06:29
				0:02:58	0:02:37
				0:03:10	0:02:42
				0:05:09	0:01:27
				0:02:41	0:02:20
				0:03:53	0:03:39
				0:02:30	0:02:30
				0:05:25	0:06:21
				0:03:45	0:03:37
				0:04:48	0:02:16
				0:04:30	0:02:38
				0:02:53	0:01:59
				0:03:02	0:03:04
				0:02:59	0:03:42
				0:06:32	0:02:38
				0:02:19	0:05:50
				0:02:09	0:02:54
				0:03:08	0:03:28
				0:05:17	0:12:06
				0:03:36	0:04:56
				0:03:15	0:06:36
				0:03:58	0:01:57
				0:03:25	

Descriptive statistics (Quantitative data):

Statistic	X1
No. of observations	131
Minimum	1,450
Maximum	19,630
1st Quartile	2,425
Median	3,020
3rd Quartile	3,945
Mean	3,652
Variance (n-1)	4,630
Standard deviation (n-1)	2,152

Monday

Box plots:

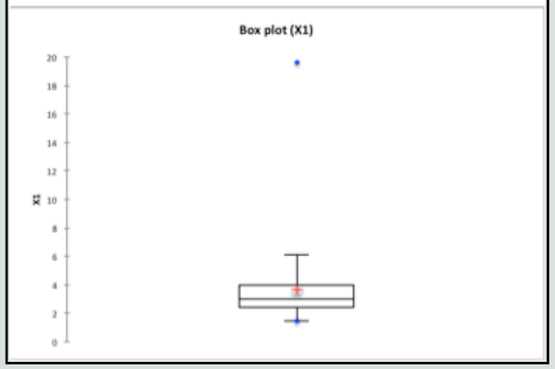


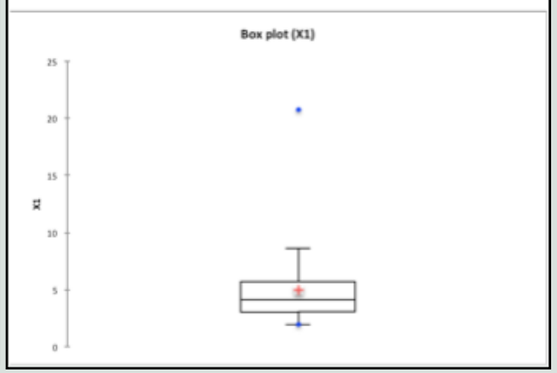
Figure D.3 Raw phlebotomy service times for Monday and Tuesday-Friday, and boxplots for the raw phlebotomy service times for Monday and Tuesday-Friday, identifying outliers

Descriptive statistics (Quantitative data):

Statistic	X1
No. of observations	135
Minimum	1,900
Maximum	20,720
1st Quartile	3,075
Median	4,120
3rd Quartile	5,670
Mean	4,972
Variance (n-1)	10,209
Standard deviation (n-1)	3,195

Tue-Fri

Box plots:



Appendix E: Secondary activities

Regular activities doable on own time & duration

- Cleaning & restocking collection rooms	15 minutes per day
- Restock ED	Mon & Fri, 15 minutes per day
- Daily stats	Mon 20 minutes, rest 10 minutes per day
- Collection stats	10 minutes per day
- Filing Reports	15 minutes per day
- Filing request forms	30 min per day

Appendix F: Interruptions

Interruptions Monday 21-11-11 n = 37	Interruptions Tuesday 22-11-11 n = 37	Division chute/non chute Monday Chute	Monday non chute	Tuesday Chute	Tuesday non chute
0:01:43	0:16:04	0:01:43	0:01:28	0:16:04	0:01:26
0:01:28	0:00:24	0:04:02	0:04:00	0:00:24	0:01:34
0:04:02	0:05:56	0:03:05	0:08:48	0:05:56	0:00:13
0:04:00	0:02:17	0:04:09	0:01:51	0:02:17	0:02:45
0:03:05	0:01:26	0:03:20	0:01:17	0:00:58	0:02:40
0:08:48	0:01:34	0:12:43	0:00:56	0:02:33	0:01:05
0:04:09	0:00:58	0:03:07	0:03:53	0:08:10	0:02:47
0:03:20	0:00:13	0:03:45	0:00:55	0:01:38	0:00:15
0:12:43	0:02:33	0:03:21	0:00:55	0:04:46	0:05:22
0:01:51	0:08:10	0:03:09	0:01:35	0:02:17	0:02:10
0:01:17	0:02:45	0:28:37	0:01:02	0:00:55	0:05:29
0:03:07	0:02:40	0:08:43	0:01:18	0:06:34	0:02:45
0:00:56	0:01:38	0:03:27		0:01:12	0:00:54
0:03:45	0:04:46	0:08:23		0:05:38	0:02:57
0:03:21	0:02:17	0:05:01		0:06:18	
0:03:53	0:00:55	0:26:10		0:02:48	
0:03:09	0:06:34	0:00:14		0:02:16	
0:28:37	0:01:05	0:06:27		0:04:49	
0:08:43	0:01:12	0:03:16		0:04:36	
0:03:27	0:05:38	0:06:28		0:03:01	
0:08:23	0:06:18	0:13:16		0:03:01	
0:00:55	0:02:48	0:11:28		0:02:37	
0:05:01	0:02:57	0:04:05		0:01:45	
0:26:10	0:02:16	0:05:59			
0:00:55	0:04:49	0:02:01			
0:00:14	0:02:47				
0:06:27	0:00:15				
0:03:16	0:05:22				
0:06:28	0:04:36				
0:01:35	0:02:10				
0:01:02	0:05:29				
0:13:16	0:03:01				
0:11:28	0:03:01				
0:04:05	0:02:45				
0:05:59	0:02:37				
0:01:18	0:01:45				
0:02:01	0:00:54				

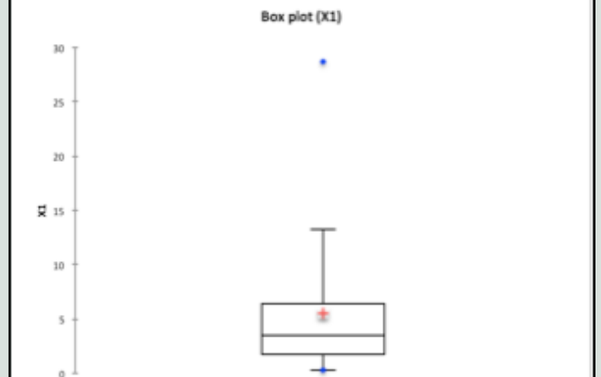
Figure F.1 Raw interruption times for Monday and Tuesday-Friday and boxplots for the raw interruption times for Monday and Tuesday-Friday, identifying outliers

Descriptive statistics (Quantitative data):

Statistic	X1
No. of observations	37
Minimum	0,233
Maximum	28,617
1st Quartile	1,717
Median	3,450
3rd Quartile	6,450
Mean	5,512
Variance (n-1)	39,115
Standard deviation (n-1)	6,254

Monday

Box plots:

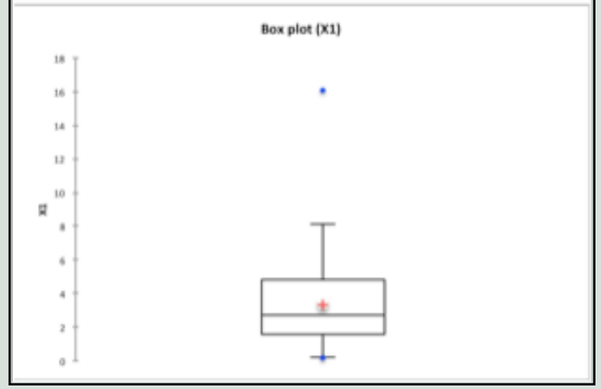


Descriptive statistics (Quantitative data):

Statistic	X1
No. of observations	37
Minimum	0,217
Maximum	16,067
1st Quartile	1,567
Median	2,667
3rd Quartile	4,767
Mean	3,322
Variance (n-1)	8,507
Standard deviation (n-1)	2,917

Tue-Fri

Box plots:



Appendix G: Performance Measures

		Observed Utilization	Waiting time	# Patients
Monday	Average		18,81	4,62
	Max		50,07	16,00
	St. Deviation		14,26	4,73
Tue-Fri	Average		12,92	1,70
	Max		30,77	5,00
	St. Deviation		6,52	1,34

		Model Monte Carlo Utilization	Waiting time	# Patients
Monday	Average	0,81	18,49	4,92
	Max	1,00	41,36	14,62
	St. Deviation	0,21	11,50	4,41
Tue-Fri	Average	0,72	9,87	1,73
	Max	0,99	20,81	5,19
	St. Deviation	0,16	4,61	1,41

		No absence Utilization	Waiting time	# Patients
Monday	Average	0,67	5,21	1,72
	Max	1,00	21,32	9,37
	St. Deviation	0,29	6,62	2,65
Tue-Fri	Average	0,55	1,26	0,25
	Max	0,96	8,25	1,99
	St. Deviation	0,24	1,99	0,41

		Extra bench worker Utilization	Waiting time	# Patients
Monday	Average	0,62	5,25	1,71
	Max	1,00	21,58	8,54
	St. Deviation	0,27	6,60	2,49
Tue-Fri	Average	0,52	2,59	0,59
	Max	0,90	8,99	2,64
	St. Deviation	0,21	2,37	0,69

		Dedicated bench worker Utilization	Waiting time	# Patients
Monday	Average	0,92	48,06	12,08
	Max	1,00	74,80	25,51
	St. Deviation	0,13	17,41	7,26
Tue-Fri	Average	0,90	33,40	5,02
	Max	1,00	49,43	10,31
	St. Deviation	0,10	8,15	2,35

		Extra 0,5 bench worker Utilization	Waiting time	# Patients
Monday	Average	0,71	7,29	2,03
	Max	1,00	21,56	8,54
	St. Deviation	0,26	6,59	2,39
Tue-Fri	Average	0,62	3,21	0,66
	Max	0,90	9,05	2,66
	St. Deviation	0,17	1,99	0,66

		Extra Collector Utilization	Waiting time	# Patients
Monday	Average	0,57	2,29	0,82
	Max	1,00	12,69	6,43
	St. Deviation	0,24	3,18	1,38
Tue-Fri	Average	0,52	1,25	0,29
	Max	0,90	4,19	1,61
	St. Deviation	0,19	1,21	0,39

		Extra Collector morning Utilization	Waiting time	# Patients
Monday	Average	0,68	4,61	1,16
	Max	1,00	17,58	6,43
	St. Deviation	0,26	4,46	1,33
Tue-Fri	Average	0,61	1,96	0,36
	Max	0,90	4,28	1,59
	St. Deviation	0,18	1,12	0,35

		Change opening times p2+30 Utilization	Waiting time	# Patients
Monday	Average	0,81	17,46	4,69
	Max	1,00	38,90	14,91
	St. Deviation	0,20	10,46	4,21
Tue-Fri	Average	0,72	9,91	1,77
	Max	0,99	21,77	5,31
	St. Deviation	0,16	4,29	1,48

		Change opening times p2+60 Utilization	Waiting time	# Patients
Monday	Average	0,81	16,44	4,28
	Max	1,00	34,25	14,09
	St. Deviation	0,20	9,71	3,83
Tue-Fri	Average	0,71	8,14	1,43
	Max	0,97	14,10	3,54
	St. Deviation	0,16	2,74	1,01

		Regulate demand Utilization	Waiting time	# Patients
Monday	Average	0,79	6,20	1,23
	Max	0,99	22,79	4,34
	St. Deviation	0,13	6,90	1,17
Tue-Fri	Average	0,74	4,59	0,76
	Max	0,91	7,15	1,40
	St. Deviation	0,11	1,56	0,28

Figure G.1 The average and maximum results obtained from the simulation for each alternative, including the standard deviation