A Simulation Analysis of

an Emergency Department Fast Track System

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The basis for this thesis involved a four month Accelerate Canada internship at the Grand River Hospital Emergency Department in Kitchener, Ontario. The Emergency Department (ED) Process Committee sought insight into strategies that could potentially reduce patient length of stay in the ED, thereby reducing wait times for emergency patients.

This thesis uses discrete event simulation to model the overall system and to analyze the effect of various operational strategies within the fast track area of the emergency department. It discusses the design and development process for the simulation model, proposes various operational strategies to reduce patient wait times, and analyzes the different scenarios for an optimal fast track strategy. The main contribution of this thesis is the use of simulation to determine an optimal fast track strategy that reduces patient length of stay, thereby reducing patient wait times.

Wait times were most significantly reduced when there was an increased physician presence/availability towards the fast track system. This had the greatest impact on the total time spent in the ED and also on queue length. The second most significant reduction to the performance measures occurred when an additional emergency nurse practitioner was supplemented to the fast track system. Accordingly, the nurse practitioner's percent utilization increased. There was only one two-way interaction effect that was statistically significant in reducing the primary performance measure of wait times; however, the effect did not change the queue length, a secondary performance measure, by a significant amount. Finally, the implementation of a See-and-treat model variant for fast track had a negligible effect on both the average length of stay and queue length.

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Chapter 1: Introduction

1.1 Canadian Healthcare Industry

Canada's healthcare system, Medicare, is in a crisis fuelled by high costs, poor or inconsistent quality, and inaccessibility to essential services. The total healthcare expenditure (HCE) as a proportion of gross domestic product (GDP) reached an all-time high of 11.9% in 2009[1], a cost estimated at $183.1 billion (or about $5,452CAD per capita). In Ontario alone, healthcare spending is expected to account for up to 50% of all government spending by 2011 (Adams et al., 2006). By international standards, Canada ranks 5th in per capita spending on healthcare as displayed in Table 1 (OECD, 2009).

Table 1.1: Ranking of Per Capita Healthcare Costs (OECD, 2009)

Country	Healthcare Spending (US$ per capita)
United States	$7290
Norway	$4763
Switzerland	$4417
Luxembourg	$4162
Canada	$3895[2]

[1] For a comprehensive source of information regarding the allocation of spending on healthcare in Canada, refer to Canadian Institute for Health Information's report, *National Health Expenditure Trends, 1975 – 2009*.
[2] Latest year for which data is available is from 2007 (OECD, 2009).

While the financial burden of providing healthcare to Canadians has increased 5.5% from 2008 to 2009[1], so too have the challenges associated with providing timely access to services for those in need (CIHI, 2007a). Unsuitably high waiting times have become a significant factor in restricting access to care for Canadians (CIHI, 2007a). This problem is further exacerbated by an increased demand for healthcare services by an aging population, changes in the overall health status of Canadians and a decreased supply of resources, as evidenced by hospital closures and shortages of medical practitioners (Asplin et al., 2002).

From an operations management point of view, the problem of high wait times marks an opportunity for improvement of existing healthcare processes, such that the Canadian healthcare industry can be run more effectively and efficiently, within its current infrastructure, from the perspective of both cost and care provided through implementation of organizational change.

1.2 Applications of Operations Research

Operations research encompasses a wide range of techniques that optimizes solutions to complex decision-making problems. Optimization of patient care can be achieved through the application of industrial technologies, such as Lean thinking and Six Sigma, amongst others.

Further to industrial technologies, healthcare organizations can also greatly benefit from operations research (OR) techniques – a system of applying advanced analytical methods to facilitate better decision making processes. These analytical methods and their applications include the following:

- Simulation and Modeling:

Used to analyze complex systems by evaluating various design alternatives for improvement. This OR technique focuses on interactions among and within system components. From the perspective of a hospital emergency department, simulation techniques provide a visual representation of the effect that process changes have on wait times within the whole system (Carter, 2002).

- Optimization:

  Used to determine the best feasible solution given a set of constraints. This OR technique may be utilized to determine adequate resource loading and scheduling within a healthcare delivery system (Winston & Venkataramanan, 2003).

- Probability and statistics:

  This OR technique provides a measurement of risk, helps identify important relationships between system variables to test conclusions and allows for the development of reliable forecasts (INFORMS, 2004).

Potential benefits of using OR techniques include (INFORMS, 2004):

- Business insight into complex problems;
- Business performance improvements through the implementation of model-driven intelligence to aid in decision-making;
- Cost reductions to operations;
- Informed decision making, by assessing the likely outcomes of design alternatives;
- Forecasting, for accurate planning;
- Improved scheduling of staff, equipment, and events;

- Strategic planning through the use of quantitative techniques;
- Dynamic pricing of products and services;
- Increased productivity in processes and people;
- Increased profits and improved quality;
- Greater recovery and turnaround times;
- Greater utilization from limited resources;
- Measurement and management of risk; and
- Increased throughput and decreased delays.

Canada's healthcare system is a strong candidate to benefit from the application of OR techniques to its process management. Process management provides a systematic approach to improving an organization's process. For instance, simulation and process modelling can provide a better understanding of the efficiency of resource allocation and utilization within the healthcare system. Furthermore, these techniques can provide essential tools to healthcare administrators to assess both a current and proposed future state of workflow of a system (Barrick, 2009).

The high cost of waiting times and the complex workflow throughout hospitals demand effective process management techniques. Implementation of such techniques will allow for a healthcare system that has improved quality, greater cost-effectiveness and increased efficiency (Jun et al., 1999; Carter, 2004).

1.3 The Challenge of Wait Times

This section presents an overview of the significance of waiting time in healthcare delivery systems and introduces initiatives for improvement.

1.3.1 Emergency Department – Its Role and Overcrowding Issues

Emergency departments (EDs) are designed to ensure public access to emergency care services and are also acute care systems, which are characterized by unscheduled visits. EDs play a vital role within any healthcare system.

A sudden increased volume of patients presenting to an ED can lead to a problem of overcrowding. When this occurs, the EDs operate beyond their maximum capacity to administer care, due to the high volumes of patients entering the system; this results in a secondary problem of prolonged wait times for patients (Derlet & Richards, 2000; Derlet et al., 2001; Drummond, 2002; Asplin et al., 2002; Cowan & Trzeciak, 2005).

Other factors that contribute to ED overcrowding include (Derlet & Richards, 2000; Derlet et al., 2001; MOHLTC, 2005):

- Lack of inpatient[3] beds for admitted patients,
- Medical staff shortages,
- Increased numbers of patients presenting with complex conditions,
- An aging population, and
- Use of ED beds for non-emergency patients.

Overcrowding and prolonged wait times produce adverse effects on patient-care outcomes due to the resulting delays in diagnosis and treatment (Derlet & Richards, 2000; Derlet et al., 2001). These issues also negatively impact patient satisfaction, causing an increased number of patients to leave the EDs against medical advice or without having been seen by a physician, threatening patient

[3] An inpatient is a patient that requires hospital admission and at least one overnight stay (CIHI, 2007).

safety. Therefore, the success of an ED depends to a great extent on the timeline by which healthcare professionals are able to administer care to patients. From this perspective, reducing the wait times for Canadians to see an ED physician is an important health policy issue.

1.3.2 Wait Times

Polls regularly show that Canadians are concerned about wait times and the general state of the healthcare system (Saulnier et al., 2004). This is apt, because the costs, both monetary and non-monetary, associated with a deteriorating healthcare system are borne by all Canadians. Persons faced with illness must contend with a host of challenges including "lost work time, decreased productivity associated with physical impairment and anxiety, and physical and psychological pain and suffering" (Esmail, 2009). While these problems affect individuals, an inefficient healthcare system increases the number of patients and duration by which Canadians as a whole struggle with illness. Ultimately, this translates into a persistent financial and social burden for the entire country.

To ensure an efficient allocation of scarce resources and improve wait time management, the Canadian Triage Acuity Scale (CTAS), a triage assessment tool, is used to prioritize and sort patients according to the urgency of their medical needs[4]. However, as more patients arrive to the ED, patients are reprioritized for a physician's initial assessment by ensuring that high-acuity patients are cared for first (CAEP, 2009). In this case, low-acuity patients tend to have the longest stay in ED. To address the issue of long waits for low-acuity patients, the implementation of a separate stream in the ED, known as a fast track system[5], allows low-acuity patients to be "evaluated and treated in a concurrent parallel process from individuals with more severe clinical presentations" (Wiler et al., 2010).

[4] In Canada, acuity is measured as CTAS Level I, II, III, IV or V (from high to low acuity).
[5] A fast track system can be shortened to "fast track".

1.3.3 Government Initiatives to Reduce Wait Times

The Ontario Government announced its Wait Time Strategy (WTS) in November 2004, which first focussed on reducing surgical and diagnostic imaging wait times. By October 2007 the WTS was expanded to include efforts to reduce waiting times in the EDs (MOHLTC, 2007). As part of its strategy to improve emergency room performance, the Ontario Government instituted a Pay-for-results program, which rewards hospitals that meet specific ED wait time reductions through (MOHLTC, 2009):

- Process improvement programs to help hospitals improve patient access in EDs,
- Support nurses dedicated to patients that arrive by ambulance,
- Investment in physician assistants to EDs,
- Investment in community projects for patients with chronic and palliative conditions, and
- Promotion of healthcare options that are appropriate alternatives to EDs.

1.4 Fast Track Strategy

Simulation analysis may be employed in a number of ways to evaluate potential outcomes of lean implementations to healthcare (Feld, 2001). This includes analyses at the operational, strategic, and national levels. At the operational level, it is possible to analyze the outcomes of patient flow studies. While at the strategic level, it is possible to measure the commercial well being of an organization by monitoring its financial gains, staff morale and staff involvement. Finally, analysis at the national level allows for observing the results of government initiatives at addressing the reduction of patient wait times in EDs.

At the operational level, this thesis aims to provide a concrete analysis of lean implementation of an ED, particularly within the fast track system. The introduction of fast track systems was aimed at reducing wait times within EDs. Reducing patient wait times in this manner allows an increase in the number of patients that can be treated and discharged, thus increasing the effective capacity of the ED (Wiler et al., 2010). This increase in effective capacity allows more patients to be seen, because the time in system is reduced.

At Grand River Hospital (GRH), there are a number of initiatives that are already present in the ED to help reduce patients' length of stay. These include a fast track area, the use of nurse practitioners (NPs) in the ED, emergency medical directives that allow ED nurses to begin some treatments and/or order some tests before the initial assessment, and having some tests conducted in the ED rather than transferring the patient to another department.

In queuing theory, by observing the shortest processing time (SPT) rule – serving first the client/job whose expected service time is the shortest – the overall average waiting time is minimized for the entire queuing system (McQuarrie, 1983; Baker, 2008). At GRH, the ED applies this rule in its use of a fast track system, whereby a separate service line is dedicated to assessing and treating low-acuity and/or non-urgent patients, in order to reduce their waiting time in a high volume ED. Common elements of an ED fast track system include (Yoon, 2003):

- Selection of low acuity patients as determined by a triage system,
- A separate physical space dedicated to fast track patients,
- Dedicated nursing and physician staff, and
- Attachment to a main ED or easy access to the resources of the main ED.

Prior research investigated the implementation of a fast track system in a variety of clinical settings including rural[6] and urban areas[7], paediatric centres[8], international EDs[9], and with care being supplied by either a physician[10] or midlevel provider[11] . Establishing a fast track stream for low-acuity patients resulted in a number of benefits that include, but are not limited to:

- Decreased patient wait times[12],
- Increased throughput of low-acuity patients[13],
- Consistence clinical outcomes for low-acuity patients[14] (i.e. no increased negative effects), and
- Little effect on higher-acuity patient waiting times (Schull et al., 2007).

To date, research is lacking in what determines an optimal fast track strategy. In other words, the best approach to fast tracking operations has not been identified. The research in this thesis is intended to contribute to change management initiatives to improve ED fast track operations and throughput.

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[6] Refer to Rodi et al., 2006 and Ieraci et al., 2008.
[7] Refer to Meislin et al,. 1988; Cooke et al., 2002; Darrab et al., 2006; O'Brien et al., 2006; Sanchez et al., 2006; and Kwa et al., 2008.
[8] Refer to Simon et al., 1996 and Hampers et al., 1999.
[9] Refer to Darrab et al., 2006; O'Brien et al., 2006; Ieraci et al., 2008; and Kwa et al. 2008.
[10] Refer to Simon et al., 1996; Hampers et al., 1999; Cooke et al., 2002; Darrab et al, 2006; O'Brien et al, 2006; and Ieraci et al. 2008
[11] Refer to Sanchez et al., 2006 and Nash et al., 2007.
[12] Refer to Cooke et al., 2002; O'Brien et al., 2006; Sanchez et al., 2006; Ieraci et al., 2008; and Kwa et al., 2008.
[13] Refer to Simon et al., 1996; Hampers et al., 1999; Darrab et al., 2006; O'Brien et al., 2006; Sanchez et al., 2006; and Ieraci et al., 2008.
[14] Refer to Hampers et al., 1999; Sanchez et al., 2006; and Nash et al., 2007.

1.5 Research Objectives

As a resource and management issue, wait time is complex and highly variable. Though many factors contribute to prolonged wait times for emergency care services, optimization of current resources through alternative process design holds the greatest promise in improving performance measures. This thesis focuses on the operational level of an ED's fast track system at GRH in Kitchener, Ontario.

A simulation model was developed to gain a better understanding of the current operational practices within the GRH ED's fast track system, and to provide a more direct analysis to evidence the potential of lean implementation at GRH. The model captures patient flow and resource engagement within the fast track system so that we can assess the operating efficiency of current management practices. It is further employed to compare various management strategies for reducing patient waiting times.

The simulation model is designed using Simul8® software to model operational processes within the ED. Its primary advantage lies in its capacity to evaluate the potential effects of various operational strategies over a wide range of system conditions to achieve a particular goal; in this case, reducing patient wait times. Simulation analysis of these operational strategies provides the means to answer important questions such as:

- What effects do differing operational strategies have on patient wait times?
- What effect does increasing physician presence have on the fast track system?
- What happens when there is an additional emergency nurse practitioner (ENP)?

By testing design alternatives, simulation analysis provides researchers and managers a cost-effective way of examining 'what-if' scenarios without altering the state of the current system.

1.5.1 Preliminary Studies and Terminologies

This section presents a general overview of the work done for this thesis and describes various clarifications on the information and terminologies presented.

A preliminary study of the ED operations at GRH was obtained through on-site interviews and direct observation during the Accelerate Internship from January 2009 to March 2009. Additional interviews were scheduled, as needed, for simulation modeling verification and validation purposes after this time period.

The term “emergency department” (ED) or “emergency room” (ER) refers to comprehensive EDs open 24 hours a day, seven days a week, which provide acute care to patients arriving by ambulance or by other means.

Patients are classified as either “inpatients”, requiring admission to the hospital and having at least one overnight stay, or “outpatients”, not requiring admission and typically discharged from the hospital on the same day. The simulation model does not distinguish between these two patient classifications, because hospital admission of patients occurs at the end of a visit to the ED. The scope of this thesis is exclusively focused on emergency services provided to patients within the ED.

“Low-acuity” patients are those that present to the ED with minor conditions, while “high-acuity” patients are those that present with more severe clinical presentations.

Patients presenting at the ED with minor or less- to non- urgent conditions are directed to “fast track”. In this thesis, the terms “Rapid Assessment Area” (RAA) and “Minor Treatment” (MT) are equivalent to the fast track system of an ER.

The objective of the Canadian Emergency Triage Acuity Scale (CTAS) and the Canadian Emergency Department Information System (CEDIS) National Working Groups is to develop a comprehensive national ED data set meeting the information needs of Canadian EDs to allow for comparative standards and benchmarks in healthcare (CAEP, 2009). CTAS is represented by five acuity levels in which patients are categorized. CTAS I, II and III require immediate-, emergent-, and urgent- care, respectively, and are streamed to the "Main Department"; CTAS IV and V require less urgent and non-urgent care, respectively, and are streamed to "Fast Track". There are some less severe cases of CTAS III patients who are also streamed to the fast track system as long as a treatment bed is available.

"Treatment" refers to any procedures and/or intervention conducted on a patient. There are specifically two types of tests ordered within the ED that may assist in treatment – laboratory (lab) and medical imaging (MI). Medical imaging tests include X-ray, ultrasound and computed tomography (CT) scan.

In the fast track system of the simulation model, an emergency nurse practitioner (ENP) may require a "consultation" with a physician, which may include the physician reviewing patient test results with the ENP or it may require the physician to assess and/or treat a patient. In the first case, it does not entail the physician to physically examine the patient; while in the latter, the physician meets with the patient in the exam room. Both types of consultations illustrate the collaborative practice between the ENP and ED physician.

Lean management refers to "lean thinking", "lean manufacturing", "lean production", and "Toyota Production System (TPS)". All terms refer to a set of principles and practices for effectively meeting customers' needs by efficiently making use of current resources.

“Work-in-process” (WIP), a key element in lean manufacturing, refers to inventory that is in the state of being transformed from raw material to finished product (Groover, 2007). High inventory is problematic because it incurs a cost by taking up capacity and increasing the time spent in a system. In a lean service, WIP is identified as unfinished service requests from customers. For example, in a hospital, WIP can refer to the time taken to assess, treat and discharge a patient or the number of patients in queue for assessment.

“Operations analysis” and “methods engineering” refer to the analysis and design or work methods and systems (Groover, 2007). While operations analysis studies operation(s) for potential improvements in its efficiency and effectiveness, methods engineering emphasizes the system’s design (Groover, 2007).

All costs are presented in Canadian dollars unless otherwise specified. The fiscal year for Grand River Hospital is the period beginning in April and ending in March of the following calendar year.

The primary sources of quantified data from GRH utilized for this thesis consists of the fourth quarter fiscal year 2008-2009 (Q4 FY 2008-09) Emergency Department Reporting System (EDRS) and Emergency Department Tracking Board (EDTB), and the first-quarter fiscal year 2009-2010 (Q1 FY 2009-10) Laboratory and Medical Imaging turnaround times. The EDTB and EDRS data are collected by hospitals to measure and manage ER activities and the flow of patients into and out of ERs (MOHLTC, 2007). The data include patient-specific information and times of events from GRH’s ED.

Laboratory and medical imaging turnaround time probability distributions are fitted to the actual data using Version 2.0 of Stat::Fit®, which is a probability distribution fitting software designed for use in Simul8 Professional. Using Version 17.0 of Simul8®, the simulation model of the ED fast track system is developed. Simul8® is a simulation software introduced by Visual8 Corporation in 1994 (Hauge & Paige, 2004).

1.6 Thesis Organization

This section provides a brief description of each of the chapters presented in this thesis. Chapter 2 provides an in-depth description of Grand River Hospital and its ED. Chapter 3 reviews the literature related to this thesis. Chapter 4 explores the characteristics of the current system, as well as the proposed system designs being applied. With this knowledge, an appropriate model of the system is constructed that will be used to explore the issues introduced in Chapter 3. After the system description of the model has been presented, the model structure and the associated simulation model are described. Chapter 5 describes the factors to be varied and the experiments to be conducted. Chapter 6 presents the results and analysis of the simulation runs. Chapter 7 will summarize the conclusions that have been obtained and outline future avenues of research.

Chapter 2: The Hospital Environment

This chapter describes the ED in terms of a work system. Information regarding Grand River Hospital was obtained and summarized from the hospital's official website (Grand River Hospital, 2010). Details on the ED were obtained through extensive on-site interviews and direct observation during the Accelerate Internship from January to March 2009.

2.1 Grand River Hospital

GRH is a multi-site facility that provides a variety of healthcare services to more than 500,000 residents of Waterloo Region, Wellington County and surrounding areas (Grand River Hospital, 2009). The services available at GRH include (Gaskin & Lydia, 2007):

- Cancer care
- Maternal/child health
- Mental Health
- Renal Dialysis
- Trauma
- Neurology
- Complex continuing care and rehabilitation
- Emergency Medicine
- Surgery
- Medical Imaging, Nuclear Medicine, Laboratory Services

GRH has about 3,500 professional staff and more than 700 volunteers. During the fiscal year 2008/09, GRH experienced 21,971 admissions and 57,445 emergency visits to its ED (Grand River Hospital, 2009).

The Grand River Hospital's ED is the largest operating ED in the Waterloo Region. Their staff provides paediatric and adult emergency care 24 hours a day, 7 days a week. The department has 39 treatment rooms with an average of 160 emergency visits a day. In this study, we investigate the flow of patients, which comprise mostly outpatients, in the fast track system.

2.2 Healthcare Team for Emergency Services

Upon arrival to GRH's ED, one or more members of a multidisciplinary team first assesses a patient's needs before determining the required treatment. The healthcare team in the ED consists of:

- ED clinical administrator;
- Emergency medicine physicians (EMPs);
- Emergency nurse practitioners (ENPs);
- Resource/charge nurse;
- Emergency medicine nurses;
- Clinical medicine specialists;
- Clinical support staff such as:
  - Geriatric Emergency Management nurse (GEM),
  - Crisis nurse, and
  - Mental Health Rapid Response Liaison nurse (MHRRLN);
- Non-clinical support staff;
- Pharmacists and pharmacy technicians;

- Social workers and Community Care Access Center (CCAC);
- Diagnostic imaging staff;
- Laboratory staff;
- Occupational therapists;
- Physiotherapists;
- Medical students;
- Security; and
- Volunteers.

The present study had the support of the ER/ICU Program Director and the Chief of Emergency Medicine, whose responsibilities include team leadership to the frontline healthcare team to ensure patient care; and non-clinical support staff, who provide a wide-range of services and support including clerical and housekeeping.

2.3 Emergency Department

Fundamentally, an ED is a self-contained clinical unit into which patients enter with an acute medical condition and from which patients leave after that condition is addressed. At this point, each patient is either admitted to the hospital or discharged home. Alternative possibilities for patient outcomes include:

- Transfers to another healthcare facility,
- Departing the ED without being seen by a physician,
- Departing the ED against medical advice,
- A prolonged observation mode such as a clinical decision unit, or
- Patient death in the ED.

The system becomes more complex when one accounts for the individual patient, the ED caregiver(s), the clinical decision-making and the totality of the environment (Smith & Feied 1999). The variability in many of these features makes the ED a complex system.

Patients with high acuity are attended within a time specified by the CTAS and CEDIS National Working Groups, while patients with lower acuity and consequently lower priority wait longer. Prolonged wait times become a limiting factor to public access to healthcare and as such, timely access to care is a high priority for patients, healthcare providers and the public at large.

Patients in EDs experience long wait times in waiting rooms, exam rooms, for tests and for discharge due to severe resource constraints (Asplin et al., 2002). In Canada, at least 50% of patients wait 1.2 hours or more for an ED physician (CIHI, 2007). Only 10% are seen within 0.3 hours, while that same proportion waits 3.6 hours or more (CIHI, 2007). In Canada and in many other industrialized countries, waiting for emergency care has received significant media attention. Various reports by the Canadian Agency for Drugs and Technologies in Health (CADTH)[15] and by the Canadian Institute for Health Information (CIHI)[16] confirm that ED overcrowding is not exclusively an ED problem, but rather a larger systemic healthcare policy issue.

2.4 Work System and Work Cell

Several of the ideas in this section are based upon Groover (2007). Work systems are physical entities consisting of personnel, information and equipment that are designed to accomplish some output through a prescribed process(es). This thesis will look at the GRH ED as a work system. Current operations of the ED are outlined later in Section 4.1.3. Operations analysis and methods engineering

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[15] Refer to Ospina et al. 2006, Rowe et al. 2006a, Rowe et al. 2006b, and Bond et al. 2006.

[16] Refer to CIHI 2005, CIHI 2007a, and CIHI 2007b.

will be utilized to analyze and study the design of the complex existing ED processes – consisting of material and information flows – through multiple operations, as well as proposed process enhancements. Through methods design, experiments will be conducted into the effectiveness of alternative process designs in the fast track system in order to improve current processes in the ED.

The fast track system can be described as a “work cell” within the larger “work system” of the ED. A work cell consists of a “group of workstations dedicated to the processing of a range of work units within a given type”. The fast track system, as an example of a work cell, is a separate, but concurrent, parallel stream that consists of patients as work units presenting with minor and/or non-urgent conditions. Here, the operations are integrated to facilitate patient flow for “fast-tracked” patients so that lead time and WIP are minimized.

Productivity is the level of output over time of a given process relative to the level of input. From the perspective of EDs, productivity refers to the number of patients that are evaluated, treated and released from the ED relative to the number of patients that enter the system for emergency healthcare services. The most common productivity measure is labour productivity, which, in the healthcare delivery system, gives the ratio of patients discharged from the ED (output measure) and labour hours of input. However, labour productivity as a measurement does not provide a good indication of where to seek productivity improvement. Technology is a more important factor in determining and improving productivity. “Technology” refers to a fundamental change in the way some activity or function is accomplished. This thesis analyzes different technologies that contribute to improvements in performance measures.

In any process operation, batch processing occurs when work units – material, products, information, or people – are processed in groups. This is common in many service operations including healthcare delivery systems and typically requires work-in-process (WIP). Two types of batch processing are: sequential batch processing, and simultaneous batch processing. Sequential batch processing occurs when members of the "batch" are processed individually one after another. Simultaneous batch processing occurs when members of the batch are processed at the same time.

When viewed as an operational sequence, delays occur between processing steps because multiple batches are competing for the same resource(s). Queues form, which result in long lead-times to complete tasks for the work units and high WIP.

In a healthcare delivery system, queues are undesirable to have since they lead to long wait times, and consequently, long lengths of stay, for patients. A suggested alternative to batch processing is shortest processing time (SPT). SPT sequencing partially solves both the delay problem and the inventory WIP problem that result from batch processing. The fast track system can be illustrated as an example of SPT in the sense that patients with less severe conditions are "processed" first to decrease the total number of patients waiting in queues.

Clinical and non-clinical personnel in the fast track system act as a team, whose common objectives are to work together to make fast track operations as effective and efficient as possible, while providing high quality medical care services to patients at the lowest possible cost in terms of wait times.

2.5 Summary

This chapter provided information about the hospital environment at Grand River Hospital. Complete information about the hospital and its programs can be accessed through its official website (GRH, 2010). The fast track system was detailed in terms of a work cell within a work system.

Chapter 3: Literature Review

This thesis focuses on simulating patient flow processes through the fast track system of the Emergency Department at Grand River Hospital with an emphasis on reducing patient wait times. This chapter provides a summary of related literature and subjects that are associated with the proposed operational and management alternatives investigated in this thesis.

Three major proposed alternatives are investigated:

1. The availability of one physician resource in fast track.
2. The long term effects of implementing a “See-and-treat” model in the fast track system, as specified later in Section 4.1.4.
3. The addition of one extra emergency nurse practitioner in fast track.

Since computer simulation is used to explore and evaluate these operational and management alternatives, an overview of simulation and its applications in healthcare is presented here.

The first section explores the literature on previous simulation studies in healthcare systems that are related to improvements in operational efficiencies and reductions of wait times. The second section provides a review of research topics in order to identify applicable industrial technologies that may be applied to a lean healthcare scenario. Finally, this chapter will conclude with a summary of this thesis’ research direction.

3.1 Simulation and Healthcare

With dramatic increases in healthcare expenditure (HCE), healthcare organizations are under significant pressure to provide quality healthcare while reducing costs and improving productivity.

Given the increased need for efficiency in healthcare delivery systems, coupled with the increased availability of ease-of-use of simulation software packages, simulation has become an effective and efficient means to analyze proposed process improvements for potential cost reductions and productivity improvements prior to their actual implementation (Banks et al., 2005). Healthcare management can cost-effectively address a number of issues within healthcare delivery systems and evaluate various operational and management alternatives to improve existing healthcare infrastructure such as EDs and/or plan and design new systems.

Two basic types of modeling techniques can be used to describe and analyze the system of interest (Sinreich & Marmor, 2005):

- Prescriptive models:

  Linear or nonlinear programming models "provide a prescription for how to set the decision variables in order to achieve optimal performance of a predefined objective function".

- Descriptive models:

  Queuing models, Markov chains or discrete-event simulation (DES) models all present "a detailed report on the system's operational behaviour based on its description".

Due to the size, complexity and level of detail required by the system under study, descriptive modelling in the form of DES is employed in this thesis to model the existing GRH ED fast track system and analyze the merits of alternative system designs.

3.2 Operational Strategies in Emergency Departments

Three goals of a healthcare system include (Hall et al., 2006):

- Minimizing the costs of services,
- Maximizing convenience and access to services, and
- Maximizing the likelihood of a positive outcome from the service.

All of these can be accomplished by reducing delays in the healthcare system. By removing inefficiencies in the delivery of healthcare, timely access to services can be improved and wait times reduced.

One of the most common themes in simulation studies within healthcare is the study of reducing queue time or length of stay (LOS) of patients. Such studies have concentrated on simulating EDs in the US or accident and emergency (A&E) units in the UK .

For example, a study conducted by Takakuwa and Shiozaki (2004) used ARENA to simulate patient flows of an entire ED of a general hospital. The authors' focus was to determine the factors that account for patient waiting times and to propose a stepwise procedure of operations planning to minimize these times. They discovered that ED patients spent the majority of their time waiting for treatment and that this was caused by limitations linked to treatment resources such as beds, physicians, drips and stretchers, which accounted for most of the waiting time.

Several studies used ED simulation models to evaluate the effect of various staffing levels and schedules that would yield a reduction in patient waiting times. For example, Evans et al. (1996) used ARENA to model an ED of a Louisville, Kentucky hospital. The model included the process flows of 13 different patient types and was used to evaluate various feasible schedules for ED staff, including nurses, technicians, and physicians. The authors examined five different schedules and used the average length of stay of ED patients as the main performance measure. Similarly, Rosetti et al. (1999) developed a model based on the ED at the University of Virginia Medical Center in

Charlottesville, Virginia. The authors tested eighteen different alternatives for ED physician staffing schedules to analyze the corresponding impacts on patient throughput and resource utilization.

Other studies examined operational changes to, or the implementation of, a fast track system on ED performance measures. McGuire (1994) used simulation to model an ED in a SunHealth Alliance hospital in the southeast of Charlotte, North Carolina. McGuire analyzed five alternative scenarios and each of their impacts on wait time reductions. Most notably, the use of a fast track area for patients in need of minor care assisted in reducing the patient's length of stay compared to similar patients that stayed in the main ED. Likewise, Garcia et al. (1995) modelled an ED at Mercy Hospital in Miami, Florida and studied the flow of patients in the ED with and without a fast track area. The authors found that a fast track lane reduces the time in system by almost 25% for patients with low priority without a negative impact on the wait times of patients with higher priority.

In another related study, Sinreich and Marmor (2005) noted that the quality of service is affected by delays that patients experience while being treated, such as waiting for nurses and physicians, waiting for a bed, and waiting for test results. The authors aggregated "the processes each patient goes through when treated in the ED according to patient type". Their analysis revealed that waiting time accounts for 51-63% of total patient turnaround time in the ED. They further pinpointed three process components that have the largest impact on the total process duration:

- The average time patients are out of the ED for an x-ray examination.
- The average waiting time for the results of regular blood tests.
- The average waiting time for the first physician`s examination.

This thesis will examine the effect that the initial physician assessment has on patient waiting time. Furthermore, this thesis will use the patient type driven approach to simulate alternative scenarios.

Wiler et al. (2010) provides a review of current literature that analyzes operational improvement strategies and their effect on front-end[17] operations of healthcare delivery systems. The authors identify several ED front-end strategies as important components to change management initiatives for improving throughput in individual EDs. However, it was also noted that there exists a knowledge gap as to what the optimal ED front-end strategy should be. The front-end operations that the authors have chosen to review were those identified to have a high impact on operational improvements, which include:

- Immediate bedding and "Quick" or bedside registration,
- Advanced triage protocols and triage-based care protocols,
- Physician/practitioner in triage,
- Implementation of "fast track" service line, and
- Enhanced ED information systems and communication tools.

Lamont (2005) explores factors that influence the adoption of the "See-and-treat" (S&T) model in A&E departments. It has been promoted as a solution to waiting time problems in A&E; however, no national evaluation was undertaken to evidence its effect. Rogers et al. (2004) evaluated a S&T pilot study in an ED at Addenbrookes NHS Trust Hospital in the UK. The authors undertook a retrospective analysis of statistics which were collected during two study periods (non S&T-pre pilot and actual

[17] Front-end operations typically include initial patient presentation, registration, triage, bed placement and medical evaluation (Wiler et al., 2010).

pilot trial) and compared the results. They found that the S&T model did reduce waiting times for patients with minor conditions. The current operations at GRH include a fast track area for streamlining patients with minor or non-urgent conditions. Using simulation, this thesis will examine the operational S&T strategy in the fast track system of GRH.

Another theme in the literature that focuses on reducing ED waiting time includes a triage-team method (Grant et al., 1999; Ruohonen et al., 2006; Medeiros et al., 2008). In this scenario, an emergency physician is placed at triage alongside with the triage nurse to assess patients as they arrive into the ED. The ideology behind the triage-team method is to streamline the care of patients to the appropriate treatment area and to ensure that all the tests the patient needs are ordered right after arrival so that it quickens the referral to treatment. Results from these studies indicate that the triage-team method reduces waiting times in the ED. A similar approach is employed in the fast track system, involving a fast-track team that consists of a ED physician, an ENP and two nurses to assess, treat and discharge patients. Current operations at GRH have the ED physicians dividing their time between the main ED and fast track area.

3.3 Industrial Technologies

From an operations management perspective, healthcare organizations and hospitals have been characterized by many industry experts as some of the "most complex, barely manageable places ... in human history" (Barrick, 2009). However, a variety of tools and techniques developed from manufacturing industries have yet to be implemented for management-related issues in service industries, such as healthcare. These techniques include various ways to design, implement, manage, operate, monitor and improve processes and systems for more efficient performance. Programs such as process analysis, quality management, continuous process improvement, business process reengineering as well as the more modern Six Sigma, Lean principles, and organizational transformation are used to assess systems effectiveness. Each program is described as follows:

- Process Analysis:

  Used to define a process that consists of several operations, each of which consists of several tasks. Once a process is defined, it can become standardized so as to meet an established specification, with minimal variation. Improvements in processes occur when the process in question is repeatable, consistent and meets patient or customer requirements (Nicholas & Soni, 2006; Barrick 2009).

- Quality Management (QM):

  A management methodology based on the statistical process control (SPC), which features recognition, analysis and elimination of variation. It features quality training, process improvement, and benchmarking to reduce the errors produced during production. Or, service processes with the aim to increase customer satisfaction (Ruffa, 2008; Barrick, 2009; Samson & Terziovski, 1999).

- Continuous Process Improvement:

  Also known as *kaizen* (Japanese for "improvement"). This occurs through the ongoing efforts of workers to resolve problems and remove wastes. It requires high-level employee involvement (Nicholas & Soni, 2006).

- Business Process Reengineering (BPR):

  A rethinking or radical redesign of current business processes while measuring changes to performance indicators, such as costs, quality, service and speed. This is accomplished through the use of BPR teams to analyze existing processes, discard preconceived notions, and learn and understand the critical components of a process from a patient's or customer's point of view (Barrick, 2009).

- Six Sigma:

  A disciplined, data-based approach for eliminating defects and improving processes. A "sigma" is a statistical quantity representing the degree of deviation in a given process variable from an ideal result. The objective is to optimize the quality and yield from a process through systematic reductions in potential variation for each component of a process (Ferrin et al,. 2005; de Koning et al., 2006; Nicholas & Soni, 2006).

- Lean Principles:

  Originating from the Toyota Production System (TPS), lean thinking uses various strategies to increase efficiency, decrease waste, and improve quality. The lean concepts emphasize visual management – value stream mapping (VSM) – and "pull versus push" systems to highlight opportunities of streamlining operations, which allows analysts to determine the value from a customer's perspective by identifying value-added (VA) activities from non-value-added (NVA) activities. Lean principles are deeply rooted in manufacturing but it can be universally applied to other industries, such as business, government and healthcare (Groover, 2007; Barrick, 2009).

- Organizational Transformation:

  Driven by leaders who actively initiate and manage organization-wide change, this industrial technology features forward-thinking managerial innovation to achieve successful process redesign, which requires deliberate planning, disciplined strategy, and tactical deployment structure (Barrick, 2009).

3.3.1 Application of Industrial Technologies in Healthcare

This thesis emphasizes the use of lean thinking and simulation methodology in the fast track system at GRH to determine an optimal operational strategy for the ED that reduces patient waiting times. Lean techniques can be used to study the operational system of a hospital, in which a model may illustrate non-value added activities. By removing these non-value added activities, an improved process flow for hospitals may be realized.

Lean thinking can be traced back to the early days of the Ford Motor Company (de Koning et al., 2006); however, it was not until the 1950s that Japanese automotive companies, most notably Toyota, fully developed and successfully transferred the concept into their operations. The spread of lean thinking was facilitated by the publication of Womack, Jones and Roos (1990). Five key principles in lean thinking were identified in the business environment within which they saw lean techniques being successful (Womack and Jones, 1996). In regards to the healthcare industry, these key concepts include:

1. Identifying value from the patient’s point of view,
2. Using value stream mapping to identify wastes (i.e. rework, waiting, travel, processing, inventory, motion, and defects),
3. Establishing operational flow,

4. Implementing a pull system, and

5. Perfecting processes by reducing variation through continuous improvements.

The concept of lean lies in its approach to improve a system by eliminating waste from any sub-process or product. It emphasizes employee engagement and ownership of the organizational change process for successful transformation. The value of any activity is perceived from the customer's point of view, therefore, steps that do not add value, such as delays, are considered deviations from the intended objectives. Furthermore, variation within steps is considered symptomatic waste (Ruffa, 2008).

Walley (2003) reviewed the literature on manufacturing process design and found that modern manufacturing theories are applicable in healthcare. The author used two health site regions of North Cheshire and Lewisham, UK, to demonstrate lean principles in the design of treatment processes for patients in A&E departments. It was found that 85% of the emergency demand was biased towards patients with minor or non-urgent illnesses. The author found the S&T method to be an effective example of a cellular operation – a "manufacturing approach to segmentation that divides clusters of work by the similarity of the process sequence and not by other characteristics, such as reported symptoms". The author further emphasizes that the S&T method does not trade off performance for one group of patients at the expense of another but rather provide all patients with the best quality of service that is possible given a set of environmental factors.

A study by Brandao de Souza (2009) detailed an increasing rate of lean healthcare applications in different countries (i.e. USA, UK, Australia, others). The author further identified that a higher number of speculative works related to lean implementation had been produced rather than methodological works, and that the gap in methodological works provides a "need for more concrete analysis to evidence the potential of lean healthcare" (Brandao de Souza, 2009). It is the intention of this thesis to provide a more tangible analysis of a lean healthcare by employing simulation to test the effects of a number of lean initiatives in the fast track system at GRH.

Young (2005) hypothesized that the strategic application of lean principles may enable higher standards of care and also reduce costs and waiting times in healthcare delivery systems. The author suggested the use of simulation to describe the sequential activities and interactions of patients and evaluate the effects of different scenarios. It was proposed that doing so will allow healthcare providers to create strategic scenarios that could help deliver high quality care to many patients. However, the author noted that preliminary work on patient pathways was required in order to effectively simulate a lean healthcare system. In addition to simulating lean initiatives in the fast track system at GRH, this thesis will also detail the various patient pathways within the fast track system.

While lean thinking emphasizes waste reduction through the practice of "doing more with less", Six Sigma provides the analytic tools to reduce variation in the process flow (Nicholas & Soni, 2006). Six Sigma uses a five-step problem solving strategy (DMAIC) to improve quality throughout an organization. This includes (Nicholas & Soni, 2006; Barrick, 2009):

- <u>D</u>efining the problem from the customer's point of view,
- <u>M</u>easuring the performance of critical processes,
- <u>A</u>nalyzing the key factors that contribute to process variation,
- <u>I</u>mproving the system elements to achieve performance goals, and
- <u>C</u>ontrolling system-level value-critical characteristics.

Miller et al. (2003) used Six Sigma and simulation for a large hospital in the southeast United States to implement major facility planning changes in their main ED. Using Six Sigma's design of experiments (DOE), process improvements were planned prior to implementation and the simulation provided hospital executives with the quantitative comparisons to meet their goals.

Ferrin et al. (2005) explored the relationships between the two process innovation approaches (lean thinking and Six Sigma) and simulation. In addition to assessing the impact of alternative strategies, the authors found that simulation is a six sigma capable tool that is capable of delivering a "statistically robust solution" and ensuring that customers are confident that a process will meet their expectations for quality.

A study by King, Ben-Tovim, and Bassham (2006) applied concepts from lean manufacturing in redesigning an emergency department patient flow at the Flinders Medical Centre in Adelaide, South Australia. A process map for ED processes was used to identify value streams in redesigning ED processes and in streaming patient care. The proposed system reduced the complexity of the queuing process which reduced the total treatment times and the total patient numbers in the ED as well as provide important implications for triage (King et al., 2006).

3.4 Summary

This section summarizes the evidence presented in this chapter and shows its significance. It highlights gaps in the literature and indicates how previous research leads to the current thesis research.

This thesis will utilize simulation to analyze different operational strategies in fast track that reduces low priority patient waiting times without compromising the waiting times for high priority patients in the main department.

The present study will model the fast track system of an ED at GRH and simulate the effects of lean thinking on current operations. Through the use of six sigma’s design of experiments and simulation methodology, the optimal fast track management design that minimizes patient waiting times will be determined. The operational strategies include varying the assigned fast track physician availability, implementing S&T, and adding an additional emergency nurse practitioner within the fast track system.

Chapter 4: Simulation Model Development

This chapter provides an introduction to the concept of discrete-event simulation modelling and describes the development process for the model generated in this thesis using the Simul8® environment. The model is based on the characteristics of the current fast track system at the Emergency Department of Grand River Hospital and features certain proposed design alternatives, which are further described in the following sections. The chapter concludes with the corresponding verification and validation procedures used to authenticate the model.

4.1 Discrete Event Simulation Modelling

This section provides a description of discrete-event modelling as applied to the GRH ED fast track system and patient flow through the department.

4.1.1 System Components

In discrete-event simulation (DES), a system is shown as a chronological sequence of events, each of which occurs at an instant in time and changes the state of the rest of the system. Some terminology related to DES modelling and their associations to this thesis are summarized below (Banks et al., 2005):

- An *entity* is an object of interest in the system. The entities in this thesis include patients, ER rooms, nurses, nurse practitioners and emergency physicians, and are analogous to the "work units" discussed previously in Section 2.4.
- An *attribute* is a property of an entity. These data values determine the route the patient takes through the system. Refer to Table 4.9 for a list of attributes used in the simulation model.

- An *activity* represents a time period of a specified length. The activities in the simulation model include the physician's initial assessment, treatment, laboratory examination, medical imaging examination, reassessment, and discharge process.
- The *state* of a system is the collection of variables used to describe the system at any time in terms of the objectives of the study. In the study of the ED, examples include the number of patients waiting in queue or being served, the arrival time of the next patient, and the utilization of medical staff.
- An *event* is an instantaneous occurrence that might change the state of the system. *Endogenous* events are those that describe activities and events that occur within the system; whereas, *exogenous* events are activities and events in the environment that affect the system. In the simulation model, the arrival of a patient is an exogenous event, and the completion of the discharge process of a patient is an endogenous event.

This thesis takes a "process" approach to simulation modeling i.e. the simulation is viewed in terms of the individual entities involved, and the programming "describes the 'experience' of a 'typical' entity as it 'flows' through the system" (Law, 2007).

4.1.2 Patient Flow Description

The model was constructed based on the actual operational fast track system at Grand River Hospital's Emergency Department. A thorough understanding of the system was obtained through on-site observations and interviews with various clinical and non-clinical staff in the ED. This method provided abundant information about patient flow at the level of detail required to construct a robust simulation model for analysis.

Data was collected from each patient entering the ED; the simulation time unit was expressed in minutes. The data was extracted from the Emergency Department's Information System (EDIS), which included the triage level, the chief complaint/reason for visit, as well as the date and time of:

- Arrival
- Registration
- Triage
- Physician initial assessment date and time
- Disposition decision
- Departure

The process of data collection is thoroughly described in Section 4.3.

All ED patients, regardless of their type, proceed through the ED in a generic manner, as shown in Figure 4.1. Typically, when a patient arrives in an ED, a triage nurse first assesses the patient in a cubicle outside the treatment areas and determines the acuity level. In some cases, a high acuity patient (labelled as L1/L2 i.e. CTAS I, II, respectively) may be immediately placed inside the ED treatment area; otherwise, the patient is registered by a clerk. At this point, the patient waits for a treatment bed to become available to be placed inside the ED, where treatment begins. Laboratory and/or medical imaging (MI) tests may be ordered by the triage nurse, nurse practitioner, or physician, for the patient, depending on the patient's chief complaint. Once assessment and treatment are completed, the patient is discharged from the ED.

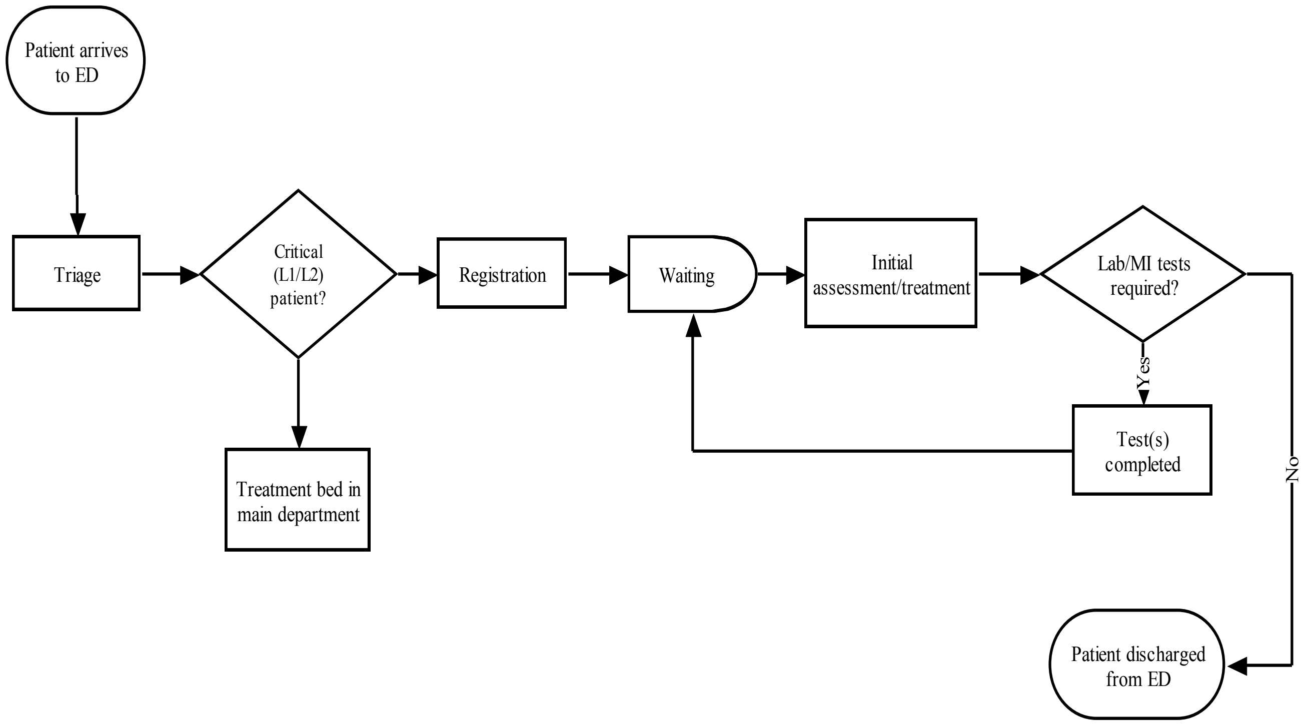

Figure 4.1: Patient Flow Description

4.1.3 Current Operations

Patients arrive to the ED either by ambulance or are termed 'walk-in' patients. Patients entering the ED by other means have not been included in the model. The process difference for ambulance patients versus walk-in patients occurs prior to a patient being taken into a treatment area. Both patient types may ultimately be processed through either the fast track area or the main department depending on their acuity levels. However, ambulance patients are more likely to be assessed and treated in the main department, since their presenting complaints will typically be more severe (i.e. have higher acuity). The patient is either rushed to an ER treatment room or is in offload delay[18].

[18] Ambulance offload delays occur as a result of overcrowding and congestion in EDs. It refers to a situation where an ED is unable to accept ambulance patients in a timely manner due to lack of hospital resources such as staff and bed capacity (Derlet & Richards, 2000).

Under certain circumstances, emergency medical directives enable ED nurses to initiate treatment before the patient is assessed by the nurse practitioner or ED physician.

A walk-in patient begins his or her course through the ED by first signing in at reception and waiting until a triage nurse is available. Patients are assessed on a first come first served (FCFS) basis. If the triage nurse determines that a patient requires immediate care (high acuity level – CTAS I, II & III), the patient is expedited to treatment in the main department. If the triage nurse determines a patient does not require immediate attention (low acuity – CTAS III, IV & V), the patient waits to be registered. During the registration stage, the triage nurse may initiate orders for tests based on the presenting complaints of patients prior to their initial assessment by a physician. This step ensures that necessary test results are already available by the time the patient is first seen by their physician.

Once the triage assessment is finished, registration is completed by a clerk. Afterwards, patients return to the waiting room to be taken to a treatment room by a nurse or clerk for further assessment. Depending on the severity of a patient's condition, patients are either taken to the fast track area or the main department.

Upon completion of registration, if laboratory tests have been ordered, the patient then waits for the mobile phlebotomist to collect samples for analysis. If radiology exams have been ordered, the patient is transported to the radiology department. The lab and/or radiology testing concludes with the patient waiting in the waiting room for the results to be interpreted by an examining medical professional.

If a patient arrives by ambulance, triage is immediately performed on the patient by a nurse. Once the nurse confirms the patient requires immediate attention, the registration process and medical directives are performed at the bedside by the nurse. However, if upon examination, the nurse determines that the patient does not require immediate emergency care, the patient joins the queue designated for walk-in patients.

Once a patient occupies a treatment room within the ED, it is anticipated that there will be another delay while waiting for a secondary assessment by a nurse within either treatment areas; this is followed by an examination by the emergency room physician. In the fast track area, the nurse practitioner brings her own patients to the treatment room to examine. Both the emergency physician and the emergency nurse practitioner have the same role in examining patients; however, the range of patients seen by the nurse practitioner is limited to those that are within her medical scope of practice.

If results from tests initiated by the triage nurse are ready, a patient has a higher priority of being seen by the examining medical professional for initial assessment. Otherwise, the examining medical professional decides if tests should be ordered. There are specifically two types of tests ordered within the ED, laboratory or x-ray (including CT). Patients may go through more than one series of tests, but typically not more than two. The medical examiner may also discharge a patient without tests being performed. If discharged, the emergency physician or nurse practitioner performs the discharge process and the patient is released from the ED.

If the ED physician and/or ENP orders tests after the initial assessment, patients must be moved to the applicable testing area for the appropriate tests. Once tests have been completed, there is further delay until a clinical decision is made by either the nurse practitioner or the emergency physician. The clinical decision determines whether a patient is admitted or discharged from the hospital. In the fast track area, patients entering the system are most likely to be discharged to go home rather than being admitted to the hospital. If a patient is discharged, the nurse practitioner, physician, or nurse performs the discharge process and the patient is released to go home.

4.1.4 The Proposed System Designs

The principle behind triage is to "make the best possible use of the available medical and nursing personnel and facilities" and "to assist in determining which patients need immediate care and which patients can wait" (Dolan & Holt, 2008). Triage should be a rapid and reproducible assessment tool that accurately allocates a priority to each patient based on clinical need; however, there have been opportunities to add in other aspects of examination. In addition to the assessment, first aid and prioritization, triage examination may include (Dolan & Holt, 2008):

- Administering analgesia,
- Referring patients to x-ray or other investigations,
- Advising on the subject of self-care, and
- Initiating patient pathways to other specialties.

This extends the time taken to triage each patient, which in turn increases the risk for those queuing for triage (Dolan & Holt, 2008).

The traditional S&T model is a system of ED organization that is "based on the principle that [a senior] clinician is able to see, treat and discharge the patient after initial assessment, thereby reducing the length of time these patients stay in the department" (Rogers et al., 2004). The S&T model operates under the assumption that where there is sufficient capacity in the ED, triage is not required and thus patients with the most minor conditions are seen very quickly by a senior clinician after they arrive in an ED. The S&T model operates as follows (Dolan & Holt, 2008):

- Once a patient is recognized as presenting with a minor injury or medical condition, the triage nurse sends the patient directly to the queue for the fast track system. Patients requiring in-depth assessment or treatment are streamed to the appropriate area.
- Triage of walk-in patients is unnecessary when See-and-treat is operating and patients are seen shortly after arrival.
- The first person to see the patient, namely the emergency physician or emergency nurse practitioner, in the fast track area is able to make autonomous clinical decisions about treatment, investigations and discharge.
- An ED physician is set to work exclusively in the fast track system for any particular shift.

The S&T model stipulated in this thesis is a slight variation of the traditional S&T model. Once patients are identified as fast track or non-fast track patients within the simulation model, patients proceed to the appropriate treatment area. The nurse secondary assessment is a form of triage. In order to implement the S&T model within the fast track system, the nurse secondary assessment is eliminated for the same reasons outlined above for the traditional S&T model. Henceforth, S&T will refer to the elimination of the nurse secondary assessment. Thus, in this thesis, simulation is used to analyze the potential impact of the S&T model with GRH's fast track system.

The benefits of implementing the See-and-treat model as stipulated in this thesis is hypothesized to result in wait time reductions, since patients with minor conditions are not delayed by a triage system and will not have to wait between the initial assessment and receiving the prescribed treatment.

Other proposed system designs include increasing the priority that physician assigns to seeing and treating patients, and adding another emergency nurse practitioner to supplement the healthcare team in fast track. The first is measured by increasing the availability of the ED physician to patients within the fast track system. The second is increasing the length of an ENP's shift from an 8-hour day-shift to a 12-hour day shift. The number of days the ENP works throughout the week is increased by 1 so that there is an ENP on shift 6 days per week.

4.2 Simulation Software

A discrete-event simulation software package known as Simul8® was selected on the basis of its graphical user interface, ease-of-use as well as its robust modeling options and features; Simul8® represented a more attractive model platform for this thesis than alternatives such as GPSS/H. Description of Simul8® and other simulation packages can be found in Banks et al. (2005) and Law (2007).

The main objective of the simulation model developed in this thesis was to understand the system performance relative to various strategies for operational and management enhancements within the fast track system of the GRH ED. This was accomplished by modelling the overall patient flow as well as the ED system processes for realistic operating conditions.

Using the patient flow process descriptions and their corresponding activity flow for each patient group as a guide, each section of the patient flow process was translated into Simul8® simulation logic. The simulation model was developed using a number of assumptions to simplify the modeling effort and eliminate any insignificant parameters.

4.3 Data Collection and Organization

One of the biggest challenges in solving a real problem is data collection. Even with the available data, input data may not be accurately collected, appropriately analyzed, or representative of the environment. The simulation output data may therefore be misleading when used in the decision making process (Banks et al., 2005).

The development of the simulation model required correct and sufficient data to be collected in order for the model to accurately simulate the actual system. Information on the system structure and operating procedures were collected in order to specify model parameters and input probability distributions. The level of detail was chosen to reflect the thesis objectives, data availability, as well as time and resource constraints.

The data required to build the model included:

- Volume and direction of patient flow,
- Patient’s chief complaint for ED visit,
- Laboratory and medical imaging tests required for each patient complaint,
- Test turnaround times,
- Physician initial assessment time, and
- Patients’ length of stay.

Patient flow volume refers to the number of patients that enter the ED. Information collected from patients is stored daily in the hospital database. The data acquired for this thesis provided the detail to model and simulate the existing fast track system at GRH ED.

Electronic data was provided in a number of spreadsheets: the first dataset contained information during the 90-day time period of January to March 2009 and the second dataset contained information during the 91-day time period of April to June 2009. The first dataset included Emergency Department Tracking Board (EDTB) data and Emergency Department Reporting System

(EDRS) data. The EDTB data is 'real time' data while the EDRS data is CIHI validated data. The second dataset contained EDRS data and ED laboratory and medical imaging turnaround times. Data for laboratory and medical imaging test turnaround times were unavailable for the first dataset. The second dataset did not contain EBTB data.

In this thesis, turnaround times are defined as the time from when the test is ordered to the time when the results are available to the healthcare provider. The ordering of tests by clinical staff was compiled based on ER medical directives and from numerous ER staff interviews.

The EDTB data was used to determine the volume and direction of patient flow within the ED. In addition to the chief complaints[19], patients were also identified as either fast track or non-fast track patients within the EDTB data; whereas, the EDRS data did not make that distinction and only identified the patient by ICD-10[20] code. Since variations in treatment pathways differ significantly between patients within a particular CTAS level, patients were categorized according to their chief complaints.

Based on the EDTB data, a total of 157 chief complaints presented were recorded for the fast track area. Whenever possible, each chief complaint was matched to its corresponding ICD-10 code using the presenting complaint list version 1.1 (Grafstein et al., 2008). This was to ensure that information between the EDTB and EDRS data could be matched for validation and consistency purposes. Using information obtained from medical directives and medical professionals, resources and treatment pathways were defined for each patient group (including the ordering of tests).

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[19] Chief complaint refers to the presenting complaint. It describes the symptom or condition that is the reason for a medical examination.

[20] ICD-10 stands for the International Statistical Classification of Diseases and Related Health Problems, 10th Revision.

Estimations regarding the different service times were obtained through on-site interviews with various medical professionals.

The EDRS data contained time stamped information regarding the patients' ED stay. The information included the date and time of:

- Registration,
- Triage,
- Initial assessment,
- Disposition, and
- Patient exit of the ED.

Information was organized by ICD-10 codes (i.e. only those codes that matched the presenting complaint from the fast track area were used).

In the simulation model, patients' chief complaints were classified into 29 categories/groups. Each group was defined by a sequence of activities and associated resources required to perform those activities. The time durations for each activity were verified by medical professionals.

Table 4.1 lists the chief complaints and its corresponding ICD-10 code as organized by patient group (CCID#[21]) in the simulation model. The information was gathered from CEDIS Version 1.1 Presenting Complaint List provided in Appendix A.

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[21] CCID# refers to the chief complain identification number. It is used to describe the different groups of patients that enter the simulation model.

Table 4.1: Chief Complaints and Corresponding ICD-10 Code

CCID#	Presenting Chief Complaint	ICD-10 code
1	abdominal pain	R10.4
	groin pain/mass	R190
	jaundice	R17
2	upper extremity injury	T11.9
	lower extremity injury	T13.9
3	laceration/puncture	T14.1
	abrasion	T00.9
4	fever	A50.9
	periorbital swelling and fever	H05.0
5	cough/congestion	R05
	hemoptysis	R04.2
	wheezing-no other complaints	R06.8
6	nausea and/or vomiting	R11.8
	diarrhea	K52.9
	exposure to communicable disease	Z20.9
	blood and body fluid exposure	Z20.9
7	imaging tests	Z01.6
	cast check	Z47.8
	medical device problem	T85.9
	dressing change	Z46.8
	rabies vaccination	NA

8	localized swelling/redness	L03.9
9	back pain	M54.9
10	chest pain-non cardiac features	R07.4
11	lower extremity pain upper extremity pain	M79.61 M79.60
12	pregnancy issues, <20 weeks	O28.80
13	DVT protocol unilateral reddened hot limb: DVT symptoms	NA M79.89
14	sore throat	J02.9
15	shortness of breath	R06.0
16	head injury	S09.9
17	headache	R51
18	UTI complaints 160	R39.8
19	ear-related complaints	H92.0, S00.4, T16, H92.1, H91.9, H93.1
20	skin-related complaints	R21, T14.0, T30.0, Z09.8, L98.9, L98.8, R06.2, Z48.9
21	obstetrical–gynecological related complaints	N93.9, N94.8, R22.9, N89.8, N92.6, T19.2, R36
22	tests initiated in fast track, streamed to main dept after PIA	

23	no tests initiated in fast track, streamed to main department after PIA
24	seen by MD, no tests
25	seen by MD, lab test
26	seen by NP, MD order required
27	seen by NP, major MD consult
28	seen by NP/MD
29	direct to main department

It was determined that patient groups 1 through 21 comprised approximately 20% (specifically, 37/157 = 0.236) of the chief complaints that presented in the fast track area and thus consumed the most resources. The chief complaints in patient groups 22 through 29 were organized according to similar treatment processes in the ED. Individually, many of these chief complaints were less frequent presentations in the ED. Because of the rare occurrence, these chief complaints were grouped together by similar treatment processes and/or resource consumption.

Table 4.1 was compiled accordingly: Patient group 22 consists of patients with chief complaints that have tests initiated in fast track, and are streamed to the main department after the initial assessment. Patient group 23 consists of patients with chief complaints that do not have tests initiated in fast track, and are streamed to the main department after the initial assessment. Patient group 24 consists of patients with chief complaints that do not require any tests, and require an initial assessment by an emergency physician. Patient group 25 consists of patients with chief complaints that require only a lab test, and require an initial assessment by an emergency physician. These two patient groups (24 and 25) consist of patients that are outside the ENP's scope of practice. Patient group 26 consist of patients that are assessed and treated by the ENP but that require a physician to order the test(s). Patient group 27 consist of patients that are assessed and treated by the ENP, but, for whatever the reason, also require an emergency physician consultation. In the simulation model, patient groups 26 and 27 are mostly seen by the ENP during on-shift hours; whereas off-shift, the ED physician is assigned to assess and treat patients from these two groups. Patient group 28 consist of patients with chief complaints that can be seen by either ENP or ED physician, whichever one is available. Finally, patient group 29 consist of patients with chief complaints that are sent directly to the main department after triage assessment. This final group does not consume any fast track-assigned resources.

4.4 Simulation Model Design

The simulation model was developed to better understand the current fast track system and to analyze potential areas for wait time reductions. The simulation model presented in this thesis is an example of a *stochastic* simulation model, which has random variables as inputs. These random variables include the volume and frequency of patient arrivals, patient type i.e. by grouping of chief complaints, and service times for each patient type. In conducting the simulation, probability distributions were specified for each source of randomness. Since random inputs lead to random outputs, the outputs of a stochastic simulation model are estimates of the true characteristics of the system (Banks et al., 2005).

Appropriate probability distributions are important to yield useful results of the actual system. Once data is collected from the real system of interest, a frequency distribution, or histogram, is constructed to help identify the probability distribution used to represent the input process (Banks et al., 2005). Distribution fitting programs, such as the one used in this study, Stat::Fit, are available to facilitate fitting the histogram to well-known theoretical distributions. Unless otherwise specified, a fitted analytic distribution was used for all input processes. For input processes that used empirical distributions, it should be noted that although an empirical distribution reflects reality, it has a finite range and thus the values generated will not occur outside this range.

4.4.1 Input Probability Distribution – Patient Arrivals

Patient arrival patterns were obtained using the EDTB data that distinguished patients as either fast track or non fast track patients. During the January to March 2009 time period, 9,114 out of 14,303 ED patients were identified as fast track patients.

To observe differences in the volume of patients arriving to the ED, the number of patient arrivals per hour and per half hour were plotted in histograms (refer to Appendix B). Half hour segmentation began at 0800 hour. The graphical comparison was completed for each patient group. There was very little difference observed between the two graphs. Thus, by using the volume of patients arriving per hour of a day, the input probability distribution for each patient group's arrival was determined. The patient arrivals were modelled in the simulation using a Poisson distribution.

Simul8's distribution fitting software, Stat::Fit, was used to transform raw data into a single distribution that best represented the collected data. The distribution fitting for laboratory and medical imaging service times were obtained as follows.

4.4.2 Input Probability Distribution – Laboratory Tests

Data was collected during April to June 2009 of all laboratory tests ordered from the ED. From the interviews with subject matter experts, the most common tests ordered in the fast track area were identified to be:

- ABO/RH Typing - A blood test,
- BHCG – Human chorionic gonadotropin. Used to detect early pregnancies and to evaluate the development of the embryo), INR (standardized way of monitoring blood clotting)
- MONO test – For infectious mononucleosis,
- Troponin-T – Test for heart damage, and
- Urine dipstick – Test for glucose, ketones, blood, protein, nitrite, pH, urobilinogen, bilirubin, and leucocytes in urine.

The data was organized in an Excel spreadsheet with 9,752 data points from the three month time period. The lab sample collection service time (in minutes) is defined as the period of time when the lab order was placed to the time the sample was collected. The lab sample processing time (in minutes) refers to the time between when the lab sample was collected to the time the results were ready. Using the statistical distribution software, Table 4.2 and Table 4.3 were obtained. As shown in these two tables, all distributions were rejected for both lab collection and lab processing service times.

Table 4.2: Distribution Fitting for Lab Sample Collection Service Time

Auto::Fit of Distributions		
distribution	**rank**	**acceptance**
Beta(8., 7.37e+003, 1.28, 393)	0	reject
Erlang(8., 1., 17.5)	0	reject
Exponential(8., 23.4)	0	reject
Gamma(8., 1.34, 17.5)	0	reject
Lognormal(8., 2.73, 1.01)	0	reject
Pearson 5(8., 1., 8.65)	0	reject
Pearson 6(8., 69.9, 1.61, 5.71)	0	reject
Triangular(7., 115, 8.62)	0	reject
Uniform(8., 115)	0	reject
Weibull(8., 1.13, 24.9)	0	reject
Rayleigh(8., 23.1)	0	reject
Chi Squared(8., 16.4)	0	reject
Power Function(8., 115, 0.516)	0	reject

Table 4.3: Distribution Fitting for Lab Sample Processing Service Time

Auto::Fit of Distributions		
distribution	**rank**	**acceptance**
Beta(19., 78.1, 1.27, 2.43)	100	reject
Erlang(19., 2., 10.)	0	reject
Exponential(19., 19.8)	0	reject
Gamma(19., 1.97, 10.)	0	reject
Lognormal(19., 2.71, 0.883)	0	reject
Pearson 5(19., 1.12, 10.1)	0	reject
Pearson 6(19., 1.38e+005, 1.79, 1.22e+004)	0	reject
Triangular(18., 76.2, 21.1)	0	reject
Uniform(19., 74.)	0	reject
Weibull(19., 1.52, 22.3)	0	reject
Rayleigh(19., 17.)	0	reject
Chi Squared(19., 16.)	0	reject
Power Function(19., 74., 0.77)	0	reject

The laboratory tests, as a population, did not appear to fit a common probability distribution to fit the available data. However, when the data was further separated by its individual test, as shown in Table 4.5 and Table 4.6, a better statistical fit was realized. The rest are shown in the tables in Appendix C. Due to the scope of the model, each of the distributions that were obtained from

Stat::Fit were equally sampled in order to give a representative view of the laboratory collection and processing service times for fast tracked patients.

As stated previously, the most common tests ordered for fast track patients were identified to be ABO/RH Typing, BHCG, INR, MONO test, Troponin-T, and urine dipstick. The data points were separated according to each individual test, with negative values eliminated as well as the lower and upper 5% of data points. Deleting the lower and upper 5% of data points for each test ensured that outliers did not affect the distribution fitting. The tables in Appendix C provide a comparison of the individual test with the first distribution fitting (for all data points, excluding negative values) and also for the second distribution fitting (with the upper and lower 5% data points deleted).

For the BHCG, INR, MONO and Troponin-T tests, deleting the upper and lower 5% of the data points provided the best distribution fit for each test, as shown in Table 4.4. Goodness-of-fit tests (Kolmogorov-Smirnov (KS) and Anderson-Darling (AD) tests) were also performed and p-values were obtained for a level of significance 0.05.

Table 4.4: Stat::Fit Fitting Distributions for Individual Lab Test

Test	Distribution	KS p-value	AD p-value
BHCG	Beta distribution, rank 100, do not reject	0.674	0.752
INR	Beta distribution, rank 100, do not reject	8.61e-002	0.206
MONO	Beta distribution, rank 100, do not reject	0.581	0.96
Troponin-T	Weibull distribution, rank 95.6, do not reject	0.206	0.518

The Pearson 6 was the best distribution fit for ABO/RH Typing (rank 100, do not reject); however, deleting the upper and lower 5% of data provided a wider range of distributions to choose from, with the Beta distribution ranked 95.2.

Probability-probability (P-P) plots were generated for both the Pearson 6 and Beta distributions to visually determine the best fit. The P-P plot is a plot of the probability of the *ith* data point in the input data from the data table versus the probability of that point from the fitted cumulative distribution. This plot tends to be sensitive to variations in the centre of the fitted data. As shown in the P-P plots in Figure 4.2, the Beta distribution provided a better fit to the data than the Pearson 6. Hence, the Beta distribution was used for the ABO/RH Typing test (KS p-value = 0.61; AD p-value = 0.776).

Table 4.5: Distribution Fitting for ABO/RH Typing

Auto::Fit of Distributions		
distribution	**rank**	**acceptance**
Pearson 6(1., 248, 5.56, 8.53)	100	do not reject
Lognormal(1., 5.05, 0.574)	30.3	do not eject
Gamma(1., 3.47, 52.5)	15	do not reject
Weibull(1., 1.8, 206)	9.38E-03	reject
Rayleigh(1., 150)	4.75E-04	reject
Beta(1., 7.43e+003, 1.89, 62.4)	0	reject
Erlang(1., 3., 52.5)	0	reject
Triangular(0., 709, 86.7)	0	reject
Uniform(1., 702)	0	reject
Pearson 5(1., 2.41, 302)	0	reject
Exponential(1., 182)	0	reject
Chi Squared(1., 157)	0	reject
Power Function(1., 703, 0.666)	0	reject

Table 4.6: Distribution Fitting for ABO/RH Typing (upper and lower 5% data points deleted)

Auto::Fit of Distributions		
distribution	**rank**	**acceptance**
Beta(62., 466, 1.5, 4.03)	95.2	do not reject
Weibull(62., 1.57, 122)	94.3	do not reject
Erlang(62., 2., 55.8)	13	do not reject
Triangular(61., 382, 74.4)	4.82	do not reject
Pearson 6(62., 4.32e+004, 1.93, 758)	3.4	do not reject
Gamma(62., 1.96, 55.8)	3.33	do not reject
Rayleigh(62., 91.8)	2.96E-03	reject
Lognormal(62., 4.42, 0.889)	0	reject
Uniform(62., 373)	0	reject
Pearson 5(62., 0.861, 36.1)	0	reject
Exponential(62., 109)	0	reject
Chi Squared(62., 84.)	0	reject
Power Function(62., 373, 0.756)	0	reject

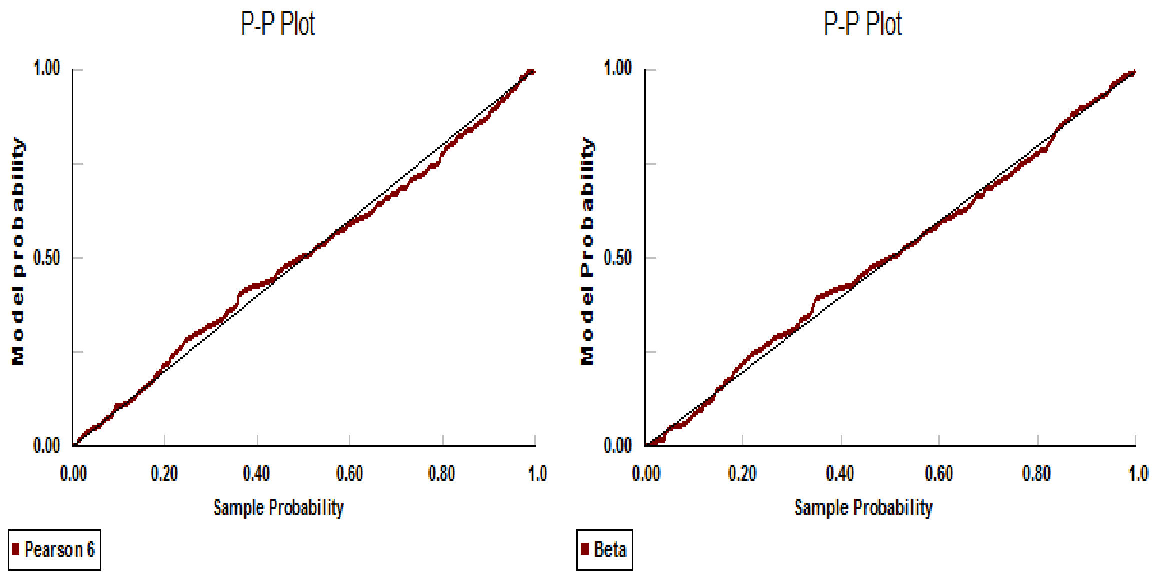


Figure 4.2: P-P Plot of ABO/RH Typing

As shown in Table C.9, Appendix C, none of the theoretical distributions fitted the data for the urine dipstick test. All distributions were rejected even when the upper and lower 5% of data were eliminated from the fitting, see Table C.10, Appendix C. Since the input data was not fitted to any of the analytical distributions, the empirical distribution was used for the urine dipstick test.

The following table lists the input distributions that were obtained from Stat::Fit for use in Simul8®.

Table 4.7: Input Probability Distributions for Laboratory Tests

Test	Distribution
ABO/RH Typing	Beta, 1.5, 4.03, 62., 466
BHCG	Beta, 1.37, 1.78, 63., 147
INR	Beta, 1.57, 3.19, 36., 123
MONO Test	Beta, 1.5, 2.23, 36., 127
Troponin-T	Create a combination distribution with a fixed offset of 41. then add Weibull, 1.78, 36.4
Urine Dipstick	Empirical distribution

4.4.3 Input Probability Distribution – Medical Imaging Tests

The three most common medical imaging tests that are ordered for fast track patients are computed tomography (CT), X-ray and ultrasound (US). The data points were separated according to each test, with negative values eliminated as well as the lower and upper 5% of data points. As was the case with the laboratory tests, deleting the lower and upper 5% of data points for each medical imaging test ensured that outliers did not affect the distribution fitting. The tables in Appendix C provide a comparison of the individual medical imaging test with the first distribution fitting (for all data points, excluding negative values) and also for the second distribution fitting (with the upper and lower 5% data points deleted).

Although the first distribution fitting provided a wider range of distributions to choose from for CT collection and processing times, the Beta distribution from the second distribution fitting provided a better distribution fit.

Table 4.8 lists the input distributions and p-values from Goodness-of-fit tests that were obtained from Stat::Fit for use in Simul8.

Table 4.8: Input Probability Distributions for Medical Imaging Tests

Test	Distribution	KS p-value	AD p-value
CT	Beta, 1.38, 2.49, 3., 466	0.847	0.706
US	empirical distribution	-	-
x-ray	empirical distribution	-	-

4.5 Limitations

A computer simulation model is a theoretical representation of a system or process, based on a set of rules, generalizations and assumptions. The scope of the research was affected by the design and programming issues that resulted from translating the conceptual model to Simul8®.

4.5.1 Simulation Model Structure and Assumptions

By design, each patient group defined in this model required different resources and therefore were routed to different treatment pathways (or patient care pathways). A more detailed illustration of patient flow in the ED is illustrated in Figure 4.3.

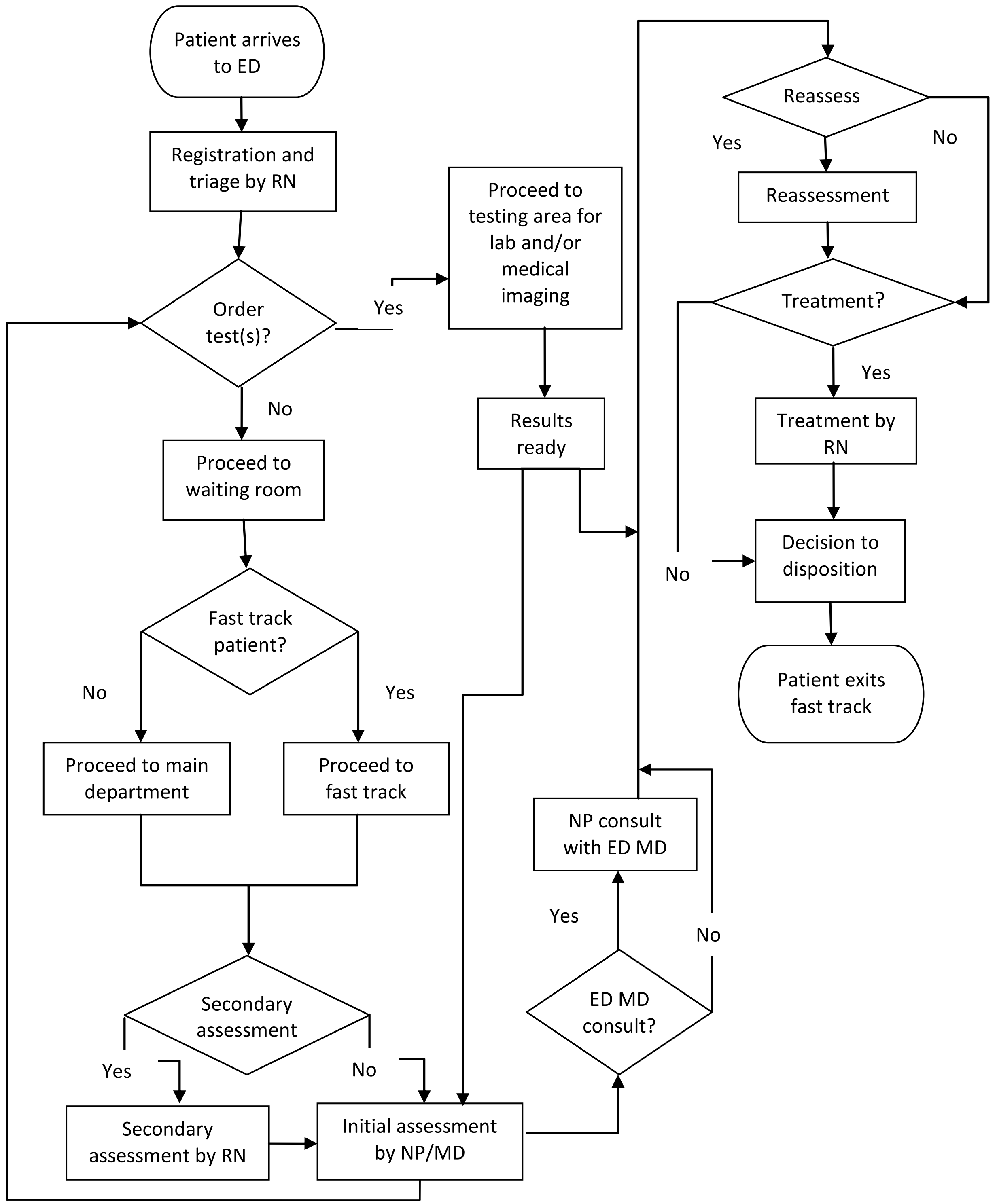


Figure 4.3: Emergency Department Patient Flowchart

An entry point was created for each patient group to model the different arrival distributions throughout the day. The information for the different arrival distributions per hour of the day was stored in an information store spreadsheet. The input probability distribution for patient arrivals included both fast tracked and non-fast tracked patients. A certain proportion of fast tracked patients (about 14%) leave without being seen (LWBS) by a physician. For two reasons, this group of patients was reflected in the simulation model by modelling an exit point right after the triage assessment. First, it ensured that the number of patients entering the system in the simulation model was consistent with what was observed in the actual ED system, and second, it ensured that LWBS patients did not affect the statistics for the length of stay of fast tracked patients. A number of dummy work centres were used to route patients to the testing area, the fast track area, or the main department.

In the simulation model, tests were either initiated in triage, or in the initial assessment by the NP and/or MD. In the first case, patients are sent directly to the testing area before the secondary and/or initial assessment in fast track. An infinite number of servers were used for all work centres in the testing area so that all tests were processed as they arrived instead of waiting in queue to be processed. The reason for this was that the laboratory and medical imaging service time distributions also included wait time.

In the simulation model, patients may have more than one test performed. Dummy work centres were set to either bypass or route patients to the next test, if required. The split and merge process occurred at the dummy work centres to ensure that the patient is split into a 'patient' piece and a 'test' piece. The 'test' piece is processed according to the test's probability distribution while the 'patient' piece proceeds through to the next test, if required. At the end of the testing area, the 'patient' and 'test' piece are matched and assembled together based on a unique identifier to ensure that the correct ‘patient’ is matched to its corresponding ‘test’ result(s). Separate queues for each test result were modelled to ensure appropriate merge transactions. The merge process occurs before the patient proceeds to the next stage of the pathway, which is the secondary or initial assessment. Patients with test results are immediately placed ahead of new patients (i.e. those waiting for initial assessment). These patients are given priority since they are closer to completing their stay in fast track.

Patients that had tests initiated in triage were distinguished from those patients whose tests were initiated after the initial assessment (either first or second set of testing) by use of a label, which was attached to each patient generated by the simulation model and used to keep track of patient routing.

In conjunction with service time estimates provided by clinical staff, the triangular distribution was chosen to model service times for each stage of the treatment process i.e. initial assessment, treatment, MD consult, discharge process. The triangular distribution was used because there was no dataset to fit, and it was thought to be a good representation of service times.

In the simulation model, ‘minor MD consult’ refers to cases in which the ENP requires a consultation with an ED physician. This activity does not require the physician to examine the patient; whereas, in the ‘major MD consult’, the ENP requires a consultation with the ED physician as well as an examination of the patient. Thus, the latter is modeled with a slightly longer service time than the minor consult.

Two groups, one for the fast track area and another for the main department, were created to limit the number of patients in either area. The main department was also modeled to show the effect of the fast track- assigned physician resource being pulled away from the fast track area.

Since simulation models are not exact duplications of the actual system, a set of assumptions concerning the operation of the ED fast track system were made during model construction. The assumptions are as follows:

1. All patients remain at the same acuity level/category throughout their entire stay in the ED. The category is assigned during triage or immediately after entering the ED.
2. Patients that have test results ready (laboratory, medical imaging or both) have higher priority of seeing the NP or MD than new patients waiting for initial assessment.
3. All laboratory and medical imaging tests (except for ultrasound) are available for processing throughout the day and night.
4. Patients are seen by medical professionals in a first-come-first-serve manner within the fast track area.
5. Due to the high variations of service times between patients within a particular patient group, triangular distributions were used, in conjunction with service time estimates by medical professionals, to model service times.
6. Since patients are served in a first-come-first-serve discipline, priorities for resources were set to the work centre instead to the patient.
7. Patients that proceed through the testing area must have their test result ready before proceeding to the secondary or initial assessment. In reality, patients may be assessed and/or treated while waiting for test results.

Table 4.9 lists the attributes and its description to work items, i.e. patients, generated in the simulation model.

Table 4.9: List of Attributes with Descriptions

Attribute	Description
CCID	Patient group number; used to identify corresponding column number in information store spreadsheet to look up value for next route
image:cc	Different image for each patient group; used to verify the route patient takes
lbl ID	Unique identifier; used to match patients to corresponding test result (split and merge process)
lbl initial assessment	Used to distinguish patients that have tests ordered after the initial assessment
lbl resource type	Used to determine which resources are used
lbl Time In	Time stamp when patient enters simulation
lbl triageTime	Time stamp when patient is triaged; used in calculations within the simulation model
Next	Used to route the patient to the next work centre; its value is stored in an information store spreadsheet

4.5.2 Simulation Modelling Issues

This section describes the two main modelling issues that were encountered in building the simulation model of the ED fast track system.

First, a matrix was used to implement time-dependent arrivals, since patients enter the ED at various times throughout the day. The use of a matrix maintained the interarrival times for each patient group. Additionally, a routing matrix ensured that the patient was routed to its correct patient care pathway. The routing matrix also guaranteed that patients were correctly joined with their respective test result(s). This fork-and-join (or split-and-merge) process allowed parallel processing of test samples while the patient proceeded through the system. The items were then rejoined in a downstream operation.

Second, there were a number of considerations in modeling resource requirements and availability. Labels were attached to resources to determine which of the listed resource at a work centre was required. Shift patterns limited the number of resources that were available throughout the day. Resources were also used to control daily start and stop times at a work centre. For example, in the simulation model, a resource was used to constrain the number of hours that the ultrasound test was available during the day for ED patients. In the simulation model, patients that required ultrasound testing outside the hours of operation had to wait in queue until the next day to receive testing.

4.6 Model Verification

Model verification is concerned with correctly transforming the model from one form to another, such as from a flowchart to an executable program. Its purpose is to ensure that the conceptual model is accurately reflected in the operational model. Guidelines for the proper methodology in the verification of the simulation model are provided in Law (2007) and Banks et al. (2005).

The following lists the verification techniques that were used to ensure the proper translation of the conceptual model to the study's simulation model:

- The computer program was written and debugged in modules or subprograms. By starting with a simple framework, the levels of detail were added and debugged successively until the model satisfactorily represented the system under study.
- The operational model was checked by an expert in the simulation software being used.
- The simulation was run under a variety of settings of the input parameters to examine the reasonableness of the model output.
- The state of the simulated system was observed after each event and compared with hand calculations to ensure that the program operated closely to the real system. This process is known as a "trace" and allows the modeller to inspect any model object during the model execution.
- The model was run under simplifying conditions to observe its true characteristics or to easily compute and compare its results.
- The animation of the simulation output was observed to assure patient flow reflected the actual system.
- The sample mean and sample variance for each simulation input probability distribution was computed and then compared with the historical mean and variance to ensure that the values were being correctly generated from the distributions.

The simulation package, Simul8®, was used as its built-in features minimized the number of probable errors occurring during the model's construction.

4.7 Model Validation

Another important process in increasing one's confidence in a model is validation, which is concerned with comparing the model to the real system and ensuring that it "behaves with sufficient accuracy in light of the study's objectives" (Swisher et al., 2001). Techniques for increasing the validity and credibility of a simulation model are provided in Law (2007) and Banks et al. (2005). Throughout the design and development of the simulation model, several techniques were employed to validate the model. The multistage validation technique, as described by Sargent (2009) was used as follows:

1. High face validity in a model:

   Ensures the analyst obtain a complete and accurate set of information from subject-matter experts (SME) in order to construct a reasonable model. By conversing with SMEs, the model logic and assumptions were reviewed before programming and model credibility was increased. For this thesis, face validity was further accomplished by observing the actual system and by obtaining historical records to validate results obtained from the simulation model.

2. Using quantitative techniques to test the model's assumptions:

   Examines the assumptions made throughout the model's design and development processes. There are a number of ways to accomplish the goal. Input data analysis was validated by using goodness-of-fit tests as well as by graphical methods. Sensitivity analysis was also applied to measure the response of model performance results to changes in input parameters.

3. Evaluating input-output transformations:

   Measures the model's ability to forecast the future behaviour of the actual system. This was accomplished when the model's input data set provided output data that closely resembled the expected output data from the actual system. The EDRS data, a separate data set from the one used to acquire the input probability distributions, was utilized to validate the model. In this study, the EDTB data set was used to obtain the input probability distributions for the simulation. The results were then compared to data produced by the actual system in the EDRS dataset, which was obtained from the same time period. In addition, the results of the empirical distributions were compared to the information provided by the SMEs. These comparisons helped validate the simulation model and are presented in Table 4.10.

The simulation model was validated by comparing the model's patient arrivals against the actual patient arrivals as gathered from hospital records. The length of stay from the EDRS dataset was used to compare with the simulation model output. The proportion of patients in the simulation model routed to the main department and to fast track (4,901/13,292 = 37% and 8,391/13,292 = 63%, respectively) correspond to the historical data (5,189/14,303 = 36% and 9,114/14,303 = 64%, respectively).

Table 4.10: Comparison of Simulation Model Output to Historical Data

Patient Type	No. Patients from EDTB	No. Patients from Simulation	Average LOS EDRS (mins)	Average LOS Simulation (mins)
Fast track	9,114	8,391	328	322.1449
Non fast track	5,189	4,901	-	-

When characteristics of a system vary as a function of time, time plots provide a visual evaluation of how a system performance measure changes dynamically over time. In the ED, for example, the number of medical personnel in fast track vary throughout the hours of a day. This affects the number of patients in queue for assessment and/or treatment. Thus, the number staff in fast track becomes a bottleneck when there is an increased demand for fast track services.

In the simulation model, the variable of interest is the queue size for initial assessment in the fast track system. The long-run dynamic system behaviour is understood by plotting this key variable over the duration of the simulation.

As illustrated in Figure 4.4, the number of patients in queue for an initial assessment varies throughout the 100-day simulation run. The data was recorded every 60 minutes after the initialization period. The simulation model was repeated for a total of 10 times with each replication using a different random number stream. Refer to Appendix D for the time plot of each subsequent replication. Similarly to Figure 4.4, the queue size for an initial assessment in the fast track system varied (from 0 to 23 patients) throughout a simulation run.

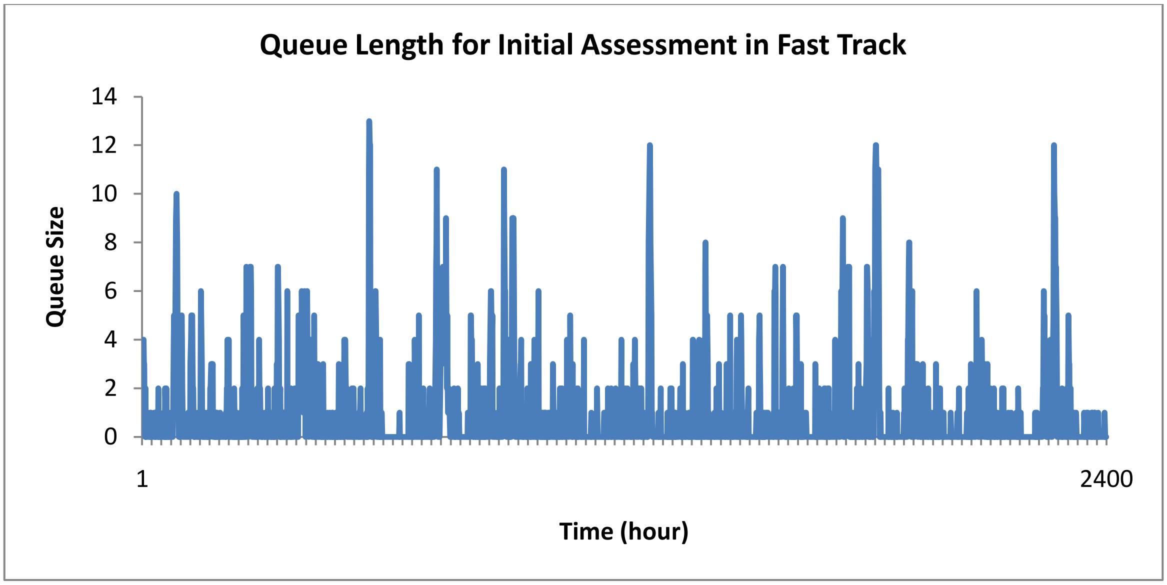


Figure 4.4: Time Plot for Number in Queue in Time Increments of 1 Hour, Current System (Replication 1)

While Figure 4.4 provides the dynamics of the queue size for a simulation run, a 2400 hour time period, Figure 4.5 shows a time plot for a period of 24 hours, or 1 day. To closely observe the change in queue size throughout a single day, the data was recorded every 5 minutes.

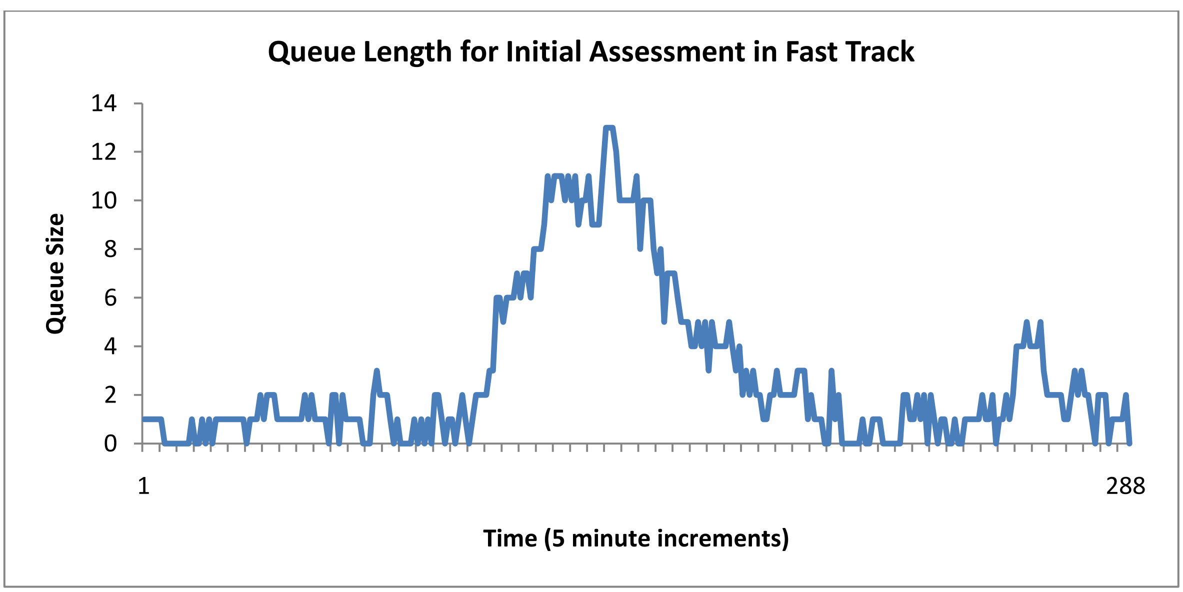


Figure 4.5: Time Plot for Number in Queue in Time Increments of 5 minutes, Current System (Replication 1)

Note the queue build-up for initial assessment in the fast track system during the peak hours of the day (approximately between 8AM and 5PM). The time plots illustrate the dynamic nature of a queuing system such as the ED. The first 48 hours (2,880 minutes) were not included in constructing the time plots.

4.8 Summary

This chapter detailed the development of both the conceptual model and the simulation model to reflect the current operating system of the fast track system at Grand River Hospital. The objectives of the conceptual model were (1) to capture the interaction of patients and resources in a fast track environment, and (2) to construct an environment which closely imitates the real system in order to observe these interactions. The simulation model was constructed in Simul8® and thus allowed for the examination of an optimal management strategy in the fast track system that reduces patient wait times. The simulation methodology – data collection, input data analysis, verification, and validation – provided a structured process to construct the simulation model. The chapter concluded with a thorough discussion of the verification and validation techniques employed in this thesis.

Chapter 5: Experimental Design

This chapter develops the framework for analysis by defining the performance measures of interest, and by specifying the conditions under which the simulation will behave. In the experimental design, the length of the initialization period, the length of simulation runs, and the number of replications of each simulation run will first be discussed. The chapter continues with an explanation of the experimental factors and the design of the experiment.

5.1 Introduction

The experimental design of a simulation is dependent upon what one intends to analyze in terms of the desired measures of performance. The simulation output data may, consequently, have a major influence on top management's decision making. And so, with respect to output analysis, a distinction is made between a terminating (transient) simulation and one that is steady-state. A terminating simulation "runs for some duration of time T_E, where E is a specified event (or set of events) that stops the simulation" (Banks et al., 2005). On the other hand, a steady-state (non-terminating) simulation is one for which there is no such natural event E that specifies the length of each run (replication) and, thus, runs continuously over a long period of time (Law, 2007). This thesis studies the long-run behaviour of the system described in Chapter 4 by developing a steady-state simulation model.

5.2 Measures of Performance

This thesis aims to provide quantifiable measures on the effect of alternative operational strategies within the ED's fast-track system. Performance measures are used to assess the long-term behaviour of the system. Those employed in this study have a point estimate and an interval estimate. The latter is a measure of error in the first estimate. The choice of the many performance measures of a system is dependent on the objectives of the simulation – this should coincide with what top management is interested in measuring.

The ability to see and treat patients in a timely manner is important to hospital administrators who are focussed on reducing patient wait times. In this thesis, the objective is to analyze the effect of alternative operational strategies on wait times in the fast track system. Thus, the primary performance measure is the average length of stay for fast tracked ED patients. The secondary performance measures are the queue length for initial assessment (by a physician or nurse practitioner) and resource utilization within the fast track system. Each performance measure is discussed further in the following:

Length of stay (LOS) is defined as the time from the earlier of registration or triage to the time the patient physically leaves the ED. In other words, LOS is the period of time a patient spends within the ED. It is the long-run or steady-state average length of stay (i.e. time spent in system) that is referred to herein.

Queue length for the initial assessment is defined as the number of patients that wait to be seen by a primary care provider in the fast track system. The thesis explores the expected number of patients that wait to be seen by a primary care provider in fast track. This secondary performance measure is important because it affects how long patients wait before being assessed by an ED physician and/or ENP. The initial assessment may then be followed by further testing or treatment (CIHI 2007b).

Resource utilization is defined as the proportion of time a resource spends working. The thesis investigates the utilization of both physician and nurse practitioner within the fast track system across the proposed designs.

5.3 Initialization Period

For a non-terminating simulation, the purpose of the stochastic simulation run is to provide an estimate of the steady-state, or long run, characteristics of a system. A single run generates observations Y_1, Y_2... Y_n. These observations are samples of an auto-correlated time series. The steady-state measure of performance is defined by:

$$\theta = \lim_{n \to \infty} \frac{1}{n} \sum_{i=1}^{n} Y_i$$

with probability 1, where θ is independent of the initial conditions (Banks et al., 2005).

The sample size *n* (or T_E) is chosen by the simulation analyst with several considerations in mind, including bias in the point estimator from initial conditions, precision of the point estimator as measured by the standard error or confidence interval, and budget constraints on computer resources (Banks et al, 2005).

The point estimator of θ is defined by

$$\hat{\theta} = \frac{1}{n} \sum_{i=1}^{n} Y_i$$

where Y_i is based on the dataset $\{Y_1, ..., Y_n\}$, and $\widehat{\theta}$ is a sample mean based on the sample of size *n*. An unbiased point estimator $\hat{\theta}$ is one in which its expected value is θ as defined by

$$E(\hat{\theta}) = \theta$$

However, real systems do have some amount of bias in its point estimator $\hat{\theta}$. The bias in the point estimator $\hat{\theta}$ is illustrated as

$$E(\hat{\theta}) - \theta$$

For any simulation model, it is desirable to have point estimation with little to no bias.

The sample mean $\overline{Y}$, which is an estimate from a number of independent replications (i.e. from a sample size of n), has an error associated with it that is bounded by a confidence interval. The confidence interval measures the precision of the point estimator and is based on how well the data being produced by the simulation is represented by a probability model (Banks et al., 2005).

There are several ways to reduce the initialization bias in the point estimator of a steady-state simulation. The first method initializes the simulation in a state that is typical of long run conditions. This, however, requires a large data-collection effort and may not be possible to implement if the system being modeled does not exist (i.e. it is a variant of an existing system).

A second method to reduce the bias resulting from initial conditions is to divide each simulation output into two periods: an initialization (transient) period from time 0 to time T_0, and a data collection period from time T_0 to the stopping time $T_0 + T_E$. Since the effect of starting a simulation run in an empty or idle state biases the response variables of interest, the results of the transient period is deleted from the statistical calculations and data collection begins from time T_0 until time $T_0 + T_E$. The time between time 0 and time $T_0$is also known as the warm-up period, after which the transient means, converge to the steady-state mean. The length of T_0 is difficult to determine as too small a transient period may provide biased data in the analysis, while a large transient period may omit useful data from analysis. Additionally, the length of T_E should be long enough to ensure sufficiently precise estimates of steady-state behaviour.

The simulation model in this thesis used the second method to determine the initialization period.

5.4 Length of Simulation Runs

The length of the simulation run was determined by the length of the initial transient period, the appropriate batch size, and the number of data points that are required.

Using Welch's procedure, which is based on making a number of *n* independent replications of the simulation, the length of the warm-up period was determined. Each *r* replication (run) used a distinct stream of random numbers. The procedure includes the following (Law, 2007):

- Perform *n* replications (runs) of the simulation with m observations such that Y_{ji} is the *i*th observation from the *j*th replication. Law recommends using *n* ≥ 5.
- Calculate the averaged process using $\overline{Y}_i = \sum_{j=1}^{n} \frac{Y_{ji}}{n} \; for \; i = 1, 2, \dots, m$. The average process from each replication will have the same mean curve with only $1/n$ th the variance.
- The moving average $\overline{Y}_i(w)$ is then defined to smooth out the high frequency oscillations in $\overline{Y}_i$. This is done as follows:

$$\overline{Y}_i(w) \begin{cases} \dfrac{\sum_{s=-w}^{w} \overline{Y}_{i+s}}{2w+1}, \text{ if } i = 1, \dots, m-w \\ \dfrac{\sum_{s=-(i-1)}^{i-1} \overline{Y}_{i+s}}{2i+1}, \text{ if } i = 1, \dots, w \end{cases}$$

The smallest value of the window w is chosen for which the corresponding plot is reasonably smooth.

- By plotting $\overline{Y_i}(w)$ for $i = 1,2, \dots, m - w$, the length of the transient period is chosen to be the value of *i* beyond which the moving averages appear to have converged.

Several replications of the model were made, initially, to determine variations in the outcome. By examining the result of each trial, the mean average LOS of fast track patients in the system was 342.41, 346.87, 340.70, 336.39, 334.30, and 335.66 minutes if the simulation was run 5, 10, 15, 20, 25 and 30 times, respectively. The standard deviation for the average LOS of fast track patients in the system was 362.46, 364.05, 354.90, 342.83, 337.04, and 341.28 for 5, 10, 15, 20, 25 and 30 replications respectively[22]. Based on this assessment, more replications do not yield outcomes with high variations and only marginally increases the value to the results. Thus, calculations were based on 10 replications.

Successive observations from a single replication are likely to be auto-correlated since the system parameters at the end of one observation period will be the starting parameters for the next observation period (Banks et al., 2005). Thus, the lack of independence leads to a biased estimator.

To resolve this problem, the method of batch means was utilized by dividing the output data of a single, long simulation run into a batch whose means are pseudo-independent. The method of batch means ensures that the data is approximately uncorrelated and that a confidence interval can be obtained. Through trial and error, the raw data output were batched in intervals of 1440 minutes or 1 day.

---

[22] Randomness and variability strongly influence queuing and system congestion (Banks et al., 2005). For many queuing systems, such as an ED, the standard deviation of a performance measure may be a bit greater than the mean. This indicates that the values in the dataset are highly variable.

The length of each replication, beyond the deletion point, should be at least ten times the amount of data deleted (Banks et al., 2005). The length of each replication was determined to be 145,440 minutes, which was large enough to provide reasonable estimates of the steady-state behaviour of the system. Hence, each replication consisted of 100 batches of data, where the average for each batch Y_{rj} was calculated. Y_{rj} is the *j*th batch mean for replication *r*.

The 100 batch means for the 10 replications are shown in Appendix E, with columns representing each replication and rows indicating the batch number. The batch means for each replication were plotted, as shown in Appendix G. The curves demonstrate the nature of queuing systems. In other words, the length of stay in the fast track system is shown to be highly variable.

To identify the initialization bias in the data, the corresponding batch means across replications were averaged and plotted. Such averages are known as ensemble averages (Banks et al., 2005). The ensemble average across all 10 replications for each batch *j* was defined by

$$\bar{Y}_{.j} = \frac{1}{R}\sum_{r=1}^{R} Y_{rj}\,, R = 10; j = 1, \dots, 100$$

The ensemble batch means are shown in Appendix F and plotted in Figure 5.1. The downward bias in these estimators may be due to the system being empty and idle at time 0. However, as time increases, the observations appear to vary around a common mean. At this point, the data collection phase started after terminating the initial period (i.e. first 2880 minutes). Data was collected for 100 days beyond the initial period.

For comparison purposes, cumulative average sample means were calculated and plotted against the ensemble average batch means. By deleting *d* observations out of a total of *n* observations, the cumulative averages were computed by

$$\bar{Y}_{..(n,d)} = \frac{1}{n-d}\sum_{j=d+1}^{n} \bar{Y}_{.j}, d = 0, 1, 2; n = 10; j = 1, \dots, 100$$

The summary of ensemble batch means and cumulative means, averaged over 10 replications is summarized in Appendix F. The cumulative averages with zero, one and two deletion of batch means is shown in Figure 5.2. The initial bias from the warm-up period can also be observed. By deleting the first batch, most of the bias was eliminated and thus the warm-up period was defined as 2880 minutes.

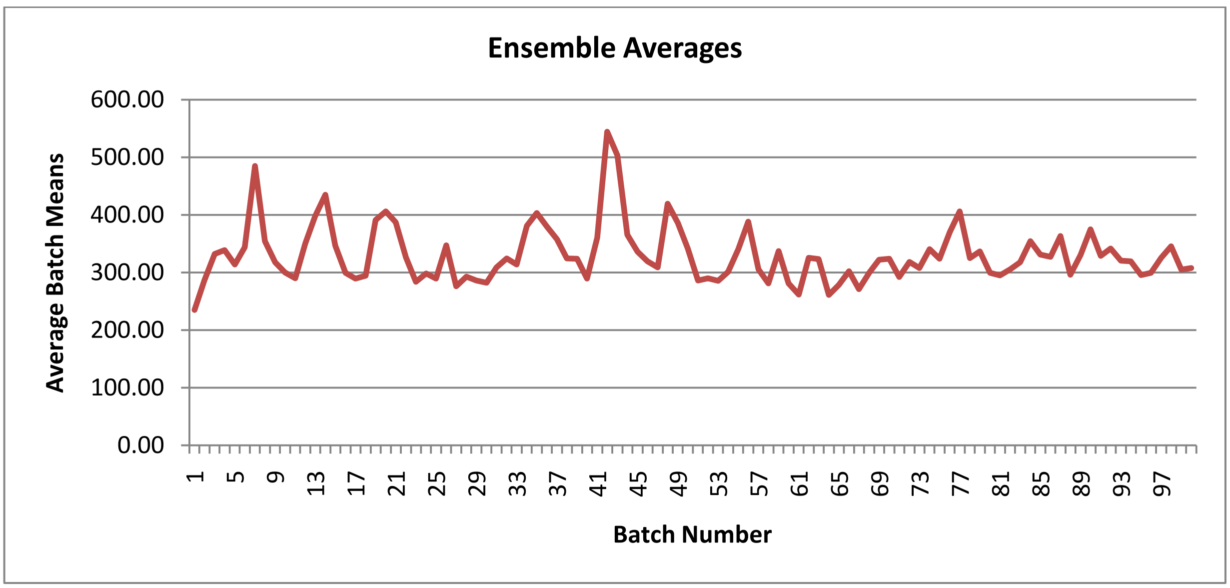


Figure 5.1: Ensemble Averages (100 batches)

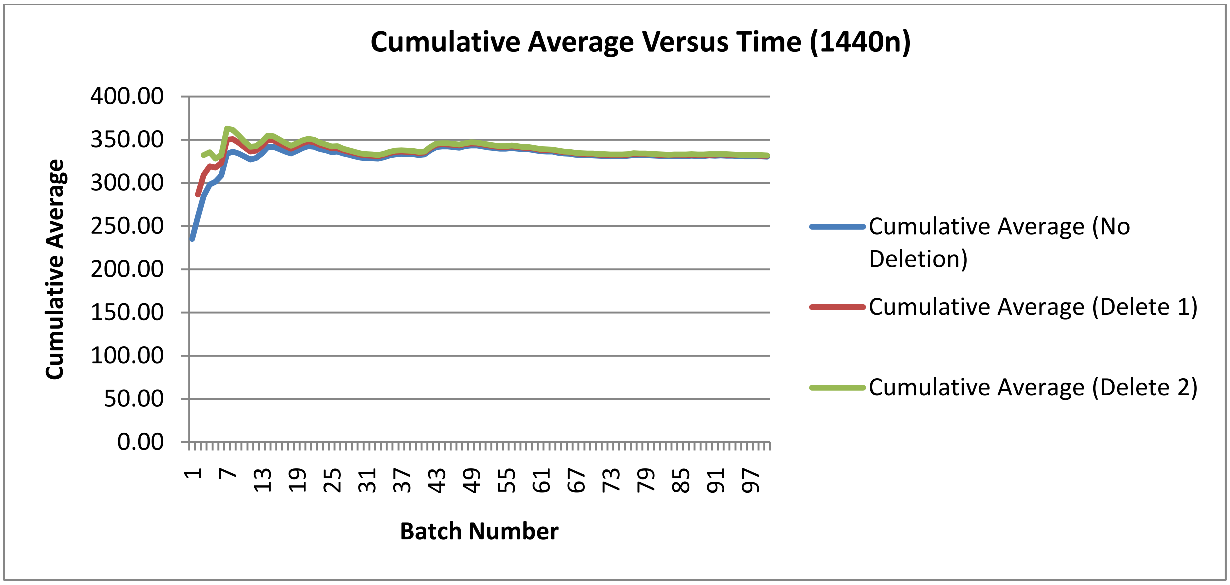


Figure 5.2: Cumulative Average Length of Stay Versus Time 1440n

5.5 Method of Independent Replications

Once the initialization bias was reduced in the point estimator, the method of independent replications was used to estimate the variability in the point estimator by constructing a confidence interval of the point estimate (Banks et al., 2005).

The simulation was repeated a total of 10 times (R = 10), each using a different random number stream. Each replication was regarded as a single sample in order to estimate θ. When the number *d* of deleted observations and the total number of observations *n* were sufficiently large, then $\theta_{n,d} \approx \theta$, and $\bar{Y}_{..}(n,d)$is an approximately unbiased estimator of θ. The replications were then used to construct a 95% confidence interval for the performance measure θ. To estimate the standard error of the overall point estimator $\bar{Y}_{..}(n,d)$, the sample variance was computed by

$$S^2 = \frac{1}{R-1}\sum_{r-1}^{R} \bar{Y}_{r.} - \bar{Y}_{..}^{\ 2}$$

where $\bar{Y}_{r.}$ is the mean of the undeleted observations from the *r*th replication, and $\bar{Y}_{..}$ is the mean of $\bar{Y}_{1.}$, ..., $\bar{Y}_{R.}$. The standard error of $\bar{Y}_{..}$ was given by

$$s.e.(\bar{Y}_{..}) = \frac{S}{\sqrt{R}}$$

Based on the *t* distribution, a 100(1 - α)% confidence interval for θ was given by

$$\bar{Y}_{..} - t_{\alpha/2,R-1}\frac{S}{\sqrt{R}} \leq \theta \leq \bar{Y}_{..} + t_{\alpha/2,R-1}\frac{S}{\sqrt{R}}$$

Where $t_{\alpha/2,R-1}$ is the $100(1-\alpha/2)$ percentage point of a *t* distribution with R – 1 degrees of freedom and is valid only if the bias of $\bar{Y}_{..}$ is approximately zero.

The results of the replication method are summarized in Table 5.1. In addition to the warm-up period observations, the replication sample mean of the data is shown in the second column. The fourth column shows the replication sample means of the data that excludes the warm-up period observations. Also presented in the table are the sample variance and standard error of the results in both columns.

Using $\alpha = 0.05$ and $t_{0.025,9} = 2.26$, the 95% confidence interval for the long-run mean length of stay is:

$$331.68 - 2.26(8.44) \leq \theta \leq 331.68 + 2.26(8.44)$$

Or

$$312.61 \leq \theta \leq 350.75 \text{ minutes}$$

With a high degree of confidence, it can be concluded that the long-run mean length of stay is between 312.61 minutes and 350.75 minutes. The confidence interval from the simulation containing data from the warm-up period would be:

$$330.27 - 2.26(8.35) \leq \theta \leq 330.27 + 2.26(8.35)$$

Or

$$311.40 \leq \theta \leq 349.14$$

Based on these two confidence intervals, it can be shown that including the initialization period in the calculations shifts the confidence interval slightly downwards, which is reflected in the downward bias in the initial observations.

Table 5.1: Data Summary by Replication

Sample Mean for Replication r			
Replication, r	(No Deletion) (100, 0)	(Delete 1) (100, 1)	(Delete 2) (100, 2)
1	342.09	341.82	342.04
2	319.85	320.55	321.39
3	365.51	366.98	367.08
4	286.25	287.08	287.36
5	299.89	300.36	300.96
6	366.25	368.00	369.26
7	316.51	317.55	318.25
8	338.18	339.43	339.97
9	320.89	321.41	322.12
10	347.25	349.09	348.41
$\bar{Y}_{..}$	330.27	331.23	331.68
S^2	697.05	714.23	711.84
S	26.40	26.73	26.68
$s.e.(\bar{Y}_{..})$	8.35	8.45	8.44

5.6 Experimental Design

The experimental design allows a systematic means of testing the impact of various factors on performance measures. An important part of the design is choosing the experimental *factors* and the *responses* that one wants to measure. The first refers to the input parameters of the model, while the latter refers to the performance measures of interest (as discussed in Section 5.2). This section outlines the factors and their various values, or *levels*, used in the simulation model. The input parameters for the simulation model are thoroughly discussed in Section 4.4.

Several factors may affect the experimental output. The purpose of the experimental design in a simulation experiment is to determine which factors have the greatest effect on a response. Traditionally, the one-factor-at-a-time (OFAT) approach was used to examine how each factor affects the response. This strategy is both inefficient in obtaining a specified precision and does not measure any interactions (Montgomery, 2005). Both of these issues are resolved by using factorial designs, where the effects of multiple factors on the response as well as interactions are measured. The following are experimental design terminology (Law, 2007):

- **Factors:** The input parameters and structural assumptions composing a model. This thesis uses qualitative, controllable factors.
- **Levels:** The various values of a chosen factor that is studied during the simulation experiment.
- **Response:** The output performance measures.
- **Design points:** The possible factor-level combinations; also known as system configurations and scenarios.

Full factorial and fractional factorial designs are both useful in the early stages of experimentation. The first provides insight into all possible factor interactions; whereas, the latter screens out an important subset of factors of interest and requires less computational effort than is required by a full factorial design (Law, 2007). This thesis uses three factors with two levels; therefore, analysis will be based on a full factorial design as illustrated in Table 5.2.

The factorial design is represented in tabular form, known as a *design matrix*, as shown in the following table. The matrix reveals the level of each factor for each experimental run, as represented by -1 or "-" for the current, or low level, of a factor, and +1 or "+" for the proposed, or high level. The variable R_i is the value of the response for the ith combination of factor levels.

Table 5.2: 2^3 Factorial Design Matrix

Design Point	Factor 1	Factor 2	Factor 3	Response
1	-	-	-	R_1
2	+	-	-	R_2
3	-	+	-	R_3
4	+	+	-	R_4
5	-	-	+	R_5
6	+	-	+	R_6
7	-	+	+	R_7
8	+	+	+	R_8

The *main effect* of factor *j*, denoted by e_j, measures the average change in the response due to moving factor *j* from its low level to its high level, while holding all other factors fixed. This average is taken over all combinations of the other factor levels in the design (2^{k-1}). The main effect is computed relative to the current design and factor levels only. The expression was obtained by taking the dot product of the "Factor *j*" column with the "Response" column and then dividing by $2^{k-1} = 4$ (Law, 2007).

The main effect of each factor is also shown in the following equations.

$$e_1 = \frac{(R_2 - R_1) + (R_4 - R_3) + (R_6 - R_5) + (R_8 - R_7)}{4}$$

$$e_2 = \frac{(R_3 - R_1) + (R_4 - R_2) + (R_7 - R_5) + (R_8 - R_6)}{4}$$

$$e_3 = \frac{(R_5 - R_1) + (R_6 - R_2) + (R_7 - R_3) + (R_8 - R_4)}{4}$$

The effect of one factor may depend on the level of some other factor. This is known as an *interaction effect*. The two-factor interaction effect 1x2, 1x3, and 2x3 and the three-factor interaction effect 1x2x3 are not included in the design matrix. To determine the effects of interacting factors, the ith signs from the columns for factors 1 and 2, 1 and 3, and 2 and 3 are multiplied, respectively, for the two-factor interactions; the ith signs from the columns for factors 1, 2 and 3 are multiplied for the three-factor interaction (Law, 2007).

In this thesis, factors 1, 2 and 3 were determined to be physician availability, See-and-treat, and an additional emergency nurse practitioner (ENP), respectively.

Using the design matrix in Table 5.2, design point 1 provides a baseline for subsequent comparisons. It represents the current fast track operations in which equal physician availability is given to both the fast track and main department treatment areas, there is no implementation of See-and-treat, and no additional ENP. Design points 2, 3 and 5 test for the main effects of factors 1, 2 and 3, respectively. Design point 4 test for higher physician availability and implementation of See-and-treat in the fast track system. The physician availability and additional ENP are tested in design point 6. The implementation of See-and-treat and an additional ENP are tested in design point 7. Finally, all three factors are tested in design point 8. The thesis studies how these factors affect the expected average length of stay and the queue length for initial assessment. The low and high levels chosen for these factors are given in the coding chart in Table 5.3.

Table 5.3: Coding Chart for Factors 1, 2 and 3 in the Fast Track Model

Factor	"-"	"+"
1	Equal MD availability to fast track and main dept. Area	Higher MD availability/presence in fast track area
2	No See-and-treat	See-and-treat
3	No additional ENP	Additional ENP

5.7 Summary

This chapter described the experimental design of the stochastic discrete-event simulation. The appropriate measures of performance were determined to include the fast track patients' lengths of stay in the ED and queue length for a primary initial assessment. By using both, it is possible to determine which operational strategy results in reduced patient wait times.

By assessing the random variability of the simulation output data, point estimates were obtained with some degree of reliability. The length of each simulation run was determined to be

145,440 minutes (~100 days beyond the transient period) with a warm-up period of 2,880 minutes (~2 days) to remove the effects of the initial transient period. Each scenario will be replicated 10 times, yielding 100 observations for each replication.

A full factorial design was used to vary the following three factors:

- Factor 1: physician availability in fast track,
- Factor 2: implementation of the See-and-treat model in fast track, and
- Factor 3: additional emergency nurse practitioner in fast track.

With factor level settings representing the current and proposed operational policies. This resulted in 8 different scenarios to be explored in order to specify the optimal operating policy for the fast track system. A total of 80 distinct experiments will be conducted. The following Chapter 6 presents the output analysis of the experiments.

Chapter 6: Output Data Analysis

The results of the simulation runs are presented and analyzed in this chapter. The output analysis was used to compare alternative designs for the fast track system at GRH ED. Also presented in this chapter are the relevant statistical methods that were used. The average length of stay for patients in the fast track system is quantified in tables shown in Appendix H.

An examination of the existing fast track management scenario is made, followed by an investigation of operational design alternatives, in order to improve current performance measures, including:

- Reduction of patient queues for initial assessment
- Reduction of total length of stay

A number of replications were performed on each scenario using common random numbers to obtain a series of observations for examination. The warm-up period for each replication was excluded in the output analysis.

6.1 Hypotheses

Several of the concepts put forward in this section are based upon McClave and Sincich (2009). When selecting and testing samples, and statistically analyzing test results, a comparison is made between two populations. Two alternative possibilities result from the comparison. The null hypothesis (H_O) states that no essential difference exists between the performance measures in the two populations. The alternative hypothesis (H_a) states that a significant difference exists between the performance measures of the two populations. The present thesis uses hypothesis testing to determine which of the two is the better population in terms of improving performance measures; μ_0 is defined as the baseline population to which all proposed design populations were compared.

The hypotheses are summarized and formally stated as follows:

1. The null hypothesis (H_O: $\mu_0 = \mu_1$) states that there is no change in performance measures when a physician allocates a higher priority to fast track. The alternative hypothesis ($\mu_0 < \mu_1$) states that a higher physician presence within fast track improves performance measures. Given that physicians have a wider scope of practice than an ENP, increasing physician presence i.e. availability to the fast track system, would allow for a greater number of patients seen and treated in a timely manner, thereby decreasing the overall average length of stay for patients in fast track.
2. The null hypothesis (H_O: $\mu_0 = \mu_2$) states that there is no change in performance measures when implementing the See-and-treat model within fast track. The alternative hypothesis ($\mu_0 < \mu_2$) states that See-and-treat implementation within fast track improves performance measures. See-and-treat is expected to decrease patient wait times as patients would be seen by a primary care provider right away.
3. The null hypothesis (H_O: $\mu_0 = \mu_3$) states that there is no change in performance measures when adding an additional emergency nurse practitioner in the fast track system. The alternative hypothesis ($\mu_0 < \mu_3$) states that an additional ENP improves performance measures within fast track. Adding an ENP would allow for a greater number of patients, those that are within the ENP's scope of practice, to be seen and treated in a timely manner. This will help in decreasing the average length of stay for patients in fast track and reduce the number of patients queuing for an initial assessment.

4. Finally, the null hypothesis (H_O: $\mu_0 = \mu_{12}$, $\mu_0 = \mu_{13}$, $\mu_0 = \mu_{23}$, and $\mu_0 = \mu_{123}$) states that there is no change in performance measures when combining the high level experimental factors. The alternative hypothesis ($\mu_0 < \mu_{12}$, $\mu_0 < \mu_{13}$, $\mu_0 < \mu_{23}$, and $\mu_0 < \mu_{123}$) states that the combination of changing the experimental factors to a high level improves performance measures within fast track. The combination of changing all the experimental factors to a high level would induce a reduction in patient wait times and also queue length for initial assessment.

6.2 Results and Analysis

The simulation results are examined in this section. A detailed statistical analysis is also illustrated. The model ran for 145,440 minutes, from which the first 2,880 minutes or warm-up period, was deleted to observe the model exclusively at steady state. The response recorded was the average time a patient spent in the fast track system. The response for each day in the 100-day batch (rows) and for each replication (column) was recorded in the tables in Appendix H. Throughput was not considered, since it will approximately be 160 patients per day with any well-defined system configuration. In other words, the arrival of patients is stable in the long run.

6.2.1 Experimental Results

The complete design matrix for the 2^3factorial design and its eight different design points can be found in Table 5.2**.** There are three factors, each with the “-”, or low level, representing the current situation, and the “+”, or high level, representing the proposed system design in terms of improving performance measures. All three factors are qualitative and described in Table 5.3.

The entire design was replicated $n = 10$ times to produce confidence intervals on the expected effects. In total, there were 80 simulation runs for the experiment with common random numbers (CRN) used across all eight design points. CRN uses the same random numbers to simulate and compare alternative system configurations "under similar experimental conditions" (Law, 2007). This ensures that any observed differences in performance measures are due to differences in system configuration rather than fluctuations of the experimental conditions (Law, 2007).

The simulation results for the full factorial design are illustrated in Table 6.1. The sample mean and variance of the responses R_i across the 10 replications for each of the eight design points is shown in Table 6.2.

Table 6.1: Simulation Results for the 2^3 Factorial Design for the Fast Track Model (in minutes)

	Response (R) of Replication *r* for Scenario *i*									
Scenario	**R(1, i)**	**R(2, i)**	**R(3, i)**	**R(4, i)**	**R(5, i)**	**R(6, i)**	**R(7, i)**	**R(8, i)**	**R(9, i)**	**R(10, i)**
1	348.37	309.58	372.77	286.64	304.83	378.50	300.46	326.97	325.22	350.40
2	285.85	279.87	300.35	264.64	284.91	330.24	279.24	260.27	287.99	290.78
3	343.05	308.13	363.67	285.30	302.57	376.12	301.67	326.28	326.10	347.08
4	285.03	275.06	294.19	259.44	279.83	328.06	271.59	256.31	285.77	286.18
5	327.40	297.86	334.68	279.32	295.06	357.73	292.67	299.40	319.36	322.45
6	281.99	277.25	293.51	261.72	284.05	323.69	273.84	256.65	285.33	284.21
7	319.09	295.10	330.07	275.36	296.03	354.61	291.87	293.75	315.70	322.05
8	279.56	272.79	295.14	258.60	278.27	323.26	270.16	252.38	283.42	283.01

Table 6.2: Sample Means and Variances of the Responses for the Fast Track Model (in minutes)

Design Point	Sample Mean	Sample Variance
1	330.37	974.32
2	286.41	376.74
3	328.00	860.38
4	282.15	404.54
5	312.59	565.60
6	282.23	336.98
7	309.36	539.91
8	279.66	388.09

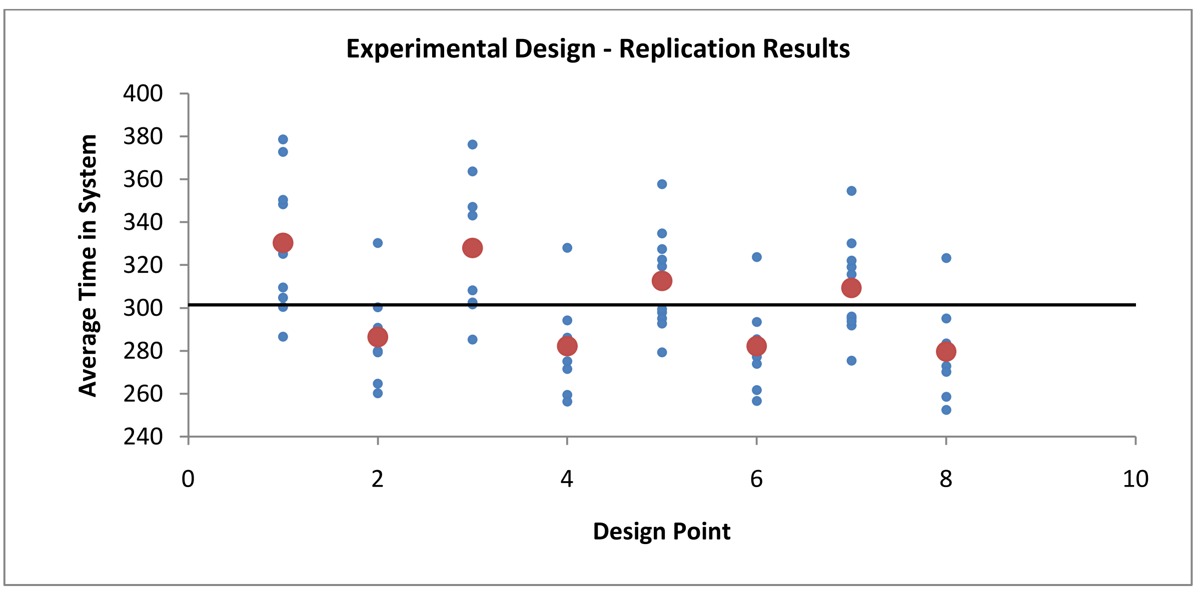


Figure 6.1: Experimental Design for Fast Track – Individual Replication and Average-Over-Replications Results

Figure 6.1 plots the responses from the 10 individual replications (in minutes) as the small dots, distributed vertically over each design point. The large dots show the average of the 10 replications at each design point. The horizontal line provides the overall average of all of the responses – i.e., the average of all 80 individual-replication results. Several observations were made directly from this graph:

- Increasing the physician's availability or presence in the fast track system (factor 1) produces an improvement of approximately 45 minutes compared to the baseline (design point 1), as shown in design points 2, 4, 6 and 8[23].
- The results from implementation of the See-and-treat model (design point 3) are comparable to those from the baseline – or current – operating model (design point 1). Thus it appears that eliminating the nurse secondary assessment in order to implement See-and-treat within fast track produces an insignificant effect since it does not change the response by an appreciable amount (i.e. less than 5 minutes).
- Adding another ENP to fast track (factor 3) in design point 5 produces a minor improvement of approximately 15 minutes in comparison to the baseline model (design point 1). However, this improvement becomes less significant (less than 5 minutes) when implemented in combination with factor 1 (i.e. comparing design points 6 & 2).
- It appears that the combination of adding another ENP and implementing See-and-treat in fast track, design 7, slightly improves the response similarly to design 5 above. The significance of this interaction will be examined in the interaction plots in Section 6.2.5.

---

[23] Confirmed formally with the effects computation.

- All three factors (increasing the physician's availability, implementing See-and-treat, and adding another ENP in fast track) in design 8 improve the performance in the system, thereby reducing patient wait times.
- The variance of the responses between the 10 replications for a particular design point is larger when the average of the 10 responses (large dots) is large – i.e. the variance appears to increase in average response. In other words, the variance is less pronounced when factor 1 is implemented. The sample variances for design points 1 (all factors at the "-" levels) and 8 (all factors at the "+" levels) are 974.3 and 388.1, respectively. Thus, the variance of the response is not constant across the 8 points, which is a fundamental assumption of the analysis of variance (ANOVA[24]).

6.2.2 Effects Analysis

Based on the experimental results, an analysis was performed to estimate how each factor affected the response and also to determine if the factors interact with one another. ANOVA was first considered to determine whether these effects were statistically significant. However, since the population variance of the response was not constant for each design point (refer to Table 6.2), confidence intervals for the expected effects were used instead to confirm the observations from Figure 6.1. The assumption of equal variances underlying ANOVA is oftentimes not observed in simulation modelling (Law, 2007).

To quantify the effects, the whole design was replicated $n = 10$ times to obtain n independent values of each effect. The values were used to form approximate $100(1 - \alpha)$ percent confidence intervals for the expected effects using the t distribution with $n = 1$ degrees of freedom

[24] Analysis of variance, used to determine whether effects are statistically significant, assumes that the response has the same population variance for each design point (Law, 2007).

(df). Using the 10 independent replicates of each of the 7 effects, 98.57% confidence intervals were obtained for both the expected main effects and the expected interaction effects for an overall confidence level of 90 percent: $E(e_1), E(e_2), E(e_3), E(e_{12}), E(e_{13}), E(e_{23})$, and $E(e_{123})$. $E(e_j)$ is the expected main effect for factor j and $E(e_{j_1 j_2})$ is the expected interaction effect between factors j_1 and j_2.

The main effects, two-factor (two-way) interaction effects, and the three-factor interaction effect were calculated for each replication using the expressions given below. The variable R_i for i = 1, 2, ..., 8 is the value of the response when running the simulation with the ith combination of factor levels.

In this thesis, each R_i is the average wait time per day from a single 100-day replication. Independent random number streams were used for each separate replication. The main effects and the interaction effects for each replication were calculated, as follows, and shown in the subsequent table. The main effects are

$$e_1 = \frac{-R_1 + R_2 - R_3 + R_4 - R_5 + R_6 - R_7 + R_8}{4}$$

$$= \frac{-348.47 + 285.85 - 343.05 + 285.03 - 327.40 + 281.99 - 319.09 + 279.56}{4}$$

$$= -51.37 \text{ minutes}$$

$$e_2 = \frac{-R_1 - R_2 + R_3 + R_4 - R_5 - R_6 + R_7 + R_8}{4}$$

$$= \frac{-348.37 - 285.85 + 343.05 + 285.03 - 327.40 - 281.99 + 319.09 + 279.56}{4}$$

$$= -4.22 \text{ minutes}$$

and

$$e_3 = \frac{-R_1 - R_2 - R_3 - R_4 + R_5 + R_6 + R_7 + R_8}{4}$$

$$= \frac{-348.37 - 285.85 - 343.05 - 285.03 + 327.40 + 281.99 + 319.09 + 279.56}{4}$$

$$= -13.57 \text{ minutes}$$

and the interaction effects are

$$e_{12} = \frac{R_1 - R_2 - R_3 + R_4 + R_5 - R_6 - R_7 + R_8}{4}$$

$$= \frac{348.37 - 285.85 - 343.05 + 285.03 + 327.40 - 281.99 - 319.09 + 279.56}{4}$$

$$= 2.60 \text{ minutes}$$

$$e_{13} = \frac{R_1 - R_2 + R_3 - R_4 - R_5 + R_6 - R_7 + R_8}{4}$$

$$= \frac{348.37 - 285.85 + 343.05 - 285.03 - 327.40 + 281.99 - 319.09 + 279.56}{4}$$

$$= 8.90 \text{ minutes}$$

$$e_{23} = \frac{R_1 + R_2 - R_3 - R_4 - R_5 - R_6 + R_7 + R_8}{4}$$

$$= \frac{348.37 + 285.85 - 343.05 - 285.03 - 327.40 - 281.99 + 319.09 + 279.56}{4}$$

$$= -1.15 \text{ minutes}$$

and

$$e_{123} = \frac{-R_1 + R_2 + R_3 - R_4 + R_5 - R_6 - R_7 + R_8}{4}$$

$$= \frac{-348.37 + 285.85 + 343.05 - 285.03 + 327.40 - 281.99 - 319.09 + 279.56}{4}$$

$$= 0.34 \text{ minutes}$$

Based on these calculations, the average effect of raising the physician's availability to fast track from a low to high level was to decrease the wait times by the greatest magnitude (51.37 minutes), followed by adding another nurse practitioner (13.57 minutes), and then implementing the See-and-treat model in fast track (4.22 minutes).

Therefore, increasing the physician's availability in the fast track system would have the greatest impact on wait time reductions. An additional nurse practitioner and implementing the See-and-treat model would also appear to be preferable in reducing wait times; however, the significance of these main effects and its interaction effect depends on the level of each factor, as will be examined.

Table 6.3 lists the expected main effects and expected interaction effects from each replication. The responses were measured in minutes.

Table 6.3: Sample Means of the Responses for the Fast Track Model

	Replication									
Effects	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
e_1	-51.37	-26.42	-54.50	-20.55	-17.86	-40.43	-22.96	-55.20	-35.97	-49.45
e_2	-4.22	-3.37	-4.56	-3.40	-3.04	-2.02	-2.73	-3.64	-1.73	-2.38
e_3	-13.56	-7.41	-19.40	-5.26	-4.68	-13.41	-6.10	-16.91	-5.32	-15.68
e_{12}	2.59	-1.26	2.29	-0.76	-2.39	0.72	-2.93	-0.48	-0.34	-0.52
e_{13}	8.90	4.96	16.45	3.37	3.47	7.73	2.69	13.14	2.81	10.81
e_{23}	-1.15	-0.24	3.07	-0.13	0.63	0.25	0.49	-1.32	-1.05	1.58
e_{123}	0.34	0.41	0.83	1.18	-0.98	0.62	1.50	1.16	1.21	0.12

6.2.3 Multiple Comparisons

The multiple-comparisons problem arises whenever there is a comparison of several system designs. The Bonferroni approach resolves the problem by constructing a confidence interval with a probability that all k confidence intervals simultaneously contain their respective true measures as illustrated in the Bonferroni inequality shown below (Law, 2007):

$$P(\mu_s \epsilon\ I_s for\ all\ s = 1, 2, \dots, k) \geq 1 - \sum_{s=1}^{k} \alpha_s$$

where $\sum_{s=1}^{k} \alpha_s$ is the overall error probability.

In this thesis, there are $c = k - 1$ confidence intervals, each constructed at level $1 - \alpha/(k - 1)$. Table 5.2 defines $k = 8$ different factor combinations for the fast track system. The first combination is the current design, and the other seven designs are considered as possible alternatives to compare to the baseline model.

In order to make several confidence interval statements at once (i.e. $c = 7$ intervals to construct), the individual levels were adjusted upward at level 98.57 percent to yield an overall confidence level of at least 90 percent $(1-\alpha)$. If the confidence interval of a particular effect contains zero, there is no statistical evidence that the effect is real. A confidence interval that does not contain zero thus suggests that there is an effect. Table 6.4 and Table 6.5 present the confidence intervals for the expected effects.

Table 6.4: 98.57 Percent Confidence Intervals for the Expected Main Effects (in minutes), Fast Track Model

Expected Main Effect	**98.57 percent confidence interval**
$E(e_1)$	-37.47 $\pm$ 11.42
$E(e_2)$	-3.11 $\pm$ 0.71
$E(e_3)$	-10.77 $\pm$ 4.33

Table 6.5: 98.57 Percent Confidence Intervals for the Expected Interaction Effects (in minutes), Fast Track Model

Expected Interaction Effect	**98.57 percent confidence interval**
$E(e_{12})$	-0.31 $\pm$ 1.38
$E(e_{13})$	7.43 $\pm$ 3.74
$E(e_{23})$	0.21 $\pm$ 1.05
$E(e_{123})$	0.64 $\pm$ 0.56

These confidence intervals for were plotted in Figure 6.2.

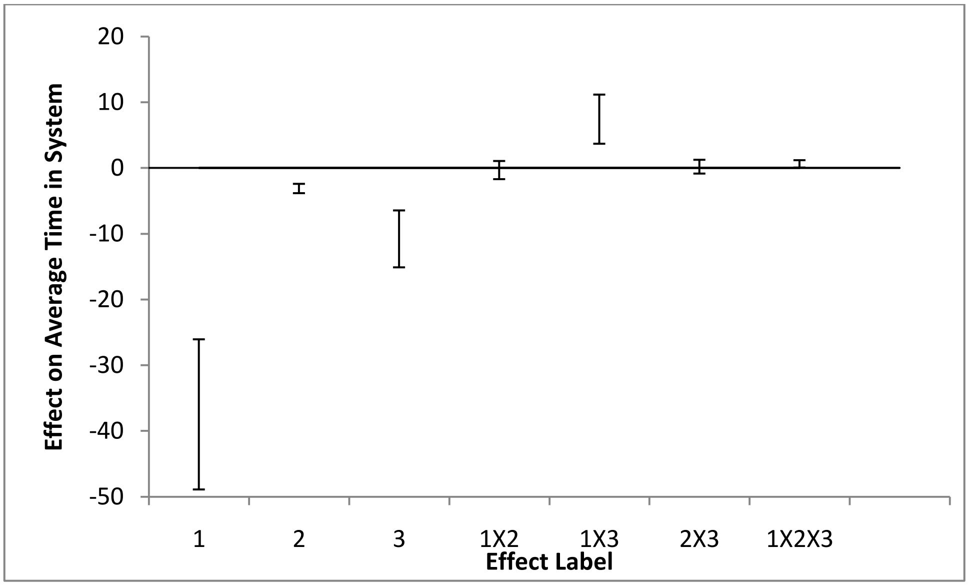
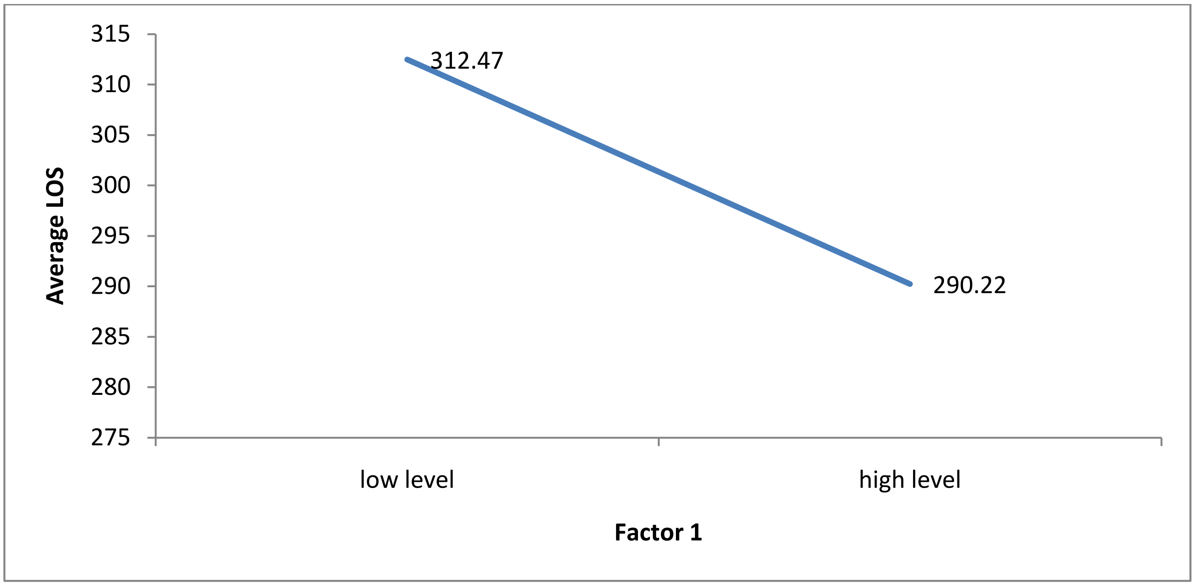


Figure 6.2: Experimental Design for Fast Track: Main Effects and Interactions

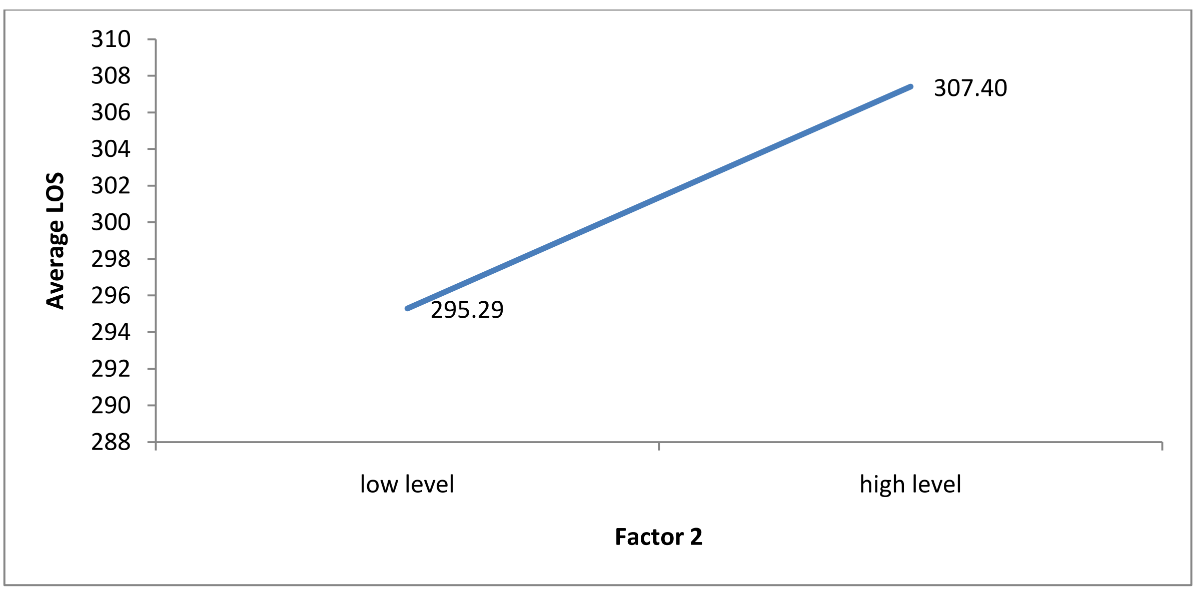
The greatest reduction in average LOS can be obtained by increasing the physician presence in fast track (factor 1). Beyond that, it seems that adding another ENP or implementing the See-and-treat (as specified in Section 4.1.4) would be the next best step. There was only one two-way interaction effect that was statistically significant which was increasing the physician presence and adding another ENP in the fast track system (factors 1 and 3). The significance of this interaction is further examined in the interaction plot, Figure 6.4b. The interactions of 1X2, 2X3, and 1X2X3 are not significant and very small in magnitude.

6.2.4 Main-Effect Plots

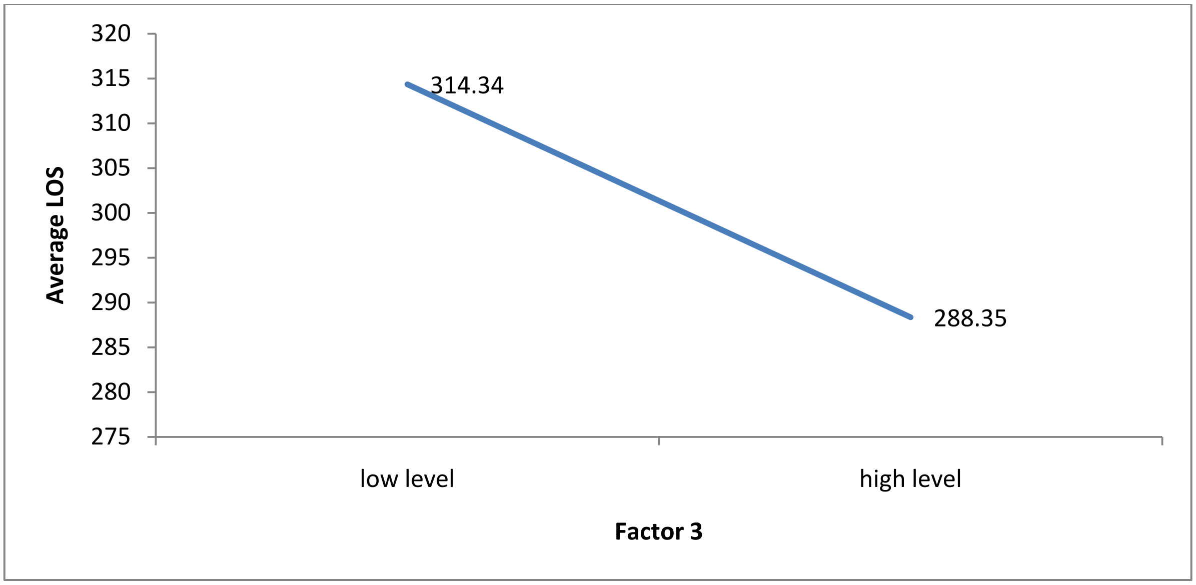
For each plot, the average LOS at a particular level for the factor of interest is the average sample means in Table 6.2 over the two levels of the other factor. Thus, 312.47 in Figure 6.3a is the average of 330.37, 328, 282.15 and 309.36. The main-effect plots for factors 1, 2 and 3 are shown in Figure 6.3.



(a)



(b)



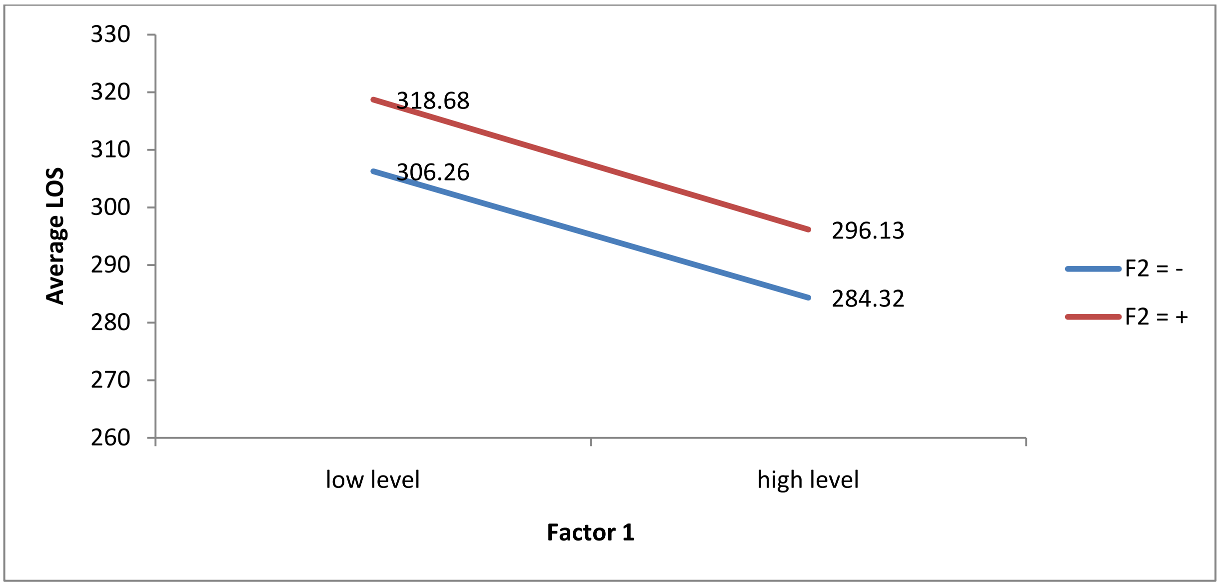
(c)

Figure 6.3: Main-effect Plots for Fast Track Model: (a) Factor 1; (b) Factor 2; (c) Factor 3

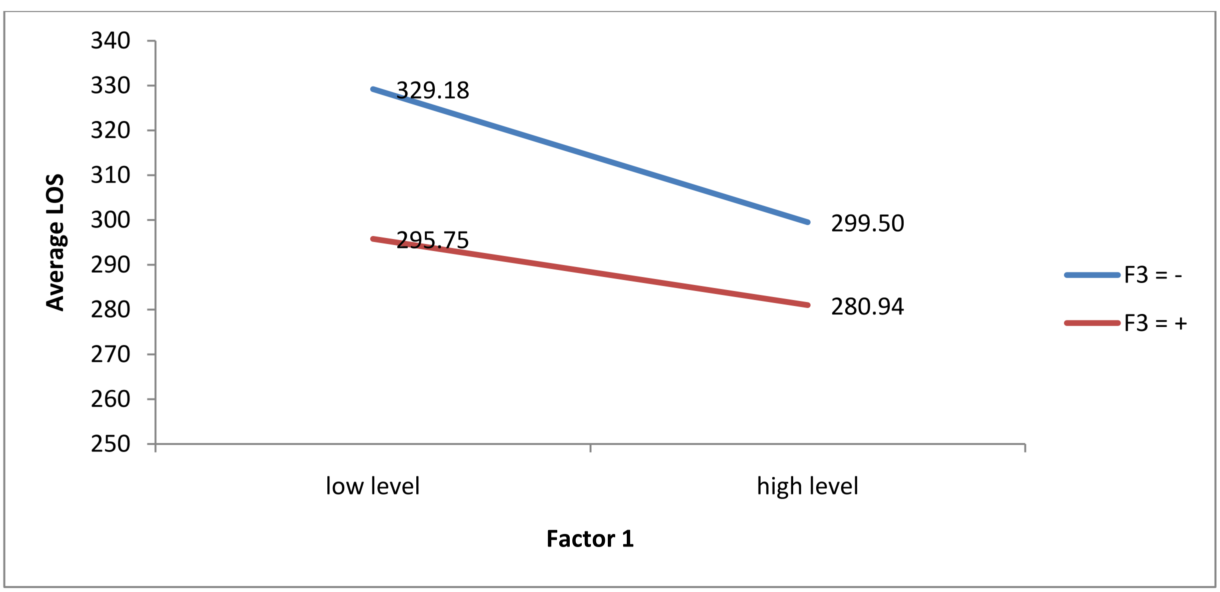
The response, average length of stay (ALOS), decreases as factor 1 and factor 3 moves from its low level setting to its high level setting. That is, in the fast track system, the increased physician presence decreases the ALOS by 22.25 minutes, and the additional ENP decreases the ALOS by 25.99 minutes. However, since there is a significant interaction between factors 1 and 3, these main effects are actually of limited value. Thus, the actual numerical change in the ALOS due to changing factor 1 depends on the level of factor 3, and vice versa. In Figure 6.3b, the response increases as factor 2 moves from its low level setting to its high level setting. That is, the implementation of See-and-treat increases the ALOS by 12.11 minutes.

6.2.5 Interaction Effect Plot

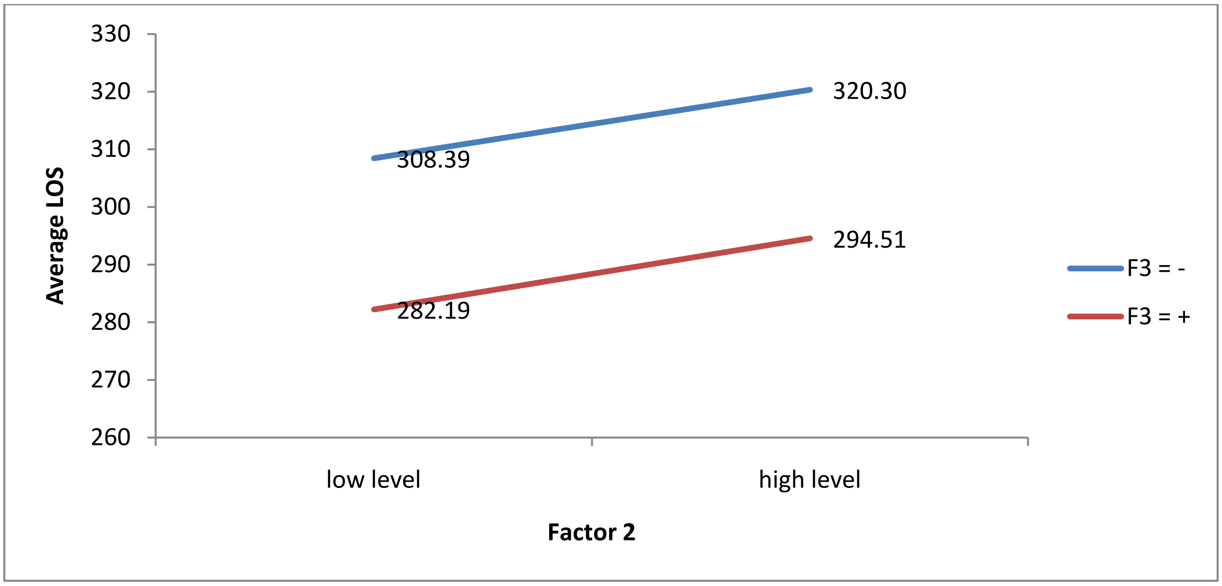
The two-way interaction effect plots for factors 1 and 2 (1X2), 1 and 3 (1X3), and 2 and 3 (2X3) in Figure 6.4 illustrates the significance of the interactions. The three-way interaction plot was not shown since its effect was not significant and was very small in magnitude.



(a)



(b)



(c)

Figure 6.4: Interaction Plots for Fast Track Model: (a) 1X2; (b) 1X3; (c) 2X3

The presence of a significant interaction is indicated by nonparallel lines in the interaction plots. Factors 1 and 2 in Figure 6.4a and factors 2 and 3 in Figure 6.4c do not show a significant interaction, as evidenced by the parallel lines. This means that there is no difference in the change of ALOS when changing the factor of interest over the two levels of the other factor. In Figure 6.4a, increasing the physician availability from a low level setting to a high level setting when See-and-treat is not implemented in fast track (F2 = -) decreases the ALOS by 22.55 minutes which similarly decreases (by 21.94 minutes) when See-and-treat is implemented in fast track (F2 = +). In Figure 6.4c, changing the implementation of See-and-treat from a low level setting (i.e. no implementation) to a high level setting (i.e. implementation) when there is no additional ENP (F3 = -) increases the ALOS by 11.91 minutes which also increases (by 12.32 minutes) when there is an additional ENP (F3 =

+). Conclusively, there is no significant interaction of factors 1 and 2, and of factors 2 and 3, which supports the observations made from Figure 6.2.

In Figure 6.4b, there is a presence of a significant interaction, as evidenced by the nonparallel lines. This means that there is a difference in the change of the response when changing the factor of interest over the two levels of the other factor. Increasing the physician availability from a low level setting to a high level setting when there is no additional ENP (F3 = -) decreases the ALOS by 29.68 minutes which also decreases (by 14.81 minutes) when there is an additional ENP (F3 = +). The difference results when the ALOS decreases by half when changing the physician availability (factor 1) over the two levels of factor 3 (addition of ENP in fast track). The difference is observed in the narrowing of ALOS when both factor 3 levels are at the high level setting of factor 1.

6.2.6 Queue Length – Secondary Performance Measure

To obtain the secondary performance measure, queue length for the initial assessment in the fast track system, a simulation trial was conducted for each design point to obtain a 99 percent confidence interval. By running a trial for the queue length for initial assessment, the long term average of the queue length for initial assessment is reflected in the results. A trial produces a number of concurrent runs that use different random numbers. The highest confidence interval allowed by Simul8® was 99 percent, which was used to obtain the results for the average queue length of each simulation run. The confidence level that the queue length will be between the upper and lower ranges can be expected 99 percent of the time.

The model contained three separate queues where fast tracked patients awaited for an initial assessment. The model labelled these queues for work centres 34, 35, and 36 (i.e. wc34, wc35, and wc36). The difference lies in its resource consumption. The queue for wc34 contain the majority of fast tracked patients where the ENP is the initial point of contact. The reason being that a number of patients may require either a minor or major physician consultation (refer to Section 1.5.1) further downstream the fast track process. The queue for wc35 contain patients that are outside the ENP's scope of practice and hence require a physician for assessment. A very small number of patients present with this case. The queue for wc36 contain patients that can be seen by either the ENP or physician. A small number of patients present with this case also. Of the three queues, the first (wc34) will be thoroughly examined with brief mention of the latter two queues. The results of the trial for each fast track design were recorded in the following table:

Table 6.6: 99 Percent Confidence Intervals for the Expected Queue Length, Fast Track Model

Design 1	99 percent confidence interval
Queue for wc34 Initial Assessment	19.80 ± 3.35
Queue for wc35 Initial Assessment	5.70 ± 1.37
Queue for wc36 Initial Assessment	3.10 ± 0.58
Design 2	
Queue for wc34 Initial Assessment	7.10 ± 1.23
Queue for wc35 Initial Assessment	6.10 ± 1.13
Queue for wc36 Initial Assessment	2.90 ± 0.76
Design 3	
Queue for wc34 Initial Assessment	20.10 ± 3.19
Queue for wc35 Initial Assessment	5.60 ± 1.21
Queue for wc36 Initial Assessment	3.00 ± 0.84
Design 4	
Queue for wc34 Initial Assessment	16.40 ± 2.75
Queue for wc35 Initial Assessment	5.60 ± 1.30
Queue for wc36 Initial Assessment	3.00 ± 0.69
Design 5	
Queue for wc34 Initial Assessment	7.40 ± 1.30
Queue for wc35 Initial Assessment	5.80 ± 1.17
Queue for wc36 Initial Assessment	2.90 ± 0.76
Design 6	

Queue for wc34 Initial Assessment	7.20 $\pm$ 1.44
Queue for wc35 Initial Assessment	5.60 $\pm$1.30
Queue for wc36 Initial Assessment	2.90 $\pm$ 0.76
Design 7	
Queue for wc34 Initial Assessment	16.10 $\pm$ 2.93
Queue for wc35 Initial Assessment	5.70 $\pm$1.29
Queue for wc36 Initial Assessment	3.00 $\pm$ 0.69
Design 8	
Queue for wc34 Initial Assessment	7.30 $\pm$ 1.46
Queue for wc35 Initial Assessment	5.50 $\pm$1.30
Queue for wc36 Initial Assessment	3.00 $\pm$ 0.84

As illustrated in Table 6.6, 99 percent confidence intervals were obtained for patients in queue for an initial assessment in fast track. There is an approximate 99 percent confidence that the expected queue length for initial assessment in fast track will be within the range of the lower and upper values.

Upon closer inspection, the expected queue length for the latter two queues (wc35 and wc36) is consistent across the system designs. That is, there is very little variation in the number of patients waiting for an initial assessment in fast track in these queues due to the fact that there is only a small proportion of fast tracked patients for these particular queues. No further analysis will be given to the queue lengths for wc35 and wc36. On the other hand, the expected queue length for the first queue for initial assessment, wc34, appears to change across the design points.

In comparison to the baseline model (design 1) of the fast track system, the greatest reduction in queue length occurred with the increased physician availability in the fast track system (design 2), with an expected queue length of 7.10. The addition of another ENP within fast track (design 5) decreased the queue length by a similar amount, an expected queue length of 7.40. Implementing See-and-treat (design 3) slightly increased the queue length to 20.10. However, when the See-and-treat was implemented alongside either the increased physician availability (design 4) or the addition of another ENP (design 7), the expected queue length decreased to 16.40 and 16.10, respectively.

It is interesting to note that, by itself, increasing the physician's presence or adding another ENP to fast track resulted in the similar queue length reductions; however, when both the increased physician presence and additional ENP are implemented in fast track (design 6), the expected queue length (7.20) is similar to when both factors are implemented by itself. The same is observed when all three policies are implemented within fast track (design 8). That is, the queue length decreased to 7.3. This indicates that having both a higher physician presence and an additional ENP may not be necessary in reducing the queue length for initial assessment. Before any conclusions are drawn, however, consideration should be given to its cost and benefit, which is outside the scope of the thesis.

Also noted is that, although the expected queue length decreased in designs 4 and 7 to 16.40 and 16.10, respectively, the interacting factors in these designs are insignificant. That is, increasing physician availability and eliminating the nurse secondary assessment for See-and-treat (design 4), and an extra ENP with implementing See-and-treat (design 7) help decrease the queue length for initial assessment but did not assist in reducing overall wait times, which is the primary performance measure.

These observations correspond to the conclusions that were reached from analyzing the main effects. The effect of having a higher physician presence in fast track greatly reduces the response for wait time and queue length, followed by the effect of an additional ENP. The effect of having both, however, does not change the queue length by a significant amount even though there is an interaction effect.

6.2.7 Resource Utilization

The expected utilization of the resource is the proportion of the resource's available time spent working. The same methodology that was used to obtain the secondary performance measure, queue length for the initial assessment in the fast track system, was also used to obtain the expected percent utilization of ED resources. Table 6.7 illustrates the 99 percent confidence intervals for the expected percent utilization of ED resources, with particular attention to the resources in fast track, in all eight system designs. The three listed resources are:

- Main Dept Emerg MD – the ED physician(s) assigned to assess and treat patient group 29 (refer to Section 4.3),
- MT Emerg MD – the ED physician assigned to assess and treat fast tracked patients, and
- Emerg NP – the emergency nurse practitioner (ENP) in fast track.

Table 6.7: 99 Percent Confidence Intervals for the Expected Utilization (%) of ED Resources, Fast Track Model

Design 1	**99 percent confidence interval**
Main Dept Emerg MD	83.61 ± 1.22
MT Emerg MD	88.24 ± 1.28
Emerg NP	66.63 ± 1.74
Design 2	
Main Dept Emerg MD	84.14 ± 1.30
MT Emerg MD	87.51 ± 1.26
Emerg NP	64.88 ± 1.39
Design 3	
Main Dept Emerg MD	83.61 ± 1.25
MT Emerg MD	88.23 ± 1.19
Emerg NP	66.67 ± 1.78
Design 4	
Main Dept Emerg MD	84.10 ± 1.31
MT Emerg MD	87.62 ± 1.17
Emerg NP	78.18 ± 1.20
Design 5	
Main Dept Emerg MD	81.69 ± 1.13
MT Emerg MD	79.73 ± 1.49
Emerg NP	71.95 ± 1.28
Design 6	

Main Dept Emerg MD	82.03 ± 1.17
MT Emerg MD	79.28 ± 1.48
Emerg NP	71.08 ± 1.25
Design 7	
Main Dept Emerg MD	81.66 ± 1.12
MT Emerg MD	79.82 ± 1.50
Emerg NP	72.01 ± 1.33
Design 8	
Main Dept Emerg MD	82.01 ± 1.20
MT Emerg MD	79.24 ± 1.44
Emerg NP	71.17 ± 1.22

Table 6.7 presents 99 percent confidence intervals for the expected percent utilization of the three listed resources. There is an approximate 99 percent confidence that the expected resource utilization will be within the range of the lower and upper values.

As shown in Table 6.7, the main department ED physician is highly and consistently utilized across all system designs. The baseline model is represented in design 1 to which comparisons are made. The fast track-assigned ED physician has a high and consistent utilization in designs 1 through 4. Interestingly, the fast track-assigned ED physician was not any more utilized when that physician`s availability was increased to fast track. The ED physician`s proportion of available time spent working when there was an increased physician availability to fast track (designs 2 and 4) is similar to when there was equal physician availability to both fast track and the main department (designs 1 and 3). This indicates that increasing the ED physician presence or availability to fast track does not increase the proportion of available time that the fast track-assigned ED physician spends working. In terms of utilization, there is no cost to the ED physician to give priority to fast track patients.

However, the fast track-assigned ED physician percent utilization did decrease (by almost 10%) when an extra ENP was also placed in fast track, as shown in designs 5 through 8. The decrease in percent utilization is consistent across these four system designs. It seems that with an additional ENP in fast track, a higher number of patients can be assessed and treated that may not require the fast track-assign ED physician`s attention. This may also explain the increase in the ENP`s percent utilization, designs 5 through 8, when compared to the baseline model, design 1.

6.3 Summary of Analysis

This chapter examined the simulation model output to gain insights into the factors that affect patient wait times, queue length for initial assessment and resource utilization within the fast track system. This was accomplished through the analytical evaluation of the model and the statistical analysis of the simulation results.

The confidence levels were adjusted using the Bonferroni principle to determine the main effects and interaction effects. Based on this analysis, increasing physician presence in fast track (factor 1) had the greatest impact on reducing overall length of stay in the ED (-37.47). Beyond that, adding an extra nurse practitioner (factor 3) also had a large impact on reducing wait times (-10.77). The wait time reduction was not as large as the reduction observed from the increased physician availability to fast track; however, it was larger compared to the implementation of See-and-treat (factor 3) (-3.11).

When the main and interaction effects were plotted in Table 6.2, only one two-way interaction effect was statistically significant. The rest of the interaction were not significant and were also very small in magnitude. The significance of the interaction between increasing the physician presence (factor 1) and adding another ENP (factor 3) in the fast track system was examined in the interaction plot, Figure 6.4b.

The secondary measure of performance, queue length for initial assessment, were consistent with the conclusions reached from the main effects analysis. That is, the effect of having a higher physician presence in fast track greatly reduces the response for both wait time and queue length, followed by the effect of an additional ENP. The effect of having both factors at its high level (i.e. the interaction effect increasing physician presence and an extra ENP in fast track) did not change the queue length by a significant amount even though there was a significant interaction effect shown in Figure 6.2 and Figure 6.4b.

Finally, Table 6.7 revealed that increasing the ED physician presence or availability to fast track did not increase the proportion of available time that the fast track-assigned ED physician spent working. In terms of utilization, there was no cost to the ED physician to give priority to fast track patients. Also, the extra ENP increased the utilization for this resource because of the longer and/or additional shifts added to this role. These observations were consistent with the main effects and queue length analysis about the effect that factor 1 or factor 3 had on the system response.

Chapter 7: Conclusions

7.1 Concluding Remarks

The objective of this thesis was to explore the characteristics of various operational designs in the fast track system and determine an optimal fast track strategy that would reduce patient queuing and consequently, wait times. The objective was accomplished by formulating a simulation model that captured the current operations of the fast track system at Grand River Hospital's emergency department. The model was designed by establishing a patient care pathway for each patient group as well as the amount of resources consumed.

The operational strategies include three factors:

- Increasing physician availability to the fast track system from the main department,
- Implementation of a See-and-treat model variant to the fast track system by eliminating the nurse secondary assessment, and
- An additional ENP on staff in fast track.

The factor levels were defined as having a "low" level and a "high" level setting. Factor combinations were created to examine their mutual effects on the performance measures of:

- Average length of stay in the fast track system, which corresponds to patient wait times;
- Expected queue length for initial assessment in fast track; and
- Resource utilization within the ED.

All three factors were expected to improve the primary performance measure, i.e. decreasing the average length of stay in the fast track system. In total, eight factor combinations were used to test for the best design point that would reduce overall wait times in the ED.

Output analysis was conducted by qualitative observations of the results, and also by statistical comparisons of the various factor combination results. Based on these analyses, it was determined that:

> *Optimizing the number of available resources dedicated to the fast track system improves the average length of stay by reducing the queue length for initial assessment and the total time spent in the ED.*

Wait times were most significantly reduced when there was an increased physician presence/availability towards the fast track system. This had the greatest impact on the total time spent in the ED and also on queue length. The second most significant reduction to the performance measures occurred when an additional ENP was supplemented to the fast track system. Accordingly, the ENP's percent utilization increased.

Combining these two initiatives also produced positive results, as is apparent from the queue lengths illustrated in Table 6.6. The designs that included the increased physician presence in fast track saw improvements in queue length for initial assessment, which is important for timely diagnosis and treatment of ED patients. The designs that included an additional nurse practitioner also saw improvements in queue length.

Implementation of a See-and-treat model variant, by eliminating the nurse secondary assessment to the fast track system, did not produce significant improvements in the performance measures. This may be due to the design of the See-and-treat model within the simulation model that this thesis is based upon. In this thesis, See-and-treat consisted of removing the nurse secondary assessment in the fast track system in order to allow patients to see a primary care provider right away. However, as observed from the simulation results, patient queue remained approximately the same and though the time spent in the ED decreased, the effect of implementing See-and-treat within fast track had the smallest magnitude (3.11 minutes) in comparison with increasing physician availability and adding another ENP in the area (31.47 and 10.77 minutes, respectively).

7.1.1 Performance Metrics

Two different metrics were used to measure and compare the effects of the various system designs. These were the total time in the system and the time to initial assessment within fast track. The first was measured as length of stay (LOS) and the latter was measured as queue length for initial assessment.

Improvements in wait times resulted from increasing the priority that physicians give to fast tracked patients and also by adding another ENP. Each recommendation, on its own, reduced average LOS within fast track and improved queue length for initial assessment. However, when both strategies were implemented together[25], there were no further improvements in the expected queue length for initial assessment.

Based on these observations, it appears that both the physician and ENP have the same effect on the time until the initial assessment, as evidenced by similar reductions in queue length. But when the total LOS metric is taken into consideration, the LOS is shorter when there is increased physician availability in fast track. Clearly, the physician presence within fast track appears to have a larger influence post- initial assessment than an additional ENP. The differential in the LOS for each

[25] This is the two-way interaction effect in design 6.

factor can be attributed to the differing scope of practice between a physician and an ENP. To illustrate, a high number of patients that see an ENP may require a physician consultation, which necessitates physician involvement in that individual patient's visit to the ED.

Further analysis is required to examine the cost effectiveness of increasing the physician presence within fast track as opposed to having an additional ENP on staff. A cost-benefit analysis, as expressed in monetary terms, may also be used to evaluate the efficiency of both strategies. The analysis could also include quantifying the amount of time the physician is required to spend in fast track that would elicit such improvements in wait times. Finally, sensitively analysis may be applied to determine whether the conclusions still hold.

7.2 Model Limitations

Certain assumptions and limitations regarding the simulation model, which if incorporated, may have yielded differing results from those obtained in this thesis. These include, but are not limited to:

1. Patient arrivals were based on the frequency of chief complaints, as illustrated by the various patient groups, rather than on the day of the week or any seasonal factors. There are a number of chief complaints that occur infrequently and also a number that did not correspond to the CEDIS Presenting Complaint List. The groupings of the chief complaints were limited to what could be matched to this list, which may have lead some groups to have an inflated number of patients presenting with a particular complaint.
2. The model did not account for those patients who balk or renege during the queuing process for assessment and/or treatment and vacate the ED. There are times when patients leave against medical advice and this was not accounted for in the simulation model.

3. Only the most common tests ordered for fast tracked patients were considered in the simulation model. These are listed in Sections 4.4.2 and 4.4.3. In reality, there are many tests that may be ordered along with the ones already listed that may lead to consumption of available resources.
4. The fast track model was only staffed with ED physicians, ENPs, and ED nurses. Other healthcare professionals were not included in the simulation model. In reality, however, patients may also require other healthcare specialists for assessment and treatment before being discharged from the ED.
5. It is difficult to collect a reliable number of data points when many patient types and many caregivers are involved, especially for treatment and service times. Based on the interviews with various healthcare providers, estimated distributions were designated for the different treatment and service times. The triangular distribution was used for all treatment times other than the distributions that were listed for laboratory and medical imaging tests in Sections 4.4.2 and 4.4.3. Other distributions, such as Log-normal or Weibull, may have been more appropriate for estimating the time to complete treatment and service, such as the physician initial assessment.

7.3 Future Research

Certain ways in which the research in this thesis could be expanded include, but are not limited to:

1. Refining the model parameters. For example, a distribution of service and treatment times for each patient group in the fast track system may assist administrators in forecasting a more accurate length of stay for patients whose wait times are uncertain.

2. Performing sensitivity analysis to observe how the conclusions of this study change and to quantify these change(s).
3. Using distributions other than the triangular distribution should provide a more accurate estimation of the ED patient's average length of stay in fast track.
4. Modelling the patient where it may change its internal state probabilistically. This better reflects the dynamic nature of the ED. For example, the probability of a patient group getting more or less ill may affect the wait times and total length of stay in the ED.
5. Creating additional conceptual models of staffing levels, and emphasizing the workload that is attributed to each type of staff member within fast track. In this thesis, it appeared that despite the additional nurse practitioner to the fast track team and its improvements in the performance measures, the increased presence of the physician in fast track had the greatest effect the primary performance measure, average length of stay. In this thesis, the only difference between the two resources were service times and scope of practice of each resource. Research is required in order to fully understand how different resource workloads affect wait times in the ED.

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Appendix A

CEDIS Version 1.1 Presenting Complaint List

No.	Code	Presenting complaint list	ICD-10 code	ICD-10 definition
	CV	Cardiovascular (000-050)		
1	001	Cardiac arrest (nontraumatic)	I46.9	Cardiac arrest, unspecified
2	002	Cardiac arrest (traumatic)	I46.9	Cardiac arrest, unspecified
3	003	Chest pain (cardiac features)	R07.2	Precordial pain
4	004	Chest pain (noncardiac features)	R07.4	Chest pain, unspecified
5	005	Palpitations/irregular heart beat	R00.2	Palpitations
6	006	Hypertension	I10.0	Benign hypertension
7	007	General weakness	R53	Malaise and fatigue
8	008	Syncope/presyncope	R55	Syncope and collapse
9	009	Edema, generalized	R60.1	Generalized edema
10	010	Bilateral leg swelling/edema	R60.0	Localized edema
11	011	Cool pulseless limb	I99	Other and unspecified disorders of circulatory system
12	012	Unilateral reddened hot limb	M79.89	Other specified soft tissue disorders, unspecified
	HN	ENT – Ears (051-100)		
13	051	Earache	H92.0	Otalgia
14	052	Foreign body ear	T16	Foreign body in ear
15	053	Loss of hearing	H91.9	Hearing loss, unspecified
16	054	Tinnitus	H93.1	Tinnitus
17	055	Discharge, ear	H92.1	Otorrhea
18	056	Ear injury	S00.4	Superficial injury of the ear
	HN	ENT – Mouth, throat, neck (101-150)		
19	101	Dental/gum problems	K06.9	Disorder of gingival and edentulous alveolar ridge, unspecified
20	102	Facial trauma	S00.8	Superficial injury of other parts of the head
21	103	Sore throat	J02.9	Acute pharyngitis, unspecified
22	104	Neck swelling/pain	R22.1	Localized swelling, mass and lump, neck
23	105	Neck trauma	S19.9	Unspecified injury of neck
24	106	Difficulty swallowing/dysphagia	R13.8	Other unspecified dysphagia
25	107	Facial pain (nontraumatic/nondental)	R52.0	Acute pain
	HN	ENT – Nose (151-200)		
26	151	Epistaxis	R04.0	Epistaxis
27	152	Nasal congestion/ Hay fever	J31.0	Rhinitis
28	153	Foreign body, nose	T17.1	Foreign body in nostril
29	154	URTI complaints	J06.9	Acute upper respiratory infection, unspecified
30	155	Nasal trauma	S00.3	Superficial injury of the nose
	EV	Environmental (201-250)		
31	201	Frostbite/cold injury	T35.7	Unspecified frostbite of unspecified site
32	202	Noxious inhalation	T59.9	Toxic effects of gases, fumes and vapours, unspecified
33	203	Electrical injury	T75.4	Effects of electric current
34	204	Chemical exposure	T65.9	Toxic effect of unspecified substance
35	205	Hypothermia	T68	Hypothermia
36	206	Near drowning	T75.1	Drowning and nonfatal submersion
	GI	Gastrointestinal (251-300)		
37	251	Abdominal pain	R10.4	Other and unspecified abdominal pain
38	252	Anorexia	R63.0	Anorexia
39	253	Constipation	K59.0	Constipation
40	254	Diarrhea	K52.9	Noninfective gastroenteritis and colitis, unspecified
41	255	Foreign body in rectum	T18.5	Foreign body in anus and rectum
42	256	Groin pain/mass	R190	Intra-abdominal and pelvic swelling, mass and

				lump
43	257	Vomiting and/or nausea	R11.8	Other and unspecified nausea and vomiting
44	258	Rectal/perineal pain	K62.8	Other specified diseases of anus and rectum
45	259	Vomiting blood	K92.0	Hematemesis
46	260	Blood in stool/melena	K92.1	Melena
47	261	Jaundice	R17	Unspecified jaundice
48	262	Hiccoughs	R06.6	Hiccoughs
49	263	Abdominal mass/distension	R19.0	Intra-abdominal and pelvis swelling, mass and lump
50	264	Anal/rectal trauma	S36690	Injury NOS of rectum, without open wound into cavity
51	265	Oral/esophageal foreign body	T18.1	Foreign body in esophagus
52	601	Feeding difficulties in newborn	F98.2	Feeding disorder of infancy and childhood
53	602	Neonatal jaundice	P59.9	Neonatal jaundice, unspecified
	GU	Genitourinary (301-350)		
54	301	Flank pain	R10.3	Pain localized to other parts of the lower abdomen
55	302	Hematuria	R31.8	Other and unspecified hematuria
56	303	Genital discharge/lesion	R36	Penile discharge, urethral
57	304	Penile swelling	N488	Other specified disorders of penis
58	305	Scrotal pain and/or swelling	N50.8	Other specified disorders of male genital organs
59	306	Urinary retention	R33	Retention of urine
60	307	UTI complaints	R39.8	Other unspecified symptoms and signs involving the urinary system
61	308	Oliguria	R34	Anuria and oliguria
62	309	Polyuria	R35.8	Other and unspecified polyuria
63	310	Genital trauma	S30.2	Contusion of external genital organs
	MH	Mental health and psychological issues (351-400)		
64	351	Depression/suicidal/deliberate self harm	F32.9	Depressive episode, unspecified
65	352	Anxiety/situational crisis	F41.9	Anxiety disorder, unspecified
66	353	Hallucinations/delusions	R44.3	Hallucinations, unspecified
67	354	Insomnia	G47.0	Disorders of initiating and maintaining sleep
68	355	Violent/homicidal behaviour	R45.6	Physical violence
69	356	Social problem	Z60.9	Problems related to social environment, unspecified
70	357	Bizarre behaviour	R46.2	Strange and inexplicable behaviour
71	608	Concern for patient's welfare	T74.1	Physical abuse
72	607	Paediatric disruptive behaviour	F91.9	Conduct disorder
	NC	Neurologic (401-450)		
73	401	Altered level of consciousness	R41.88	Other and unspecified symptoms and signs involving cognitive function and awareness
74	402	Confusion	R41.0	Disorientation
75	403	Vertigo	R42	Dizziness and giddiness
76	404	Headache	R51	Headache
77	405	Seizure	R56.8	Other and unspecified convulsions
78	406	Gait disturbance/ataxia	R26.88	Other and unspecified abnormalities of gait and mobility
79	407	Head injury	S09.9	Unspecified injury of head
80	408	Tremor	R25.1	Tremor, unspecified
81	409	Extremity weakness/symptoms of CVA	I64	Stroke, not specified as hemorrhage or infarction
82	410	Sensory loss/ parathesias	R44.8	Other and unspecified symptoms and signs involving general sensations and perceptions

83	609	Floppy child	P94.8	Other disorders of muscle tone of newborn
	GU	Obstetrical-Gynecological (451-500)		
84	451	Menstrual problems	N92.6	Irregular menstruation, unspecified
85	452	Foreign body, vagina	T19.2	Foreign body in vulva and vagina
86	453	Vaginal discharge	N89.8	Other specified noninflammatory disorders of vagina
87	454	Sexual assault	T74.2	Sexual abuse
88	455	Vaginal bleed	N93.9	Abnormal uterine and vaginal bleeding, unspecified
89	456	Labial swelling	R22.9	Localized swelling, mass and lump, unspecified
90	457	Pregnancy issues <20 wk	O28.80	Other abnormal findings in antenatal screening of mother
91	458	Pregnancy issues >20 wk	026.903	Pregnancy-related condition, unspecified
92	460	Vaginal pain/itch	N94.8	Other specified conditions associated with female genital organs and menstrual cycle
	EC	Ophthalmology (501-550)		
93	502	Chemical exposure, eye	T26.4	Burn of eye and adnexa
94	503	Foreign body, eye	T15.9	Foreign body on external eye, part unspecified
95	504	Visual disturbance	H53.9	Visual disturbance, unspecified
96	505	Eye pain	H57.1	Ocular pain
97	506	Red eye, discharge	H57.9	Disorders of the eye and adnexa, unspecified
98	507	Photophobia	H53.1	Subjective visual disturbances
99	508	Diplopia	H53.2	Diplopia
100	509	Periorbital swelling	H05.0	Acute inflammation of the orbit
101	510	Eye trauma	S05.9	Injury of eye and orbit, part unspecified
102	511	Recheck eye	Z09.9	Follow-up examination after unspecified treatment for other conditions
	OC	Orthopedic (551-600)		
103	551	Back pain	M54.9	Dorsalgia, unspecified
104	552	Traumatic back/spine injury	S39.9	Unspecified injury of abdomen, lower back and pelvis
105	553	Amputation	T14.7	Crushing injury and traumatic amputation of unspecified body region
106	554	Upper extremity pain	M79.60	Pain in limb, upper limb
107	555	Lower extremity pain	M79.61	Pain in limb, lower limb
108	556	Upper extremity injury	T11.9	Unspecified injury of upper limb, level unspecified
109	557	Lower extremity injury	T13.9	Unspecified injury of lower limb, level unspecified
110	558	Joint(s) swelling	M25.49	Effusion of joint, site unspecified
111	605	Paediatric gait disorder/painful walk	R26.88	Other and unspecified abnormalities of gait and mobility
	RC	Respiratory (651-700)		
112	651	Shortness of breath	R06.0	Dyspnea
113	652	Respiratory arrest	R09.2	Respiratory arrest
114	653	Cough/congestion	R05	Cough
115	654	Hyperventilation	R06.2	Hyperventilation
116	655	Hemoptysis	R04.2	Hemoptysis
117	656	Respiratory foreign body	T17.9	Foreign body in respiratory tract, part unspecified
118	657	Allergic reaction	T78.4	Allergy, unspecified
119	610	Stridor	R061	Stridor
120	604	Wheezing – no other complaints	R06.8	Wheezing
121	606	Apneic spells in infants	R06.8	Other and unspecified abnormalities of breathing

	SK	Skin (701-750)		
122	701	Bite	T14.0	Superficial injury of unspecified body region
123	702	Sting	T63.9	Toxic effect of contact with unspecified venomous animal
124	703	Abrasion	T00.9	Multiple superficial injuries, unspecified
125	704	Laceration/puncture	T14.1	Open wound of unspecified body region
126	705	Burn	T30.0	Burn of unspecified body region, unspecified degree
127	706	Blood and body fluid exposure	Z20.9	Contact with and exposure to unspecified communicable disease
128	707	Pruritus	L29.9	Pruritus
129	708	Rash	R21	Rash and other nonspecific skin eruption
130	709	Localized swelling/redness	L03.9	Cellulitis, unspecified
131	710	Wound check	Z09.8	Follow-up examination after treatment for other conditions
132	711	Other skin conditions	L98.9	Disorder of skin and subcutaneous tissue, unspecified
133	712	Lumps, bumps, calluses	L98.8	Other specified disorders of skin and subcutaneous tissue
134	713	Redness/tenderness, breast	N61	Inflammatory disorders of breast
135	714	Rule out infestation	B88.9	Infestation, unspecified
136	715	Cyanosis	R23.0	Cyanosis
137	716	Spontaneous bruising	R23.3	Spontaneous ecchymosis
138	717	Foreign body, skin	M79.59	Residual foreign body in soft tissue, unspecified site
	SA	Substance misuse (751-800)		
139	751	Substance misuse/intoxication	F19	Mental/behavioural disorders due to use of drugs or psychoactive substances
140	752	Overdose ingestion	T50.9	Poisoning by other and unspecified drugs, medicaments and biological substance
141	753	Substance withdrawal	F19.3	Mental/behavioural disorders due to use of drugs or psychoactive substances: withdrawal state
	TR	Trauma (801-850)		
142	801	Major trauma – penetrating	T01.9	Multiple open wounds, unspecified
143	802	Major trauma – blunt	T14.8	Other injuries of unspecified body region
144	803	Isolated chest trauma – penetrating	S21	Open wound of thorax (trauma)
145	804	Isolated chest trauma – blunt	S20.8	Superficial injury of other and unspecified parts of thorax
146	805	Isolated abdominal trauma penetrating	S31.8	Open wound of other and unspecified parts of thorax
147	806	Isolated abdominal trauma – blunt	S39	Other and unspecified injuries of abdomen, low back and pelvis
	MC	General and minor (851-900)		
148	851	Exposure to communicable disease	Z20.9	Contact with and exposure to unspecified communicable disease
149	852	Fever	A50.9	Fever, unspecified
150	853	Hyperglycemia	R73.9	Hyperglycemia, unspecified
151	854	Hypogylcemia	E16.2	Hypoglycaemia, unspecified
152	855	Direct referral for consultation	Z71.9	Counselling, unspecified
153	856	Dressing change	Z46.8	Other specified surgical follow-up care
154	857	Removal staples/sutures	Z48.0	Attention to surgical dressings and sutures
155	858	Cast check	Z47.8	Other specified orthopaedic follow-up care
156	859	Imaging tests	Z01.6	Radiological examination, not elsewhere classified

157	860	Medical device problem	T85.9	Unspecified complication of internal prosthetic device, implant and graft
158	861	Prescription/medication request	Z76.0	Issue of repeat prescription
159	862	Ring removal	Z48.9	Surgical follow-up care, unspecified
160	863	Abnormal lab values	R79	Abnormal findings of blood chemistry
161	864	Pallor/anemia	R23.1	Pallor
162	865	Postoperative complications	T88.9	Complication of surgical and medical care, unspecified
163	603	Inconsolable crying in infants	R68.1	Nonspecific symptoms of infancy (excessive infant crying)
164	611	Congenital problem in children	Q24.9	Congenital malformation of the heart, unspecified
165	866	Minor complaints NOS	-	Minor complaints, unspecified

CEDIS = Canadian Emergency Department Information System; ICD-10 = International Classification of Diseases and Related Health Problems, 10th revision; ENT = ear, nose and throat; URTI – upper respiratory tract infection; NOS = not otherwise specified; UTI = urinary tract infection; CVA = congenital ventricular aneurysm.

Appendix B

Patient Arrivals to Fast Track

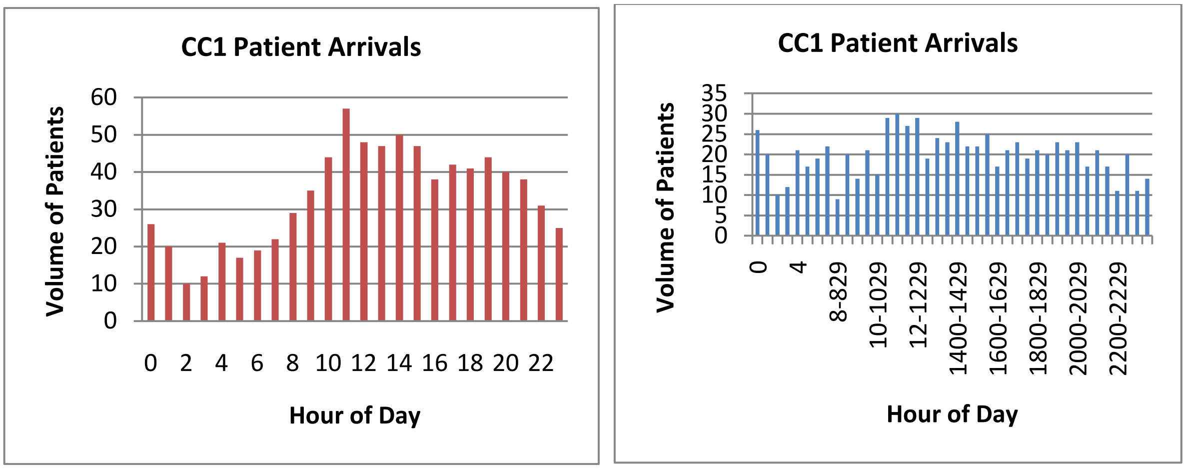


Figure B.1: Patient Group 1 Arrivals by hour (left) and by half hour (right) of day.

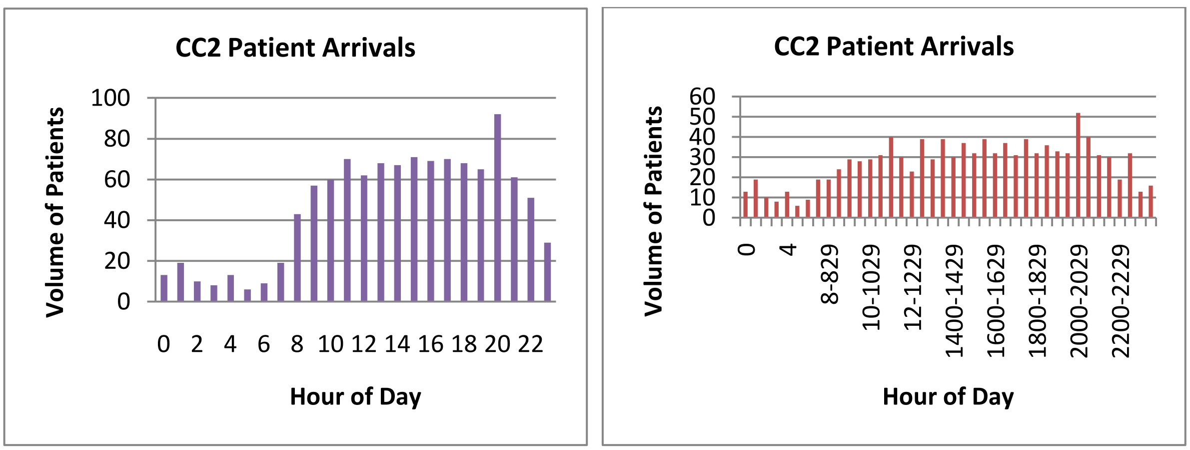


Figure B.2: Patient Group 2 Arrivals by hour (left) and by half hour (right) of day.

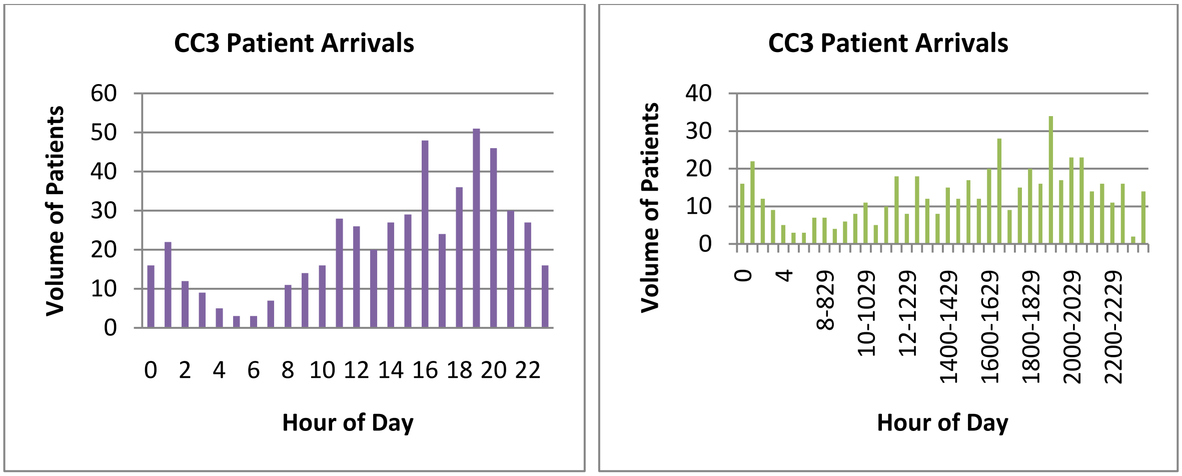


Figure B.3: Patient Group 3 Arrivals by hour (left) and by half hour (right) of day.

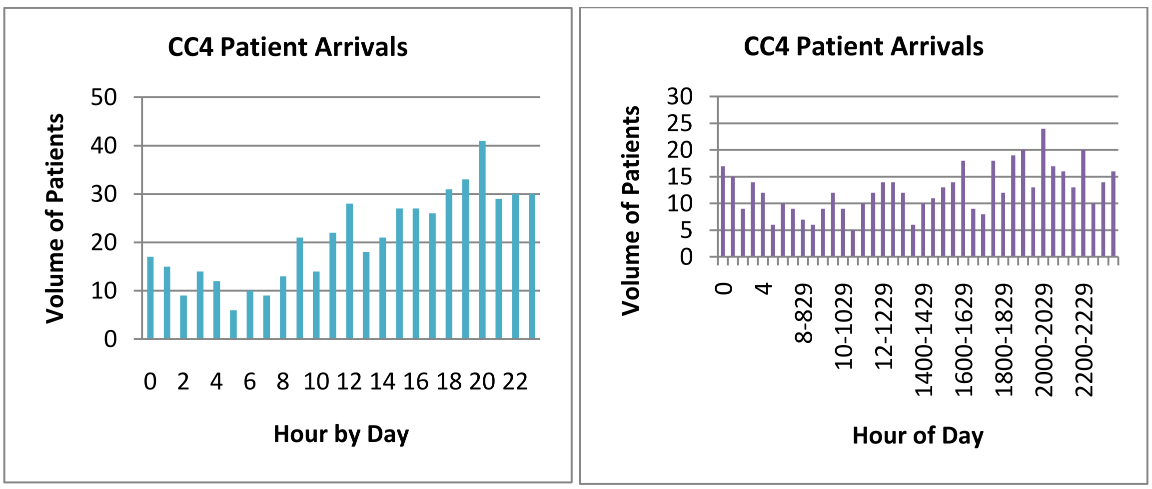


Figure B.4: Patient Group 4 Arrivals by hour (left) and by half hour (right) of day.

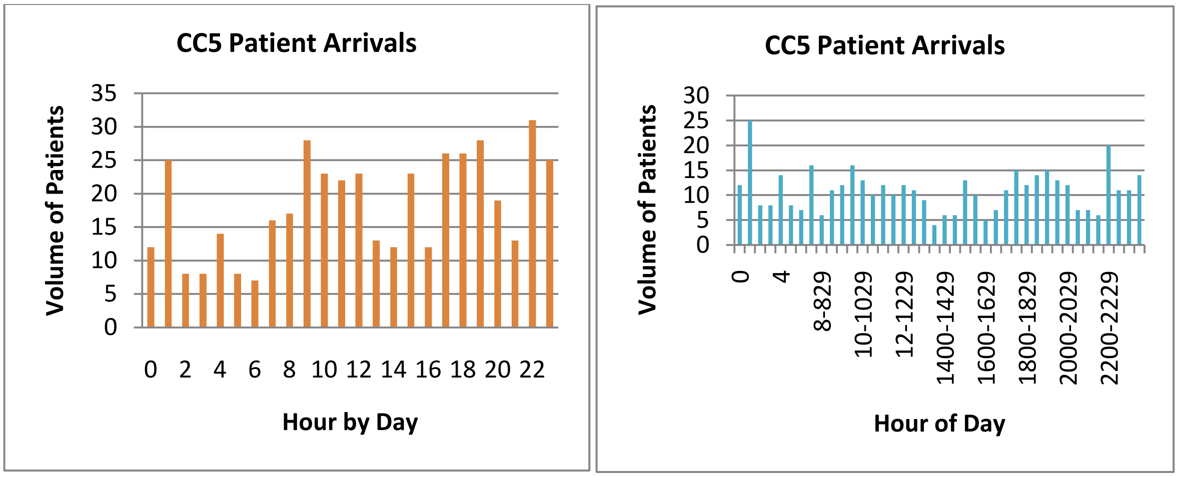


Figure B.5: Patient Group 5 Arrivals by hour (left) and by half hour (right) of day.

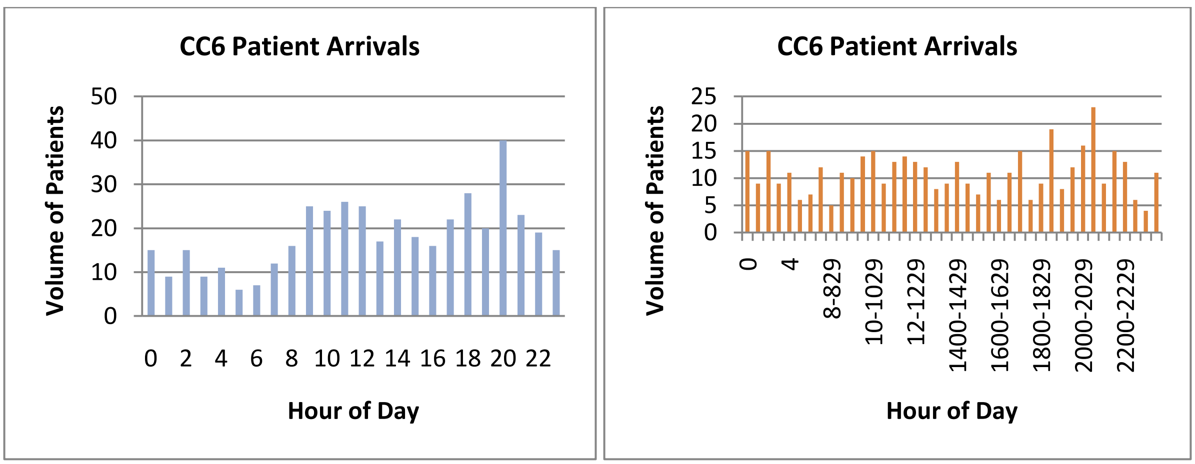


Figure B.6: Patient Group 6 Arrivals by hour (left) and by half hour (right) of day.

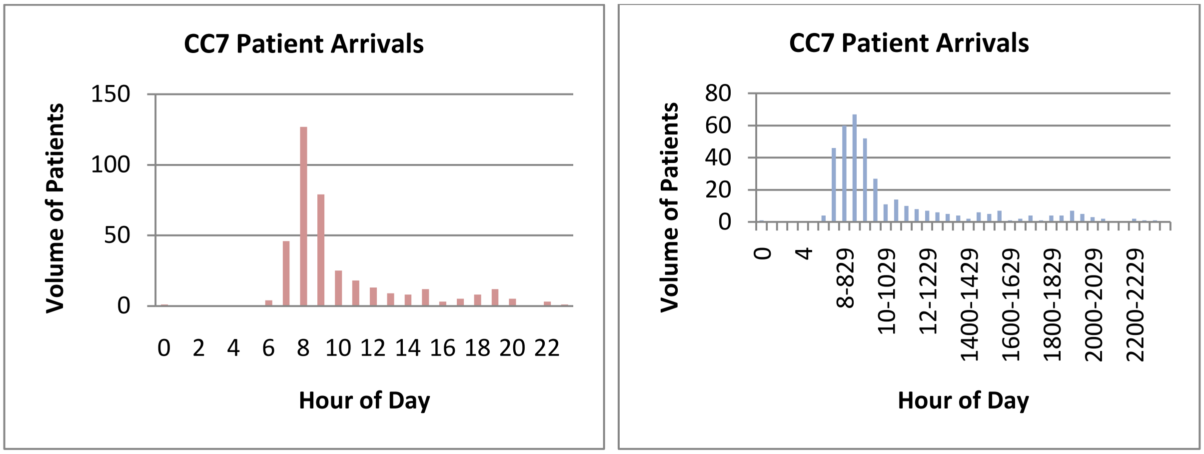


Figure B.7: Patient Group 7 Arrivals by hour (left) and by half hour (right) of day.

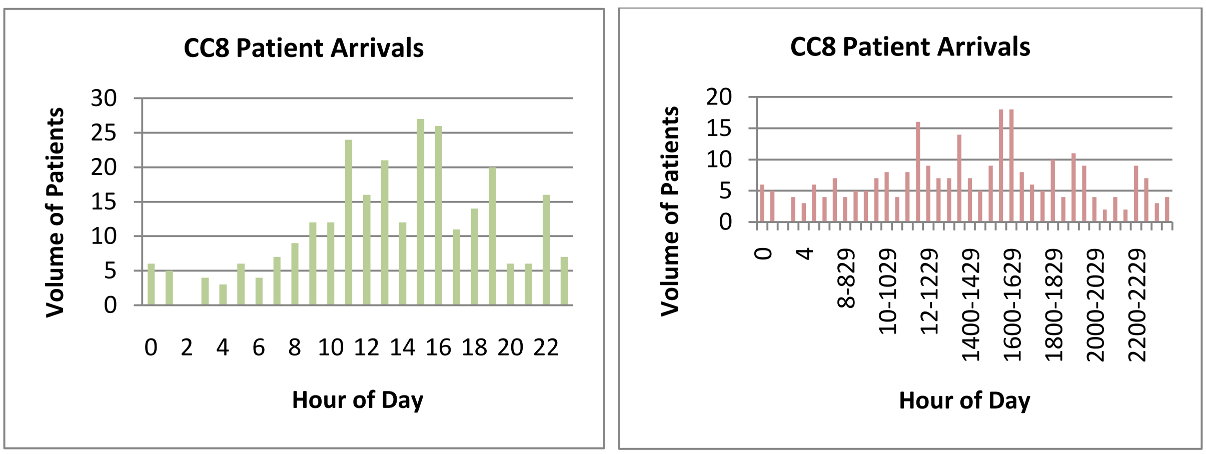


Figure B.8: Patient Group 8 Arrivals by hour (left) and by half hour (right) of day.

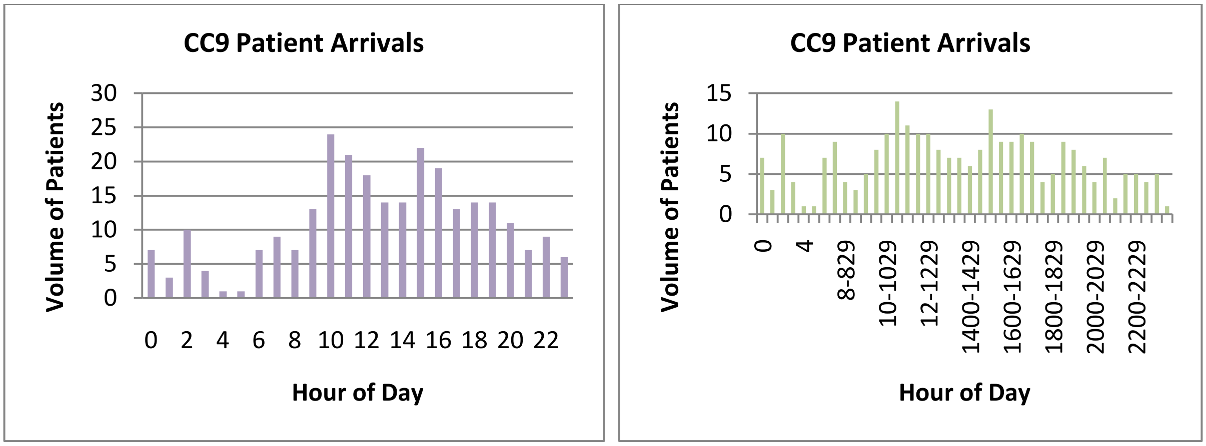


Figure B.9: Patient Group 9 Arrivals by hour (left) and by half hour (right) of day.

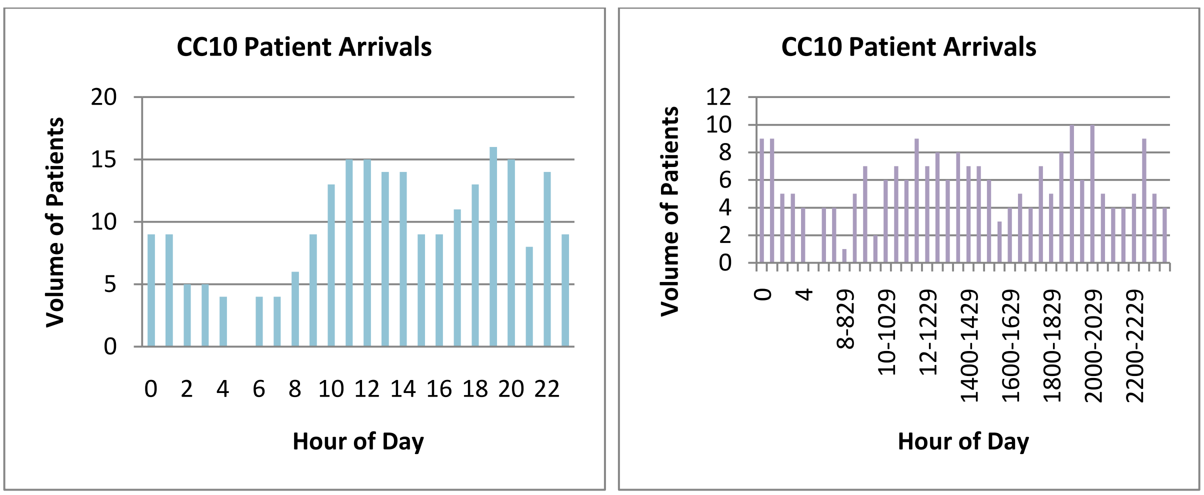


Figure B.10: Patient Group 10 Arrivals by hour (left) and by half hour (right) of day.

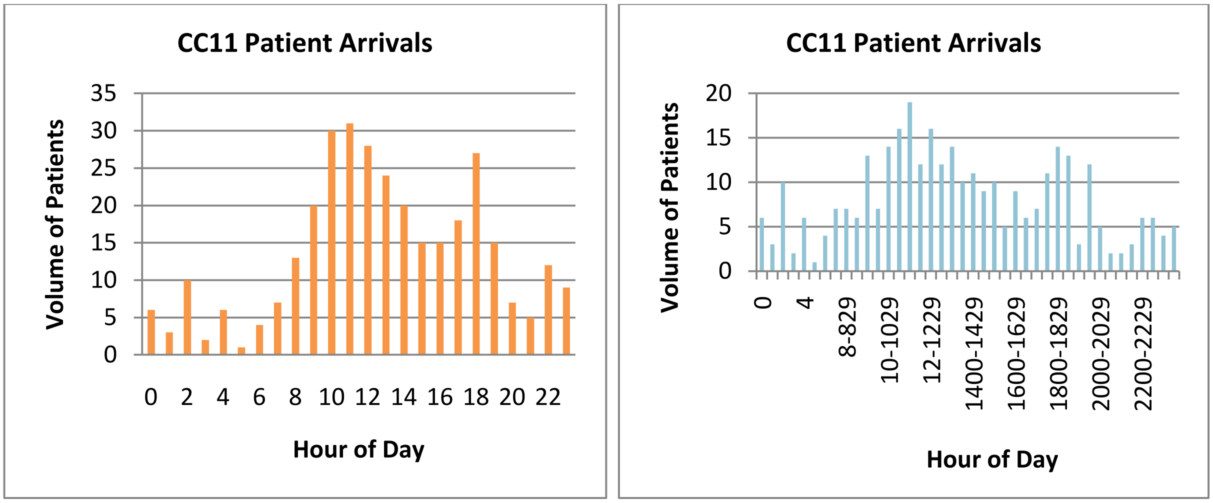


Figure B.11: Patient Group 11 Arrivals by hour (left) and by half hour (right) of day.

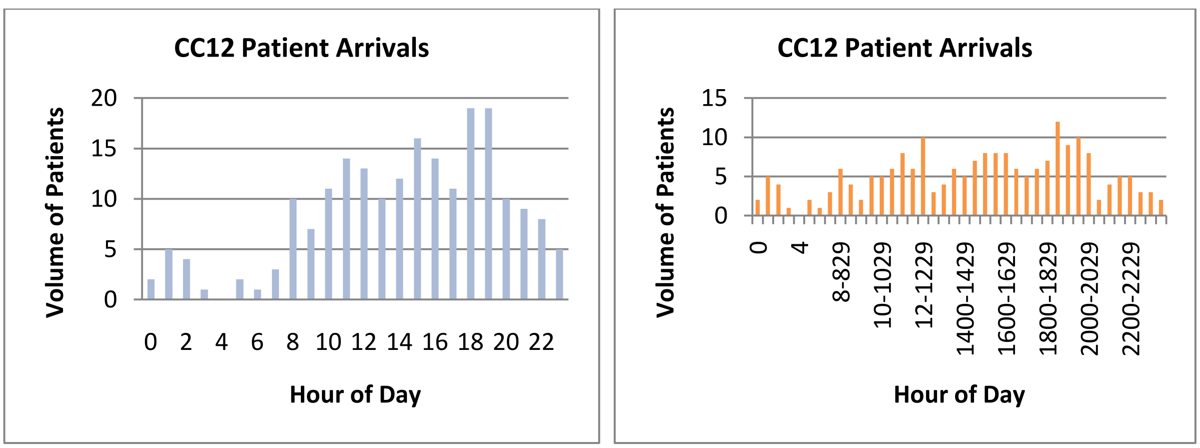


Figure B.12: Patient Group 12 Arrivals by hour (left) and by half hour (right) of day.

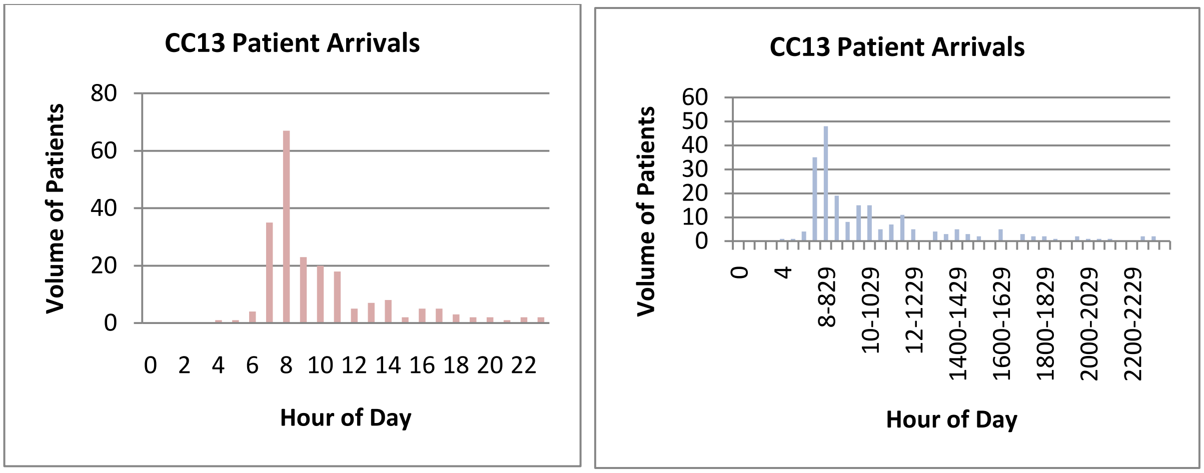


Figure B.13: Patient Group 13 Arrivals by hour (left) and by half hour (right) of day.

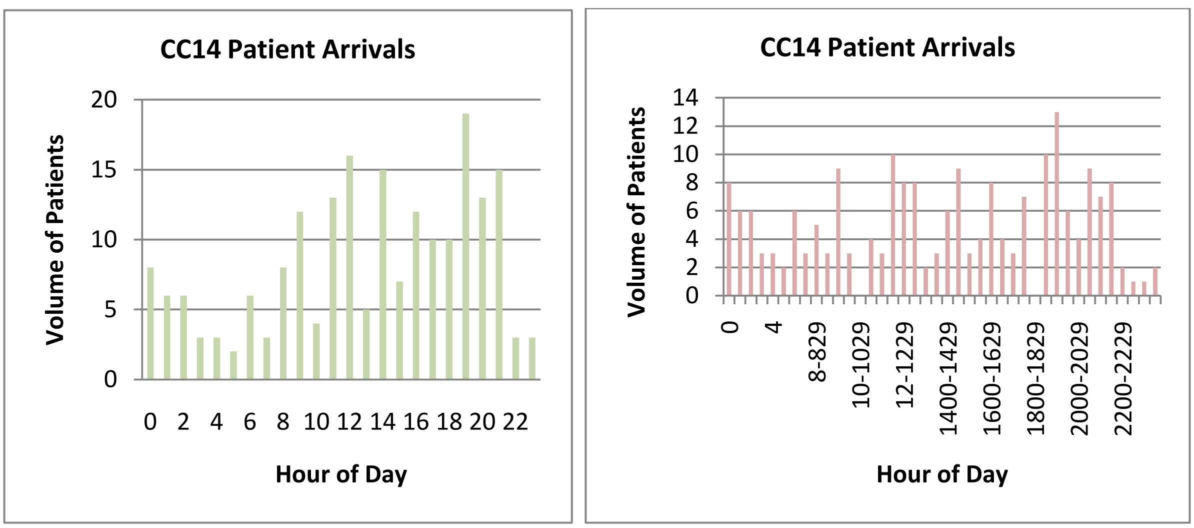


Figure B.14: Patient Group 14 Arrivals by hour (left) and by half hour (right) of day.

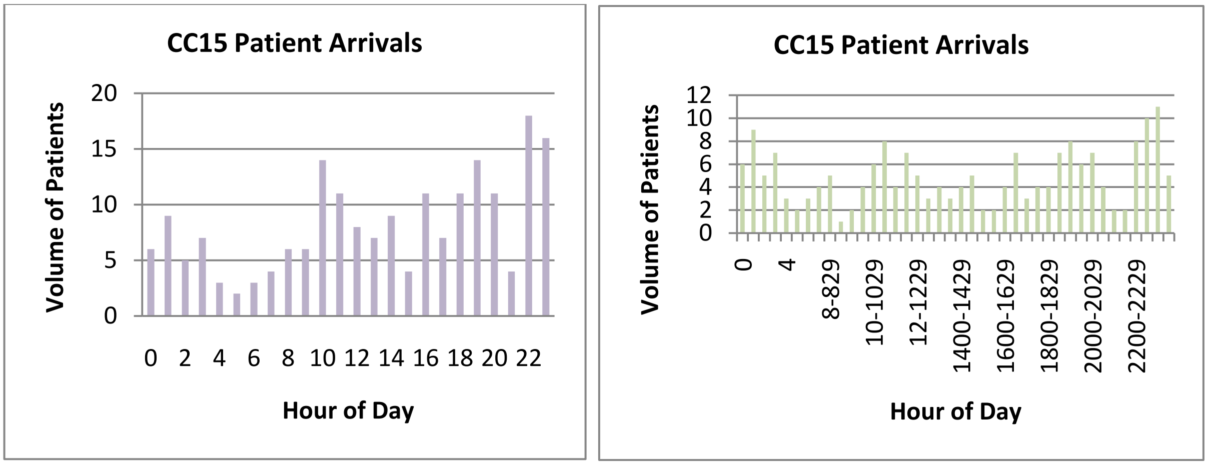


Figure B.15: Patient Group 15 Arrivals by hour (left) and by half hour (right) of day.

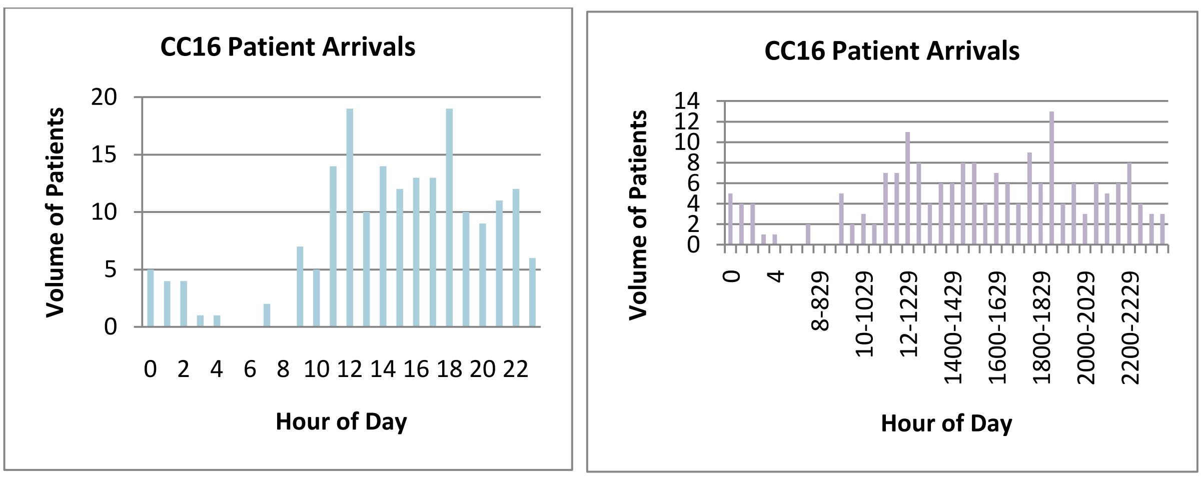
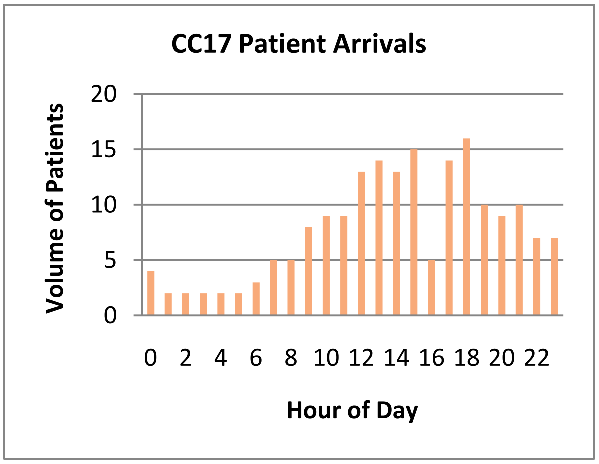


Figure B.16: Patient Group 16 Arrivals by hour (left) and by half hour (right) of day.



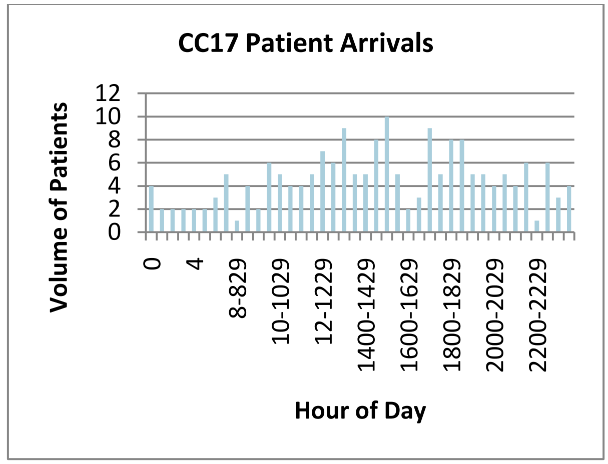
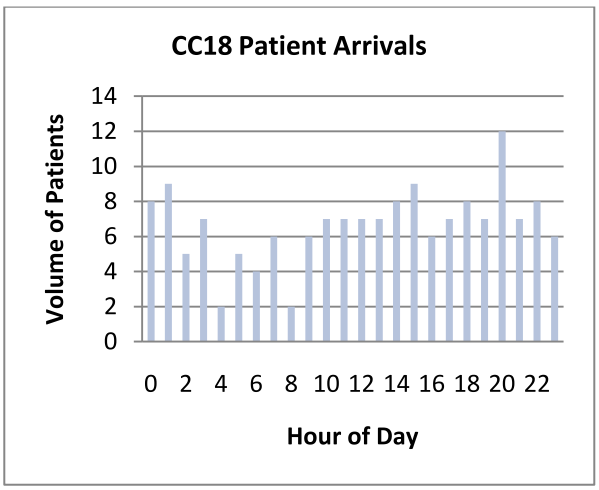


Figure B.17: Patient Group 17 Arrivals by hour (left) and by half hour (right) of day.



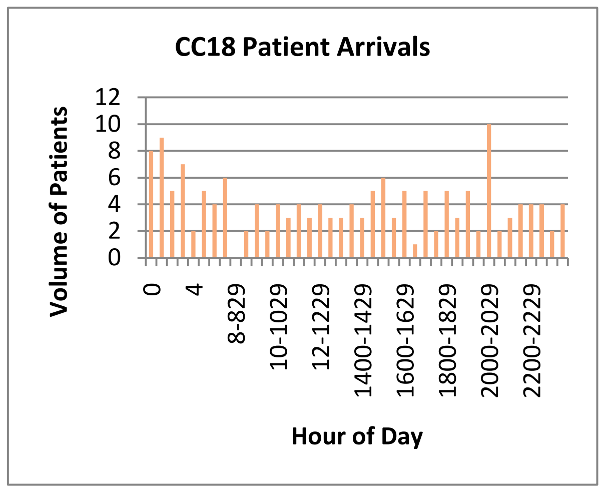


Figure B.18: Patient Group 18 Arrivals by hour (left) and by half hour (right) of day.

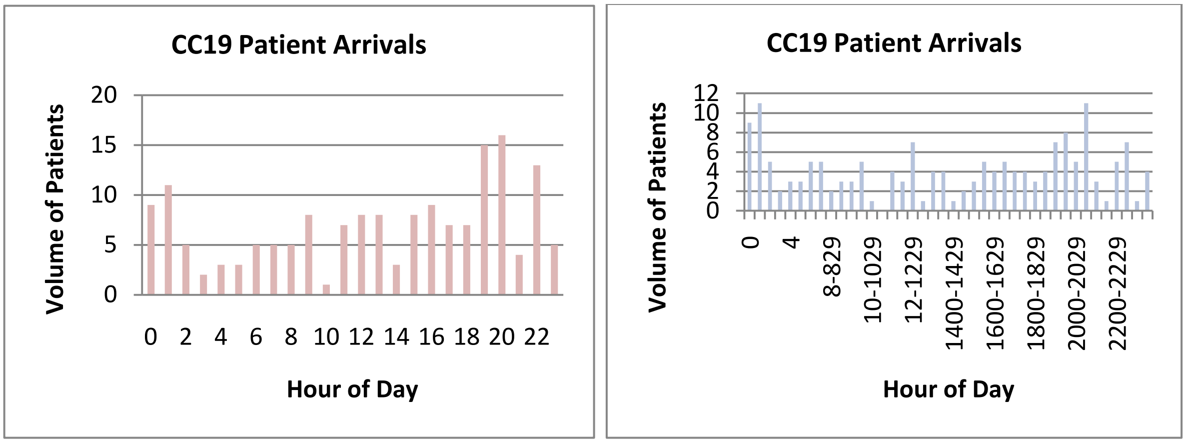


Figure B.19: Patient Group 19 Arrivals by hour (left) and by half hour (right) of day.

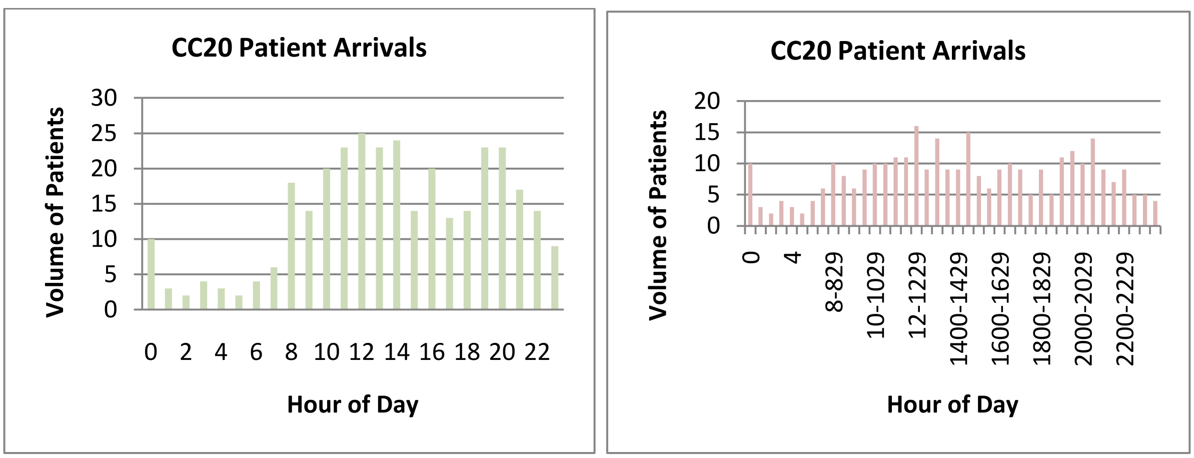
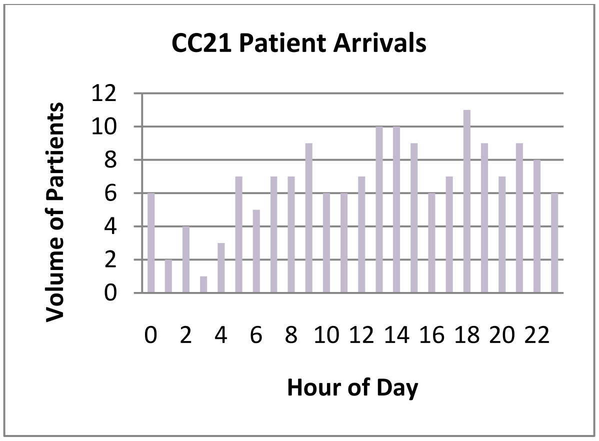


Figure B.20: Patient Group 20 Arrivals by hour (left) and by half hour (right) of day.



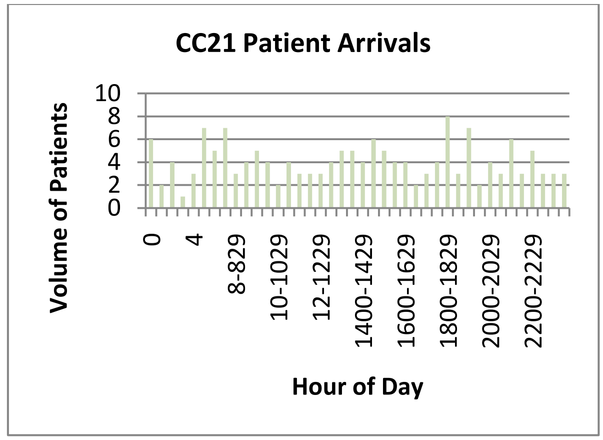
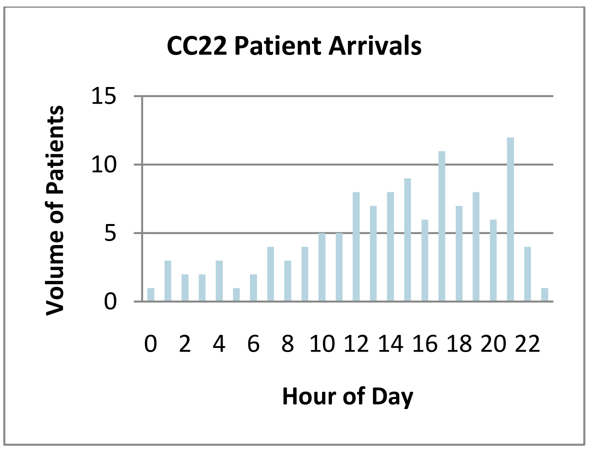


Figure B.21: Patient Group 21 Arrivals by hour (left) and by half hour (right) of day.



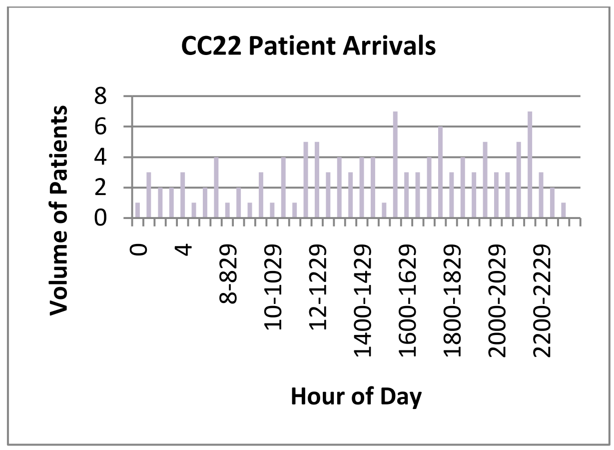
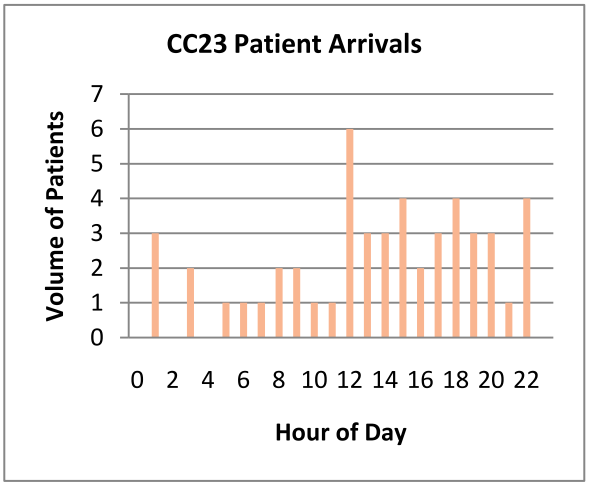


Figure B.22: Patient Group 22 Arrivals by hour (left) and by half hour (right) of day.



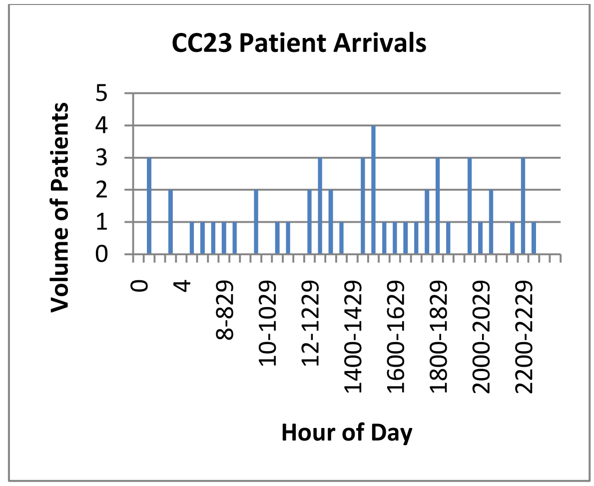
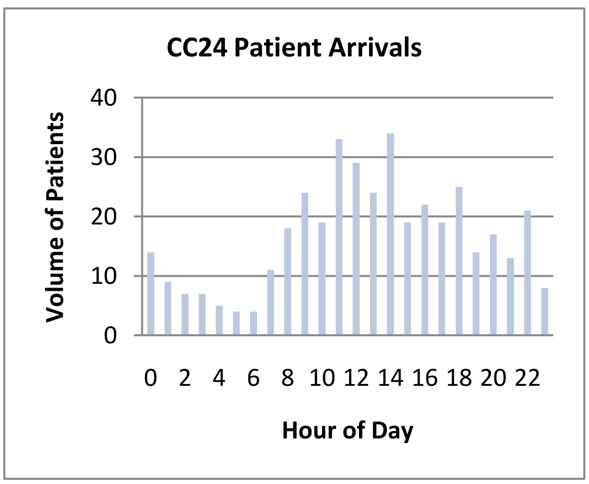


Figure B.23: Patient Group 23 Arrivals by hour (left) and by half hour (right) of day.



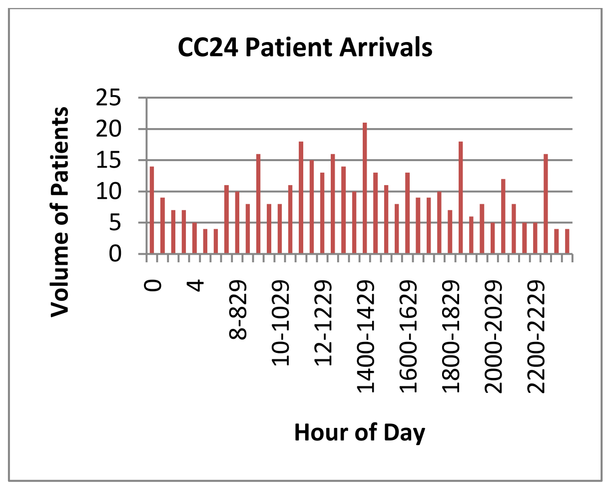


Figure B.24: Patient Group 24 Arrivals by hour (left) and by half hour (right) of day.

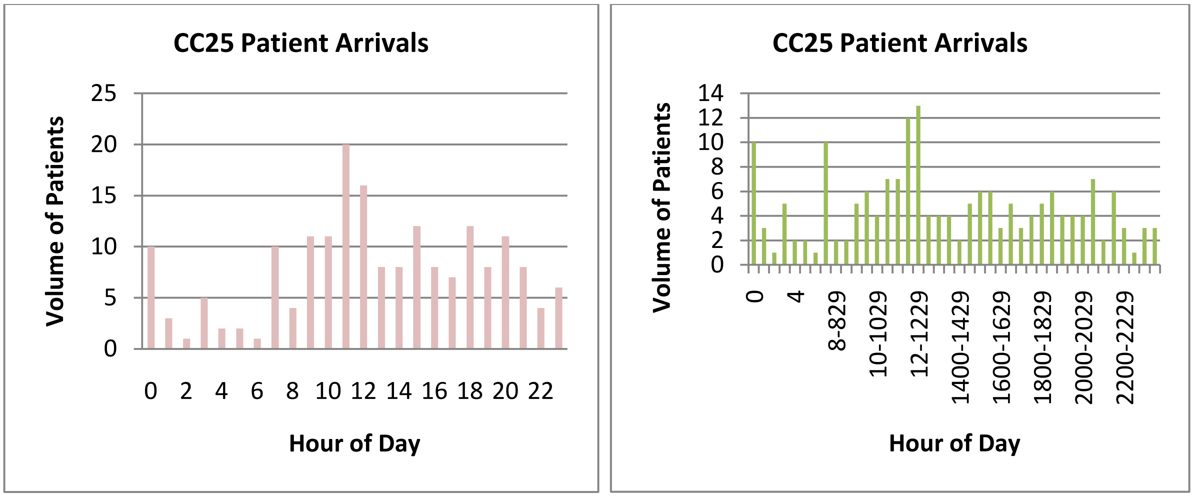


Figure B.25: Patient Group 25 Arrivals by hour (left) and by half hour (right) of day.

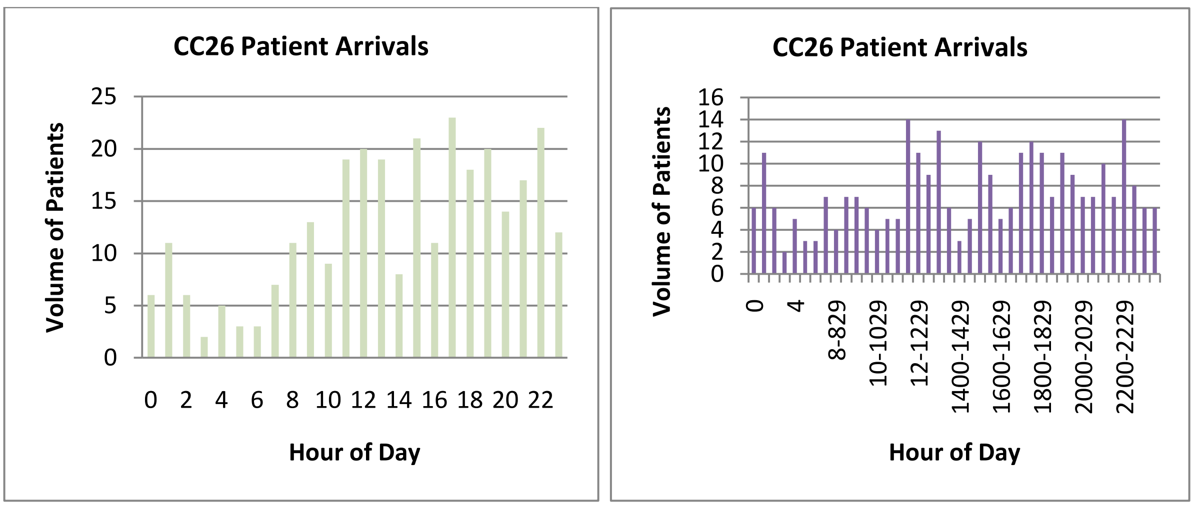
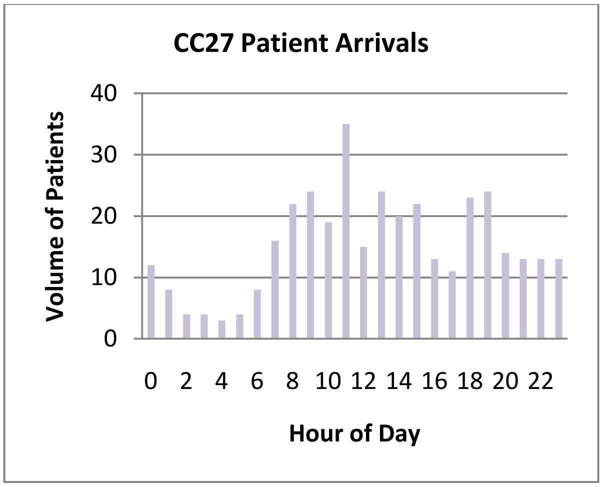


Figure B.26: Patient Group 26 Arrivals by hour (left) and by half hour (right) of day.



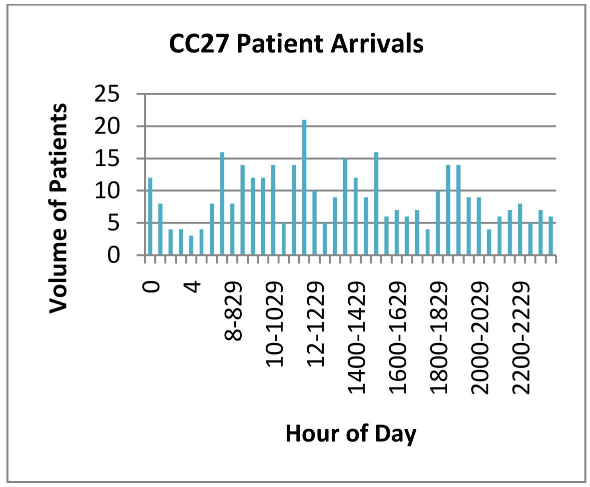
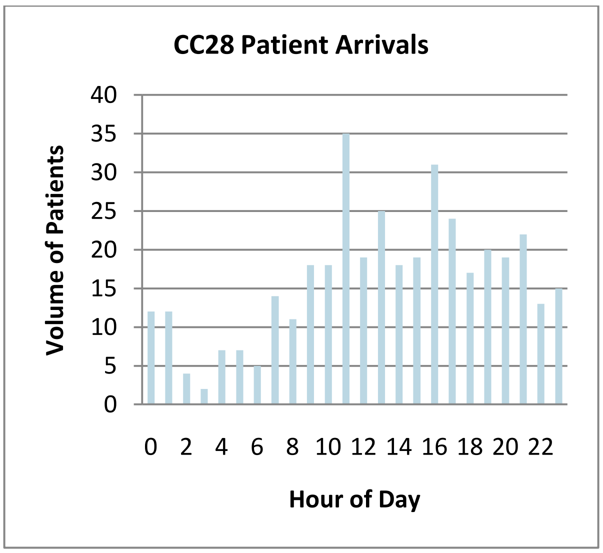


Figure B.27: Patient Group 27 Arrivals by hour (left) and by half hour (right) of day.



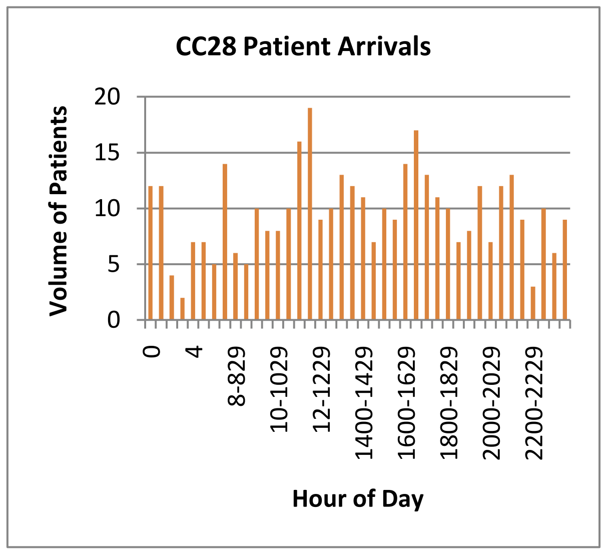


Figure B.28: Patient Group 28 Arrivals by hour (left) and by half hour (right) of day.

Appendix C

Distribution Fitting for Laboratory and Medical Imaging Tests

Table C.1: Distribution Fitting for BHCG Service Time

Auto::Fit of Distributions		
distribution	rank	acceptance
Gamma(3., 11.7, 8.45)	88	do not reject
Lognormal(3., 4.55, 0.309)	61.5	do not reject
Pearson 6(3., 1.49e+003, 11.7, 177)	35.8	do not reject
Pearson 5(3., 9.4, 841)	1.03	do not reject
Beta(3., 293, 6.78, 13.1)	0.483	reject
Erlang(3., 12., 8.45)	0.414	reject
Exponential(3., 98.6)	0	reject
Triangular(2., 294, 86.7)	0	reject
Uniform(3., 293)	0	reject
Weibull(3., 3.03, 110)	0	reject
Rayleigh(3., 73.4)	0	reject
Chi Squared(3., 95.4)	0	reject
Power Function(3., 298, 0.879)	0	reject

Table C.2: Distribution Fitting for BHCG Service Time (upper and lower 5% data points deleted)

Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(63., 147, 1.37, 1.78)	100	do not reject
Weibull(63., 1.79, 40.9)	0.859	reject
Rayleigh(63., 29.7)	0.142	reject
Gamma(63., 2.35, 15.5)	2.32E-02	reject
Pearson 6(63., 549, 2.2, 33.9)	1.48E-02	reject
Triangular(62., 155, 72.6)	9.85E-03	reject
Lognormal(63., 3.37, 0.784)	0	reject
Erlang(63., 2., 15.5)	0	reject
Uniform(63., 147)	0	reject
Pearson 5(63., 1.33, 25.2)	0	reject
Exponential(63., 36.4)	0	reject

Table C.3: Distribution Fitting for INR Service Time

Auto::Fit of Distributions		
distribution	rank	acceptance
Pearson 5(-17., 14.4, 1.12e+003)	100	do not reject
Beta(-17., 375, 9.42, 34.5)	0	reject
Exponential(-17., 83.7)	0	reject
Gamma(-17., 13.1, 6.4)	0	reject
Lognormal(-17., 4.39, 0.271)	0	reject
Erlang(-17., 13., 6.4)	0	reject
Pearson 6(-17., 478, 15.7, 91.)	0	reject
Triangular(-18., 375, 48.4)	0	reject
Uniform(-17., 375)	0	reject
Weibull(-17., 2.98, 92.7)	0	reject
Rayleigh(-17., 62.)	0	reject
Chi Squared(-17., 81.6)	0	reject
Power Function(-17., 377, 0.63)	0	reject

Table C.4: Distribution Fitting for INR Service Time (upper and lower 5% data points deleted)

Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(36., 123, 1.57, 3.19)	100	do not reject
Triangular(35., 113, 46.5)	2.37	reject
Weibull(36., 1.69, 32.1)	1.61	reject
Exponential(36., 28.7)	0	reject
Lognormal(36., 3.12, 0.796)	0	reject
Erlang(36., 2., 12.8)	0	reject
Pearson 6(36., 4.93e+004, 2.16, 3.71e+003)	0	reject
Gamma(36., 2.23, 12.8)	0	reject
Uniform(36., 111)	0	reject
Pearson 5(36., 1.26, 18.1)	0	reject
Rayleigh(36., 23.6)	0	reject
Chi Squared(36., 23.5)	0	reject
Power Function(36., 111, 0.832)	0	reject

Table C.5: Distribution Fitting for MONO Service Time

Auto::Fit of Distributions		
distribution	**rank**	**acceptance**
Gamma(1., 8.87, 8.1)	89.5	do not reject
Erlang(1., 9., 8.1)	71.1	do not reject
Pearson 6(1., 215, 10., 30.6)	61.3	do not reject
Weibull(1., 2.96, 81.2)	42.4	do not reject
Lognormal(1., 4.22, 0.375)	32	do not reject
Beta(1., 149, 3.15, 3.2)	4.75	do not reject
Pearson 5(1., 6.79, 427)	3.56	reject
Triangular(0., 154, 66.6)	3.14	reject
Rayleigh(1., 54.4)	1.26E-03	reject
Uniform(1., 149)	0	reject
Exponential(1., 71.8)	0	reject
Chi Squared(1., 68.8)	0	reject
Power Function(1., 149, 1.28)	0	reject

Table C.6: Distribution Fitting for MONO Service Time (upper and lower 5% data points deleted)

Auto::Fit of Distributions		
distribution	**rank**	**acceptance**
Beta(36., 127, 1.5, 2.23)	100	do not reject
Weibull(36., 1.77, 41.4)	62.4	do not reject
Rayleigh(36., 30.1)	13.9	do not reject
Gamma(36., 2.45, 14.9)	6.59	do not reject
Triangular(35., 133, 45.8)	4.2	reject
Pearson 6(36., 354, 2.24, 22.4)	1.73	reject
Lognormal(36., 3.38, 0.77)	7.04E-02	reject
Power Function(36., 127, 0.884)	3.71E-02	reject
Erlang(36., 2., 14.9)	0	reject
Pearson 5(36., 1.45, 28.9)	0	reject
Exponential(36., 36.5)	0	reject
Chi Squared(36., 30.4)	0	reject
Uniform(36., 127)	0	reject

Table C.7: Distribution Fitting for Troponin-T Service Time

Auto::Fit of Distributions		
distribution	rank	acceptance
Lognormal(5., 4.18, 0.367)	100	reject
Pearson 6(5., 629, 8.46, 77.)	9.55	reject
Gamma(5., 7.61, 9.22)	1.14	reject
Pearson 5(5., 7.37, 450)	2.04E-03	reject
Beta(5., 379, 5.28, 22.6)	0	reject
Erlang(5., 8., 9.22)	0	reject
Exponential(5., 70.1)	0	reject
Triangular(4., 379, 51.)	0	reject
Uniform(5., 379)	0	reject
Weibull(5., 2.41, 78.6)	0	reject
Rayleigh(5., 53.5)	0	reject
Chi Squared(5., 66.5)	0	reject
Power Function(5., 379, 0.574)	0	reject

Table C.8: Distribution Fitting for Troponin-T Service Time (upper and lower 5% data points deleted)

Auto::Fit of Distributions		
distribution	rank	acceptance
Weibull(41., 1.78, 36.4)	95.6	do not reject
Beta(41., 130, 1.6, 2.77)	6.84	reject
Gamma(41., 2.48, 13.)	0.125	reject
Exponential(41., 32.2)	0	reject
Lognormal(41., 3.26, 0.759)	0	reject
Erlang(41., 2., 13.)	0	reject
Pearson 6(41., 111, 2.69, 10.1)	0	reject
Triangular(40., 124, 59.8)	0	reject
Uniform(41., 121)	0	reject
Pearson 5(41., 1.32, 22.4)	0	reject
Rayleigh(41., 26.4)	0	reject
Chi Squared(41., 27.)	0	reject
Power Function(41., 121, 0.89)	0	reject

Table C.9: Distribution Fitting for Urine Dipstick Service Time

Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(1., 3.43e+003, 0.825, 16.8)	0	reject
Erlang(1., 1., 76.5)	0	reject
Exponential(1., 107)	0	reject
Gamma(1., 1.4, 76.5)	0	reject
Lognormal(1., 4.27, 0.891)	0	reject
Pearson 5(1., 1.35, 64.1)	0	reject
Pearson 6(1., 80.3, 2.62, 2.92)	0	reject
Triangular(0., 988, 1.4)	0	reject
Uniform(1., 988)	0	reject
Weibull(1., 1.11, 113)	0	reject
Rayleigh(1., 112)	0	reject
Chi Squared(1., 72.8)	0	reject
Power Function(1., 988, 0.381)	0	reject

Table C.10: Distribution Fitting for Urine Dipstick Service Time (upper and lower 5% data points deleted)

Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(20., 449, 0.841, 3.66)	0	reject
Erlang(20., 1., 73.5)	0	reject
Exponential(20., 77.3)	0	reject
Gamma(20., 1.05, 73.5)	0	reject
Lognormal(20., 3.8, 1.18)	0	reject
Pearson 5(20., 0.695, 13.)	0	reject
Pearson 6(20., 970, 1.12, 15.1)	0	reject
Triangular(19., 391, 21.5)	0	reject
Uniform(20., 391)	0	reject
Weibull(20., 1.02, 78.)	0	reject
Rayleigh(20., 77.1)	0	reject
Chi Squared(20., 45.8)	0	reject
Power Function(20., 391, 0.473)	0	reject

Table C.11: Distribution Fitting for CT Service Time

Auto::Fit of Distributions		
distribution	**rank**	**acceptance**
Weibull(1., 1.3, 195)	89.2	do not reject
Beta(1., 1.04e+003, 1.28, 6.25)	76	do not reject
Pearson 6(1., 1.07e+004, 1.39, 82.3)	7.4	do not reject
Gamma(1., 1.46, 121)	7.07	do not reject
Lognormal(1., 4.79, 1.2)	0	reject
Erlang(1., 1., 121)	0	reject
Exponential(1., 176)	0	reject
Triangular(0., 1.05e+003, 0.)	0	reject
Uniform(1., 1.04e+003)	0	reject
Pearson 5(1., 0.423, 10.9)	0	reject
Rayleigh(1., 159)	0	reject
Chi Squared(1., 122)	0	reject
Power Function(1., 1.09e+003, 0.455)	0	reject

Table C.12: Distribution Fitting for CT Service Time (upper and lower 5% data points deleted)

Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(3., 466, 1.38, 2.49)	100	do not reject
Weibull(3., 1.64, 185)	18.2	do not reject
Pearson 6(3., 4.72e+003, 2.14, 61.6)	1.61	reject
Gamma(3., 2.07, 79.1)	0.639	reject
Erlang(3., 2., 79.1)	1.48E-02	reject
Rayleigh(3., 137)	7.30E-03	reject
Triangular(2., 451, 2.)	7.39E-05	reject
Lognormal(3., 4.84, 0.937)	0	reject
Uniform(3., 408)	0	reject
Pearson 5(3., 0.592, 26.3)	0	reject
Exponential(3., 164)	0	reject
Chi Squared(3., 128)	0	reject
Power Function(3., 408, 0.86)	0	reject

Table C.13: Distribution Fitting for Ultrasound Service Time

Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(1., 670, 0.557, 2.87)	0	reject
Erlang(1., 1., 166)	0	reject
Exponential(1., 106)	0	reject
Gamma(1., 0.638, 166)	0	reject
Lognormal(1., 3.7, 1.76)	0	reject
Pearson 5(1., 0.446, 4.23)	0	reject
Pearson 6(1., 1.54e+004, 0.608, 85.8)	0	reject
Triangular(0., 557, 0.91)	0	reject
Uniform(1., 555)	0	reject
Weibull(1., 0.734, 92.8)	0	reject
Rayleigh(1., 112)	0	reject
Chi Squared(1., 41.6)	0	reject
Power Function(1., 555, 0.382)	0	reject

Table C.14: Distribution Fitting for Ultrasound Service Time (upper and lower 5% data points deleted)

Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(2., 336, 0.488, 1.27)	0	reject
Erlang(2., 1., 153)	0	reject
Exponential(2., 93.3)	0	reject
Gamma(2., 0.611, 153)	0	reject
Lognormal(2., 3.53, 1.82)	0	reject
Pearson 5(2., 0.419, 3.01)	0	reject
Pearson 6(2., 5.14e+005, 0.608, 3.33e+003)	0	reject
Triangular(1., 342, 1.62)	0	reject
Uniform(2., 328)	0	reject
Weibull(2., 0.729, 79.5)	0	reject
Rayleigh(2., 92.7)	0	reject
Chi Squared(2., 35.)	0	reject
Power Function(2., 328, 0.442)	0	reject

Table C.15: Distribution Fitting for X-ray Service Time

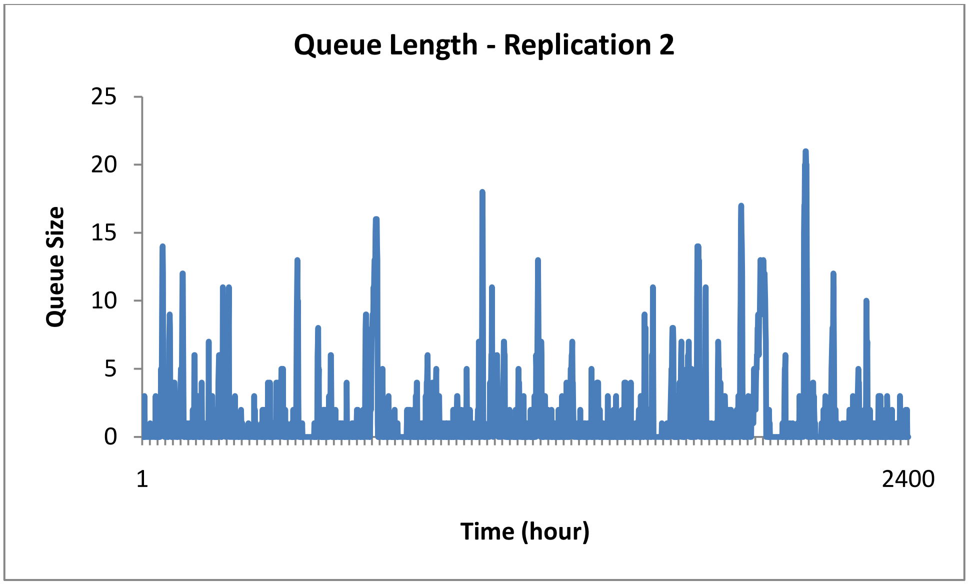
Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(1., 1.33e+003, 0.941, 8.)	0	reject
Erlang(1., 1., 94.6)	0	reject
Exponential(1., 123)	0	reject
Gamma(1., 1.3, 94.6)	0	reject
Lognormal(1., 4.38, 1.41)	0	reject
Pearson 5(1., 0.391, 5.76)	0	reject
Pearson 6(1., 927, 1.06, 7.88)	0	reject
Triangular(0., 1.33e+003, 0.557)	0	reject
Uniform(1., 1.33e+003)	0	reject
Weibull(1., 1.08, 143)	0	reject
Rayleigh(1., 131)	0	reject
Chi Squared(1., 80.9)	0	reject
Power Function(1., 1.33e+003, 0.355)	0	reject

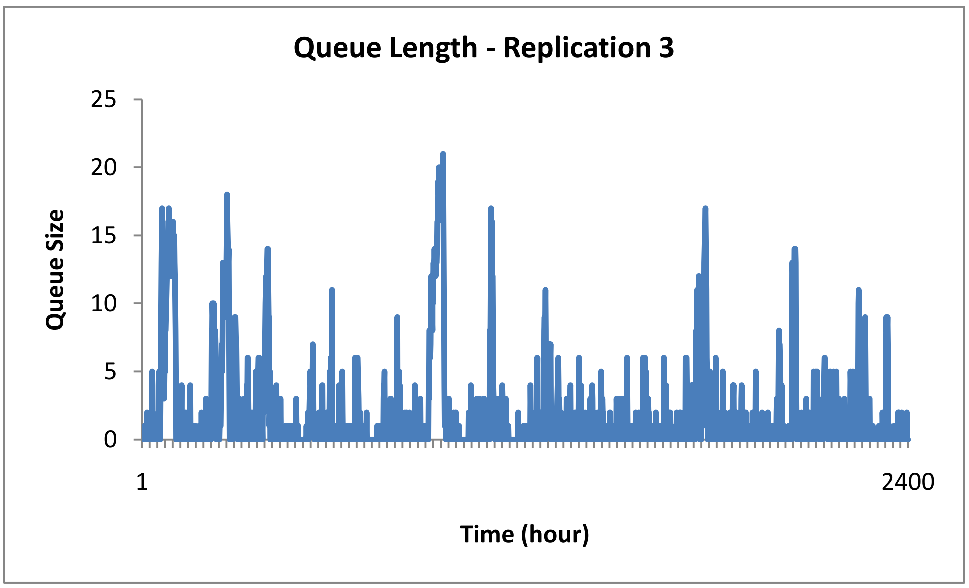
Table C.16: Distribution Fitting for X-ray Service Time (upper and lower 5% data points deleted)

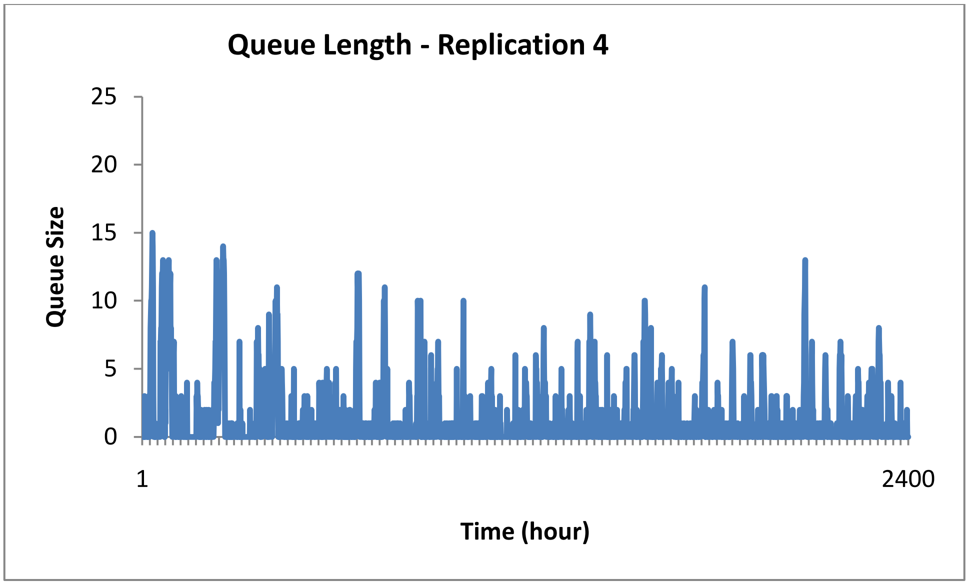
Auto::Fit of Distributions		
distribution	rank	acceptance
Beta(1., 352, 0.865, 1.75)	0	reject
Erlang(1., 1., 85.3)	0	reject
Exponential(1., 111)	0	reject
Gamma(1., 1.3, 85.3)	0	reject
Lognormal(1., 4.28, 1.39)	0	reject
Pearson 5(1., 0.4, 5.57)	0	reject
Pearson 6(1., 8.69e+003, 1.15, 84.)	0	reject
Triangular(0., 339, 0.945)	0	reject
Uniform(1., 319)	0	reject
Weibull(1., 1.19, 126)	0	reject
Rayleigh(1., 103)	0	reject
Chi Squared(1., 73.1)	0	reject
Power Function(1., 319, 0.674)	0	reject

Appendix D

Queue Length for Initial Assessment – Time Plots


Queue Length - Replication 2
25
20
15
10
5
0
Queue Size
1
2400
Time (hour)


Queue Length - Replication 3
25
20
15
10
5
0
Queue Size
1
2400
Time (hour)


Queue Length - Replication 4
Queue Size
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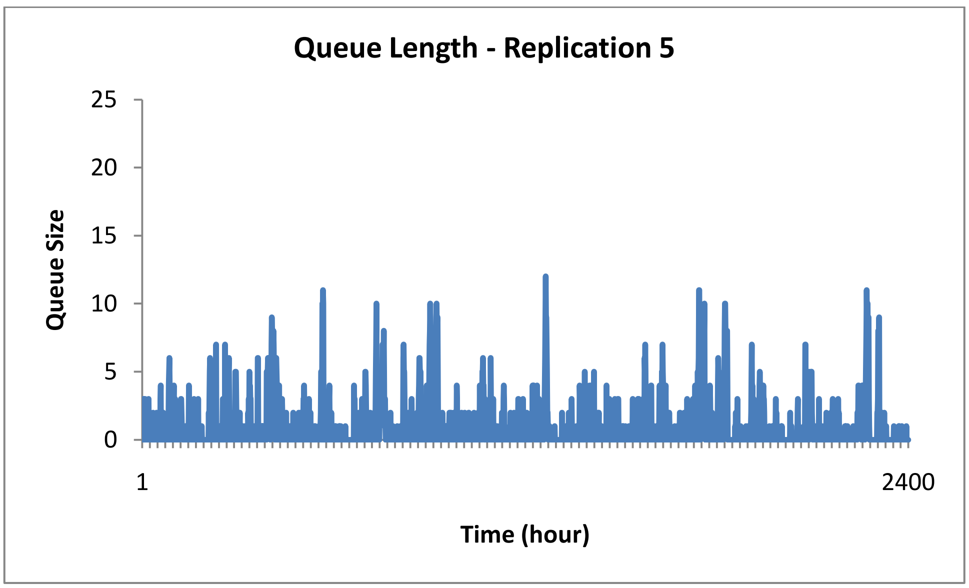
20
15
10
5
0
1
2400
Time (hour)


Queue Length - Replication 5
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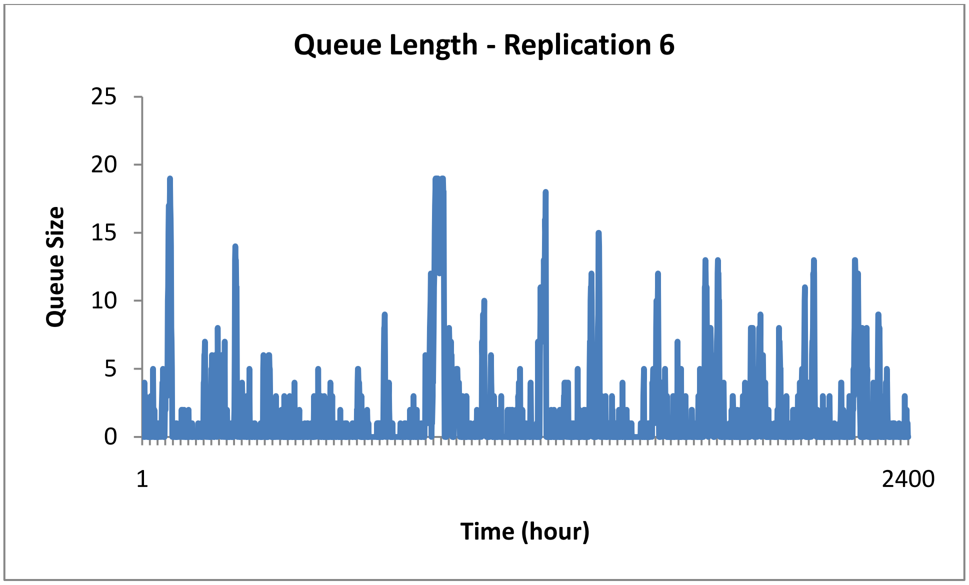
20
15
10
5
0
1
2400
Time (hour)


Queue Length - Replication 6
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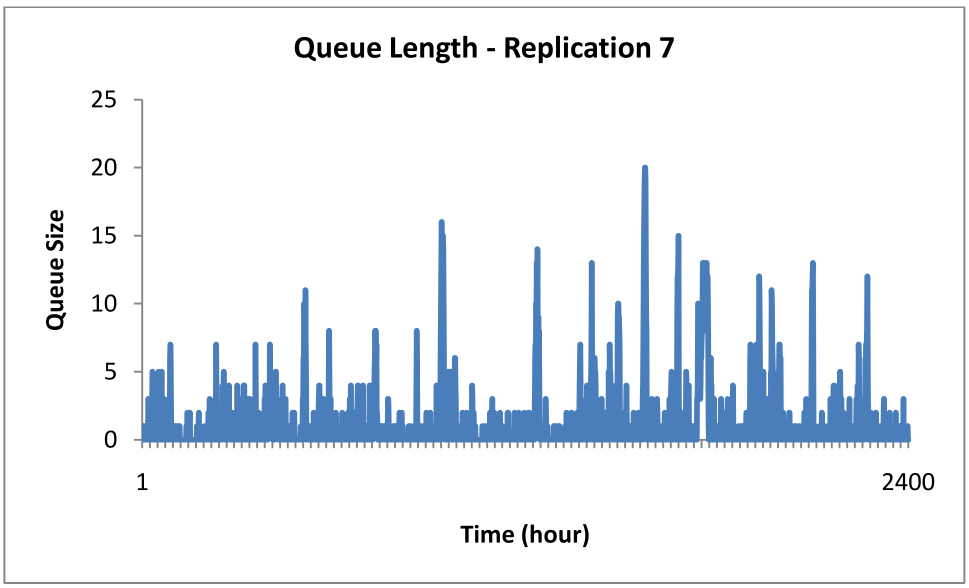
20
15
10
5
0
Queue Size
1
2400
Time (hour)


Queue Length - Replication 7
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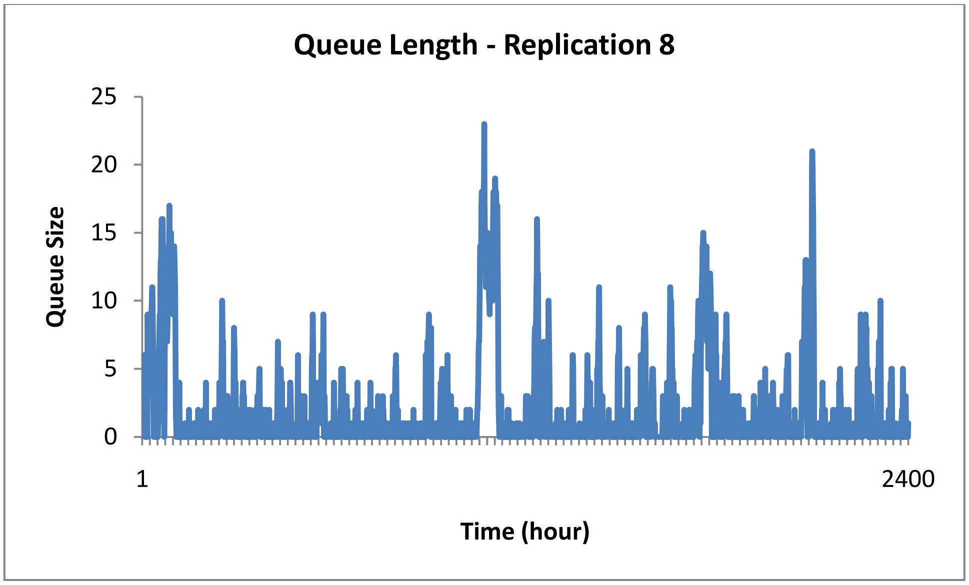
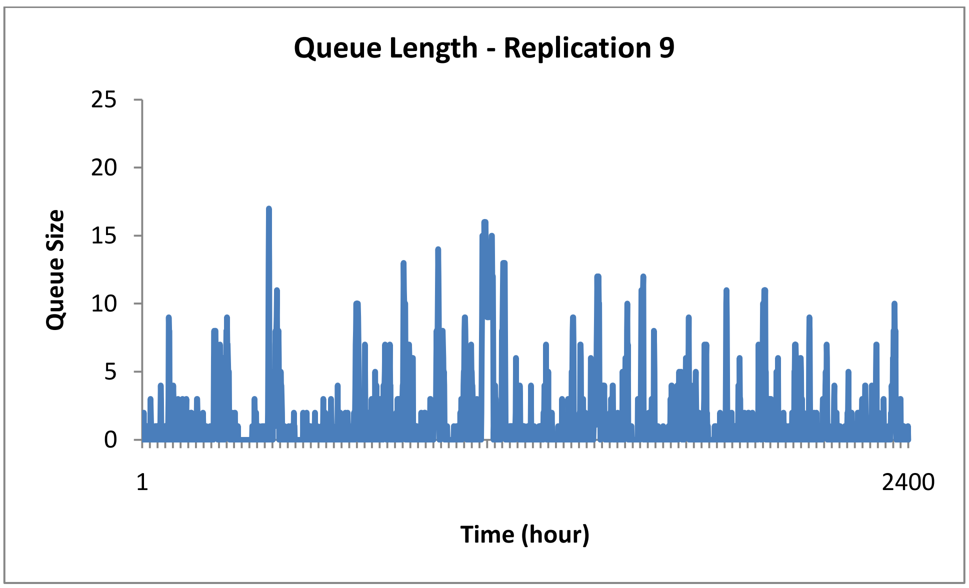
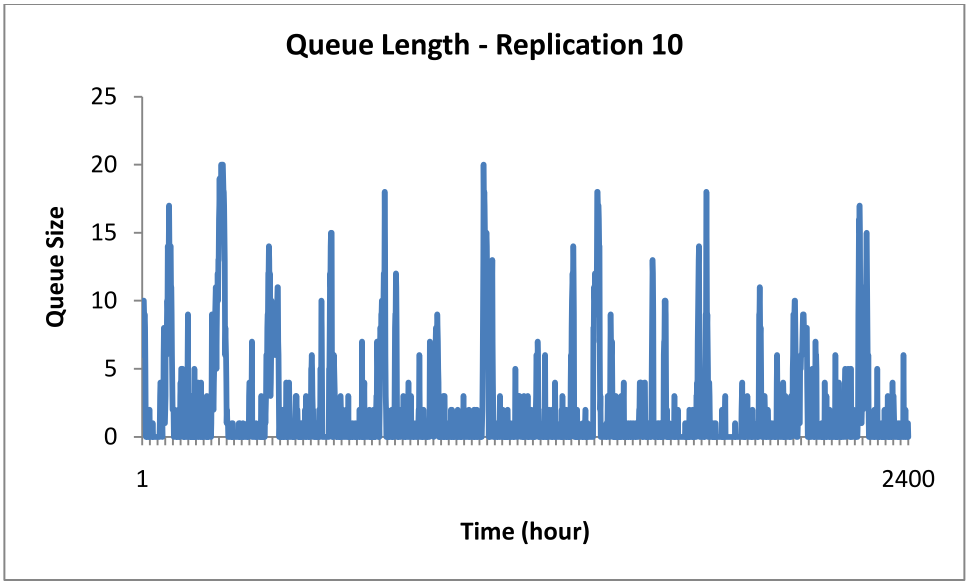
20
15
10
5
0
Queue Size
1
2400
Time (hour)



Queue Length - Replication 8
Queue Size
25
20
15
10
5
0
1
2400
Time (hour)



Queue Length - Replication 9
Queue Size
25
20
15
10
5
0
1
2400
Time (hour)


Queue Length - Replication 10
Queue Size
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20
15
10
5
0
1
2400
Time (hour)

Appendix E

Individual Batch Means for Simulation with Empty and Initial State

	Replication									
Batch	1	2	3	4	5	6	7	8	9	10
1	368.35	250.60	219.18	203.15	253.96	193.09	212.97	214.36	269.38	165.16
2	320.01	238.34	357.60	260.04	241.03	244.94	249.52	286.40	252.08	415.39
3	275.06	234.70	321.55	230.96	317.57	256.96	300.19	467.07	237.87	678.25
4	243.07	211.97	302.37	329.04	302.91	201.03	375.38	633.26	312.90	474.45
5	281.66	212.44	179.20	431.71	251.60	287.72	330.03	527.90	302.88	333.58
6	342.96	382.96	454.83	390.98	279.00	281.86	224.32	422.24	243.06	417.62
7	500.42	319.69	734.73	358.80	499.46	553.19	385.10	594.25	304.40	598.55
8	479.38	304.59	539.72	267.93	482.22	257.28	252.27	354.12	240.33	365.20
9	208.78	264.81	436.73	255.54	245.34	433.85	384.80	261.69	255.11	429.87
10	325.53	346.38	383.63	265.53	254.02	276.81	336.77	223.21	222.12	366.25
11	367.39	294.23	346.33	306.76	299.07	183.64	404.63	246.22	178.82	269.43
12	362.96	354.70	381.59	234.50	341.61	318.61	301.64	271.67	459.49	470.19
13	476.33	281.30	444.35	511.51	296.70	266.72	252.57	243.71	376.31	823.88
14	312.15	393.55	576.17	521.04	325.91	515.60	239.83	384.22	308.42	771.68
15	265.83	219.17	654.49	255.93	297.65	526.75	257.30	252.38	426.66	308.40
16	199.99	269.94	460.37	228.66	266.57	482.13	249.51	322.31	335.51	180.42
17	226.05	206.10	504.63	243.10	262.88	432.14	326.83	284.97	214.48	189.12
18	212.64	207.28	366.30	306.06	297.01	544.18	267.69	254.52	232.94	256.35
19	447.86	267.71	621.35	437.68	309.05	532.65	247.13	394.62	316.18	336.01
20	426.16	346.20	376.73	296.97	439.37	609.86	354.07	263.03	285.16	664.35
21	319.32	310.45	266.78	304.26	329.11	667.89	290.79	299.14	467.80	614.15
22	345.98	287.11	227.55	223.45	424.45	632.97	297.79	228.85	274.41	317.92
23	299.57	253.85	194.46	332.47	286.21	444.78	317.90	272.83	224.55	209.32
24	200.66	330.74	191.91	242.59	340.97	375.08	449.22	393.27	163.84	293.94
25	237.83	218.89	345.94	305.70	332.43	302.55	412.07	319.78	218.09	200.14
26	277.89	348.85	549.90	304.44	325.54	395.78	268.86	441.34	304.47	251.80
27	365.76	220.13	264.33	287.62	248.24	280.58	200.49	432.57	246.90	213.13
28	228.30	267.09	390.73	302.89	259.99	211.65	289.58	280.88	262.63	433.59
29	312.27	242.17	282.81	489.92	222.45	242.10	192.37	294.88	233.81	347.68
30	385.75	373.91	195.00	399.71	187.74	221.35	172.87	390.30	221.02	272.25
31	260.98	387.17	345.56	380.35	305.67	309.56	286.81	278.16	336.33	198.53
32	455.17	546.37	323.03	347.57	258.03	329.94	256.41	184.46	228.21	315.24
33	378.67	684.47	250.90	217.59	239.00	298.70	248.58	213.31	291.83	314.87
34	596.65	794.98	182.97	303.22	322.95	330.53	359.77	208.41	346.04	362.56
35	1086.07	369.71	197.87	371.66	449.87	339.62	319.65	247.34	335.69	313.84
36	930.56	249.97	508.43	223.97	316.81	301.25	183.19	242.64	485.59	351.31
37	820.01	162.75	443.99	248.81	518.45	168.82	243.12	331.88	346.77	290.68
38	370.81	373.06	271.84	223.53	347.96	171.19	204.59	305.76	471.95	503.17

39	258.42	240.64	287.95	265.50	514.41	304.56	354.83	250.90	412.46	347.88
40	241.47	219.30	228.69	241.17	424.06	268.96	330.87	259.39	311.53	366.20
41	288.71	267.05	549.55	245.06	292.60	514.10	225.63	373.43	282.95	564.40
42	383.73	376.46	1301.94	240.56	335.07	1206.15	449.65	285.70	373.83	487.40
43	581.66	233.64	1111.44	221.66	240.72	975.58	766.56	335.18	262.34	303.30
44	646.42	254.50	421.50	243.89	252.69	614.70	441.40	314.00	192.20	274.78
45	304.69	398.78	190.84	338.32	303.71	479.43	246.15	343.10	500.05	254.92
46	462.72	309.02	280.23	291.36	215.62	307.44	264.03	308.97	443.09	308.98
47	414.07	250.47	221.64	236.78	342.20	269.23	243.79	462.50	243.11	401.25
48	252.44	272.56	255.18	271.19	281.34	357.20	266.72	957.77	729.43	546.24
49	304.58	320.50	339.21	250.05	245.19	321.86	189.03	1041.54	536.32	311.62
50	238.46	459.67	327.14	193.56	189.95	288.00	285.00	845.15	310.69	280.12
51	337.55	309.49	254.71	213.31	219.35	268.86	295.42	260.44	365.65	334.10
52	428.20	201.38	191.18	181.21	234.04	360.13	268.86	317.65	434.50	283.42
53	318.63	293.06	253.58	203.14	184.71	400.05	386.49	171.59	348.85	295.17
54	247.42	273.24	252.82	348.84	290.39	235.22	589.97	327.42	211.55	233.91
55	394.78	332.75	253.50	312.94	235.43	302.76	649.75	333.56	286.31	302.67
56	556.43	411.06	601.37	208.85	397.95	410.07	288.63	307.38	360.62	340.75
57	365.30	359.48	643.31	209.40	224.10	196.54	260.42	266.22	267.90	258.92
58	273.24	309.66	467.26	306.42	184.26	231.09	309.01	253.84	212.25	264.98
59	272.58	580.31	546.07	233.49	209.51	366.12	269.37	218.71	367.29	309.49
60	234.72	311.03	395.35	261.25	232.13	229.72	185.82	228.12	349.76	381.93
61	292.07	222.22	309.89	265.95	354.07	220.15	324.13	190.99	249.44	188.54
62	235.99	328.24	292.64	338.13	310.07	360.84	416.79	301.39	357.54	312.90
63	270.49	357.14	264.71	249.26	240.01	278.10	385.26	277.77	506.88	402.98
64	251.51	279.25	240.51	203.21	224.00	200.42	241.71	220.43	523.05	227.99
65	228.60	249.28	279.53	202.43	251.37	289.32	274.89	219.20	451.08	337.16
66	221.76	317.87	361.32	282.62	206.62	349.68	419.39	230.48	352.63	280.33
67	223.57	356.30	345.56	260.47	246.69	322.38	267.78	231.35	227.23	230.15
68	259.25	314.19	241.09	281.66	369.11	466.37	259.41	190.06	369.57	240.87
69	284.35	275.50	272.69	303.19	271.84	272.78	482.89	439.31	380.28	238.48
70	447.43	299.90	273.32	244.23	323.51	466.93	378.39	292.76	228.15	281.08
71	243.33	213.57	187.54	296.60	267.38	584.54	256.94	229.73	294.55	345.37
72	334.97	293.40	259.85	246.42	363.48	270.39	305.39	433.08	303.09	371.05
73	309.62	446.31	255.95	231.81	256.38	287.95	282.48	395.76	332.15	275.63
74	301.88	357.04	499.95	316.30	377.50	262.73	384.97	196.33	520.62	188.78
75	265.11	485.45	296.46	255.94	327.66	258.69	375.06	303.22	435.42	234.83
76	458.12	439.98	549.79	245.65	278.54	272.26	433.14	505.97	199.06	318.04
77	655.02	396.20	583.18	328.70	249.86	371.39	509.31	499.01	204.93	260.25
78	294.82	356.92	407.26	250.84	359.66	477.32	350.29	389.80	197.71	163.19

79	299.67	411.69	281.43	249.46	420.01	329.34	335.93	500.33	239.14	295.71
80	221.54	211.17	253.25	244.39	324.58	255.22	206.64	520.24	456.96	301.57
81	328.72	284.03	295.43	362.49	225.88	386.39	270.85	223.33	290.95	280.64
82	307.60	259.46	262.10	409.75	276.22	450.15	263.55	190.45	329.72	304.42
83	293.25	417.48	270.59	311.61	422.50	528.64	201.92	280.06	251.54	198.00
84	308.19	594.55	183.90	303.73	307.93	583.36	308.13	250.19	336.43	367.44
85	219.22	226.95	371.19	369.52	273.57	360.29	285.54	394.39	478.02	333.04
86	292.38	370.65	479.40	307.38	339.09	272.29	316.40	364.32	298.49	232.42
87	386.68	376.24	456.52	255.33	296.32	348.81	318.10	610.95	324.29	261.12
88	181.26	246.94	397.31	201.95	171.31	338.57	214.05	339.48	332.95	534.69
89	231.53	227.79	329.46	251.06	417.39	380.49	212.97	216.15	312.95	724.78
90	251.53	448.79	273.92	309.87	334.31	384.20	340.20	383.82	345.70	673.20
91	252.76	261.55	307.77	327.80	321.68	489.08	342.82	314.89	320.25	348.13
92	459.45	216.45	605.52	249.21	361.81	348.97	314.44	247.48	362.81	248.67
93	266.58	388.66	445.42	262.60	287.87	344.55	397.16	226.27	336.18	245.94
94	216.21	287.59	383.90	272.88	244.03	307.04	533.84	383.18	241.13	321.84
95	324.54	281.75	242.22	283.87	189.56	284.26	377.75	277.06	307.84	383.28
96	268.94	347.03	330.48	251.24	245.39	369.02	306.25	238.45	275.07	360.24
97	383.49	379.07	275.21	237.02	292.70	447.65	263.39	331.85	272.53	373.26
98	306.17	267.27	329.18	314.22	382.75	349.38	378.22	342.60	212.17	569.28
99	303.95	217.36	173.29	333.38	339.83	290.51	271.12	455.34	295.74	369.47
100	205.92	261.39	211.51	348.77	208.73	433.49	329.26	449.60	297.85	329.70

Appendix F

Ensemble Batch Means and Cumulative Means, Averaged over 10 Replications

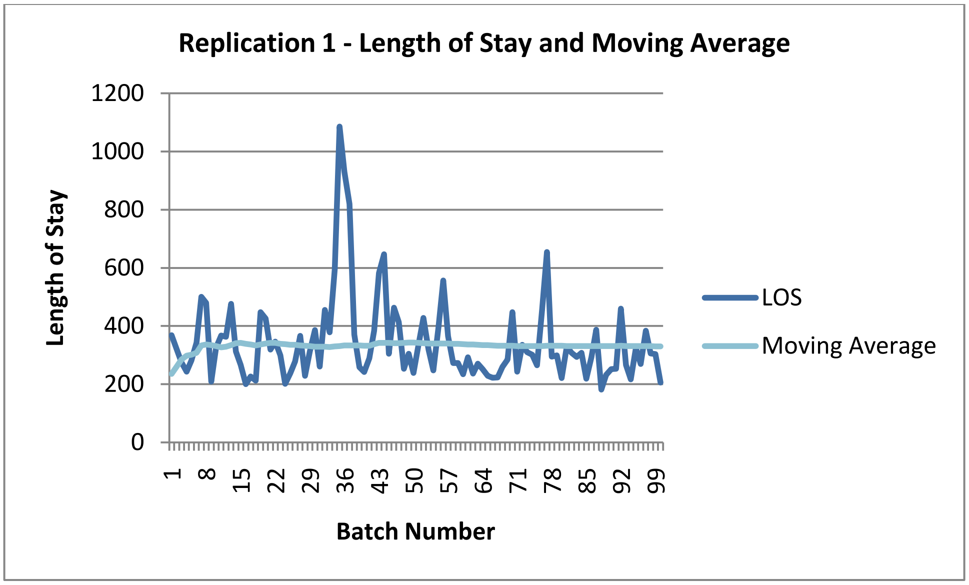
Run Length (Minutes)	Batch	Average Batch Means	Cumulative Average (No Deletion)	Cumulative Average (Delete 1)	Cumulative Average (Delete 2)
1440	1	235.02	235.02		
2880	2	286.53	260.78	286.53	
4320	3	332.02	284.52	309.28	332.02
5760	4	338.64	298.05	319.06	335.33
7200	5	313.87	301.22	317.76	328.18
8640	6	343.98	308.34	323.01	332.13
10080	7	484.86	333.56	349.98	362.67
11520	8	354.30	336.15	350.60	361.28
12960	9	317.65	334.10	346.48	355.05
14400	10	300.03	330.69	341.32	348.17
15840	11	289.65	326.96	336.15	341.67
17280	12	349.70	328.85	337.38	342.47
18720	13	397.34	334.12	342.38	347.46
20160	14	434.86	341.32	349.49	354.74
21600	15	346.46	341.66	349.28	354.10
23040	16	299.54	339.03	345.96	350.21
24480	17	289.03	336.09	342.40	346.13
25920	18	294.50	333.78	339.59	342.90
27360	19	391.02	336.79	342.44	345.73
28800	20	406.19	340.26	345.80	349.09
30240	21	386.97	342.48	347.86	351.08
31680	22	326.05	341.74	346.82	349.83
33120	23	283.59	339.21	343.94	346.68
34560	24	298.22	337.50	341.96	344.48
36000	25	289.34	335.57	339.76	342.08
37440	26	346.89	336.01	340.05	342.28
38880	27	275.98	333.79	337.58	339.63
40320	28	292.73	332.32	335.92	337.82
41760	29	286.05	330.72	334.14	335.91
43200	30	281.99	329.10	332.34	333.98
44640	31	308.91	328.45	331.56	333.12
46080	32	324.44	328.32	331.33	332.83
47520	33	313.79	327.88	330.78	332.21
48960	34	380.81	329.44	332.30	333.73
50400	35	403.13	331.54	334.38	335.83
51840	36	379.37	332.87	335.67	337.11
53280	37	357.53	333.54	336.28	337.70

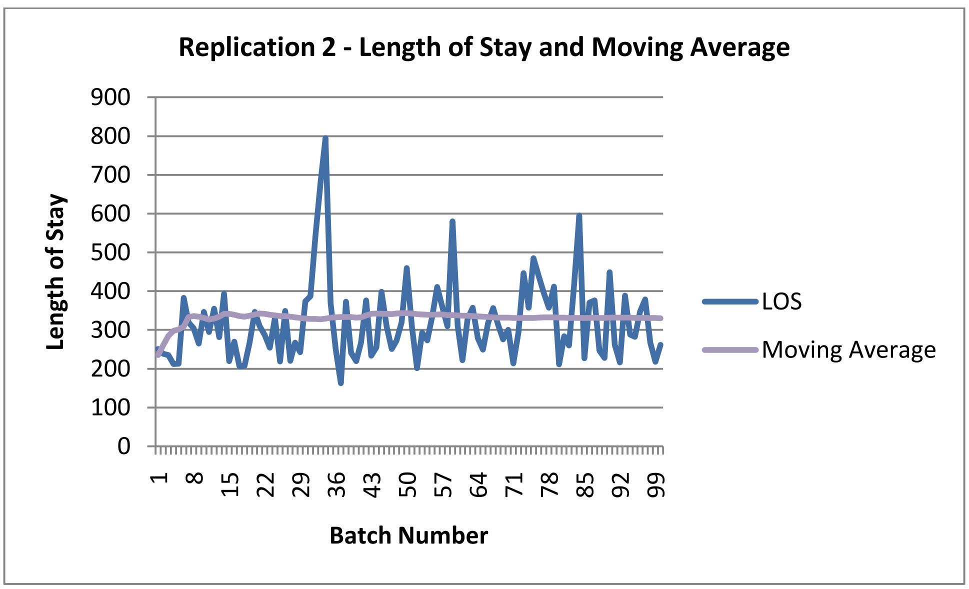
54720	38	324.39	333.30	335.96	337.33
56160	39	323.76	333.05	335.63	336.96
57600	40	289.16	331.96	334.44	335.70
59040	41	360.35	332.65	335.09	336.34
60480	42	544.05	337.68	340.19	341.53
61920	43	503.21	341.53	344.07	345.47
63360	44	365.61	342.08	344.57	345.95
64800	45	336.00	341.94	344.37	345.72
66240	46	319.15	341.45	343.81	345.12
67680	47	308.50	340.75	343.05	344.30
69120	48	419.01	342.38	344.66	345.93
70560	49	385.99	343.27	345.52	346.78
72000	50	341.77	343.24	345.45	346.67
73440	51	285.89	342.11	344.26	345.43
74880	52	290.06	341.11	343.19	344.33
76320	53	285.53	340.06	342.08	343.17
77760	54	301.08	339.34	341.31	342.36
79200	55	340.44	339.36	341.29	342.33
80640	56	388.31	340.24	342.15	343.18
82080	57	305.16	339.62	341.49	342.49
83520	58	281.20	338.61	340.43	341.39
84960	59	337.29	338.59	340.38	341.32
86400	60	280.98	337.63	339.37	340.28
87840	61	261.75	336.39	338.08	338.95
89280	62	325.45	336.21	337.87	338.72
90720	63	323.26	336.00	337.63	338.47
92160	64	261.21	334.84	336.42	337.23
93600	65	278.29	333.97	335.51	336.29
95040	66	302.27	333.49	335.00	335.76
96480	67	271.15	332.56	334.03	334.76
97920	68	299.16	332.06	333.51	334.22
99360	69	322.13	331.92	333.35	334.04
100800	70	323.57	331.80	333.20	333.89
102240	71	291.95	331.24	332.61	333.28
103680	72	318.11	331.06	332.41	333.07
105120	73	307.40	330.73	332.06	332.70
106560	74	340.61	330.87	332.18	332.81
108000	75	323.78	330.77	332.07	332.69
109440	76	370.06	331.29	332.57	333.20
110880	77	405.78	332.26	333.54	334.16

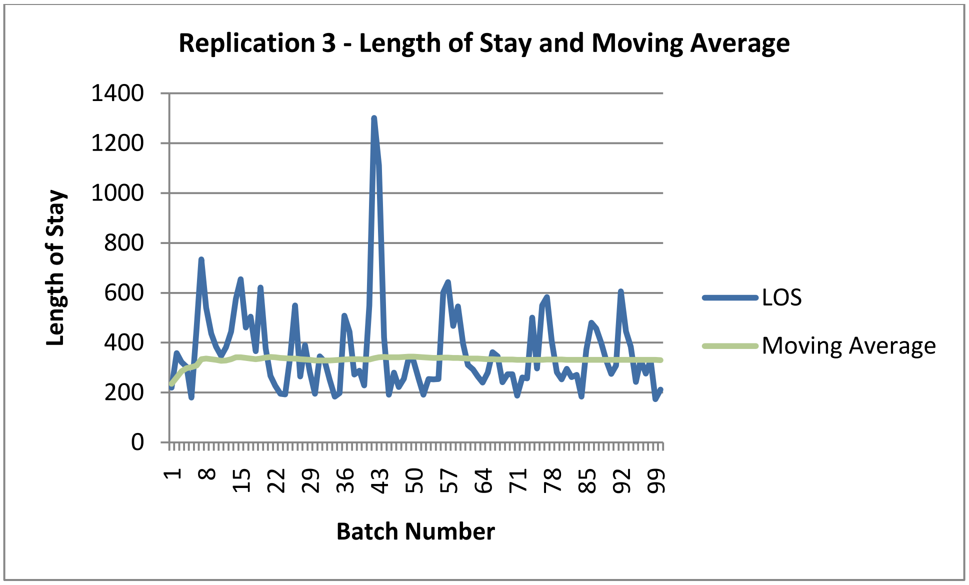
112320	78	324.78	332.16	333.42	334.04
113760	79	336.27	332.21	333.46	334.07
115200	80	299.56	331.80	333.03	333.63
116640	81	294.87	331.35	332.55	333.14
118080	82	305.34	331.03	332.22	332.79
119520	83	317.56	330.87	332.04	332.60
120960	84	354.38	331.15	332.31	332.87
122400	85	331.17	331.15	332.29	332.85
123840	86	327.28	331.10	332.24	332.78
125280	87	363.44	331.48	332.60	333.14
126720	88	295.85	331.07	332.18	332.71
128160	89	330.46	331.06	332.16	332.68
129600	90	374.55	331.55	332.63	333.16
131040	91	328.67	331.52	332.59	333.11
132480	92	341.48	331.62	332.69	333.20
133920	93	320.12	331.50	332.55	333.06
135360	94	319.16	331.37	332.41	332.90
136800	95	295.21	330.99	332.01	332.50
138240	96	299.21	330.66	331.66	332.14
139680	97	325.62	330.61	331.60	332.08
141120	98	345.12	330.75	331.74	332.21
142560	99	305.00	330.49	331.47	331.93
144000	100	307.62	330.27	331.23	331.68

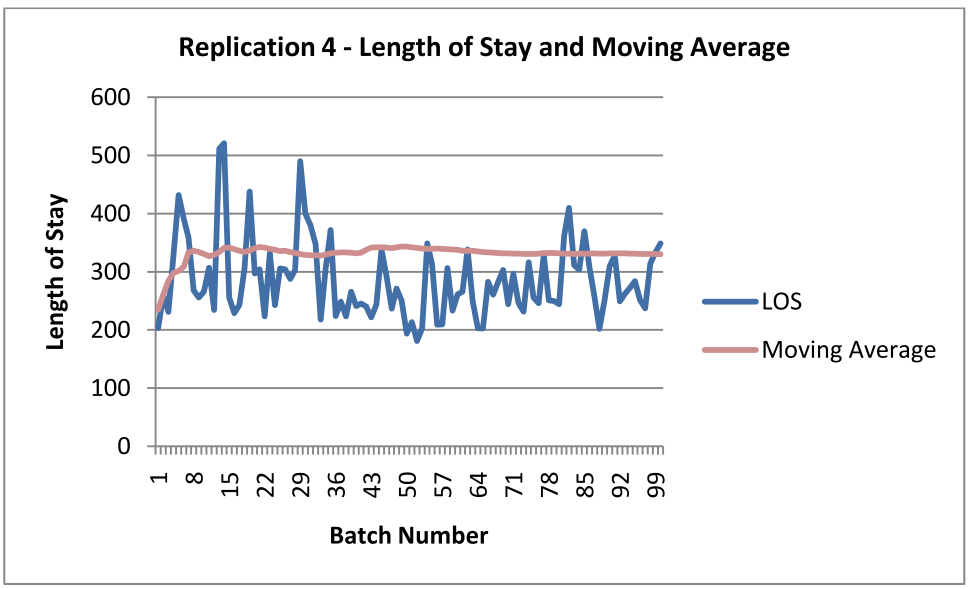
Appendix G

Length of Stay and Moving Average Diagrams – 10 Replications


Replication 1 - Length of Stay and Moving Average
Length of Stay
1200
1000
800
600
400
200
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average


Replication 2 - Length of Stay and Moving Average
Length of Stay
900
800
700
600
500
400
300
200
100
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average


Replication 3 - Length of Stay and Moving Average
Length of Stay
1400
1200
1000
800
600
400
200
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average


Replication 4 - Length of Stay and Moving Average
Length of Stay
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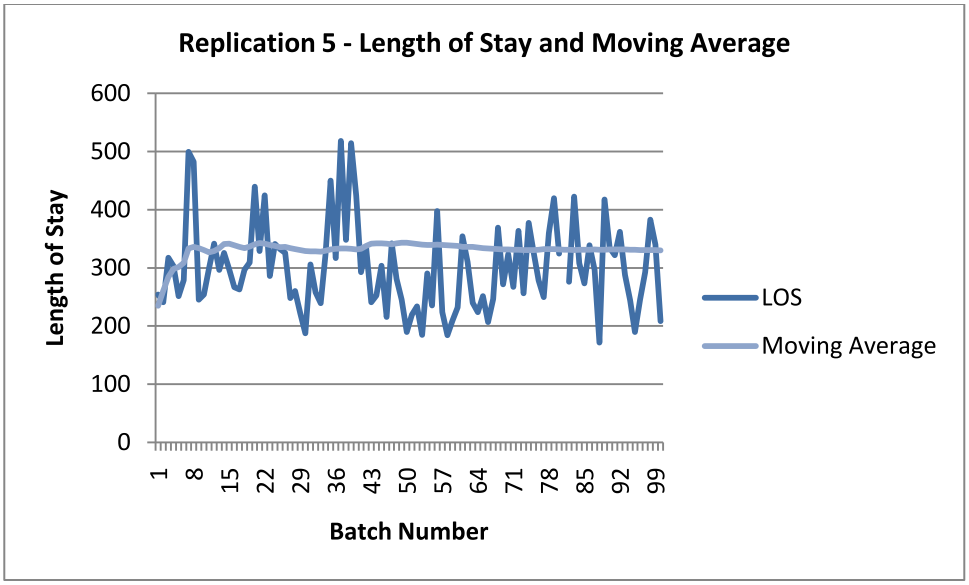
500
400
300
200
100
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average


Replication 5 - Length of Stay and Moving Average
Length of Stay
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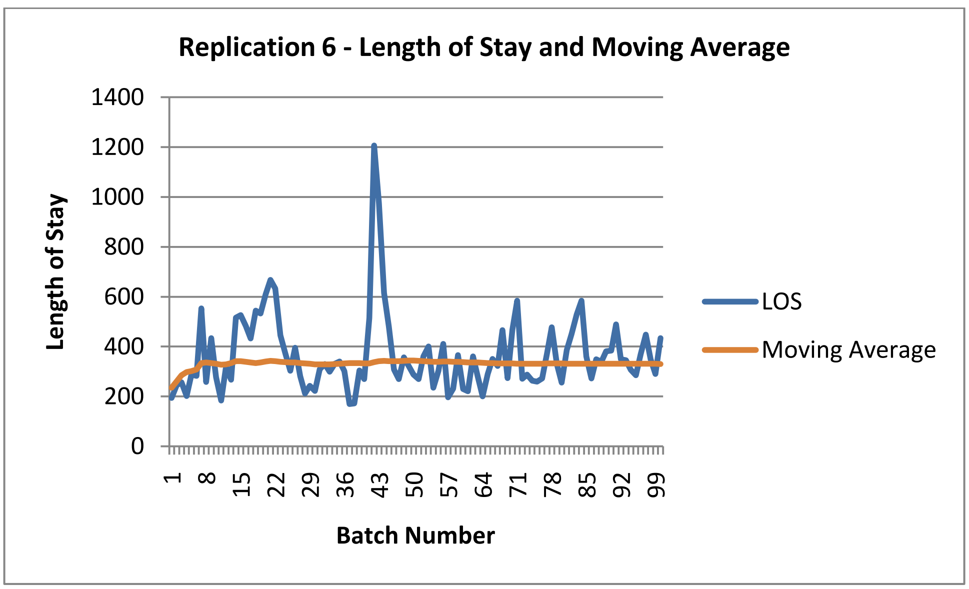
500
400
300
200
100
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average


Replication 6 - Length of Stay and Moving Average
Length of Stay
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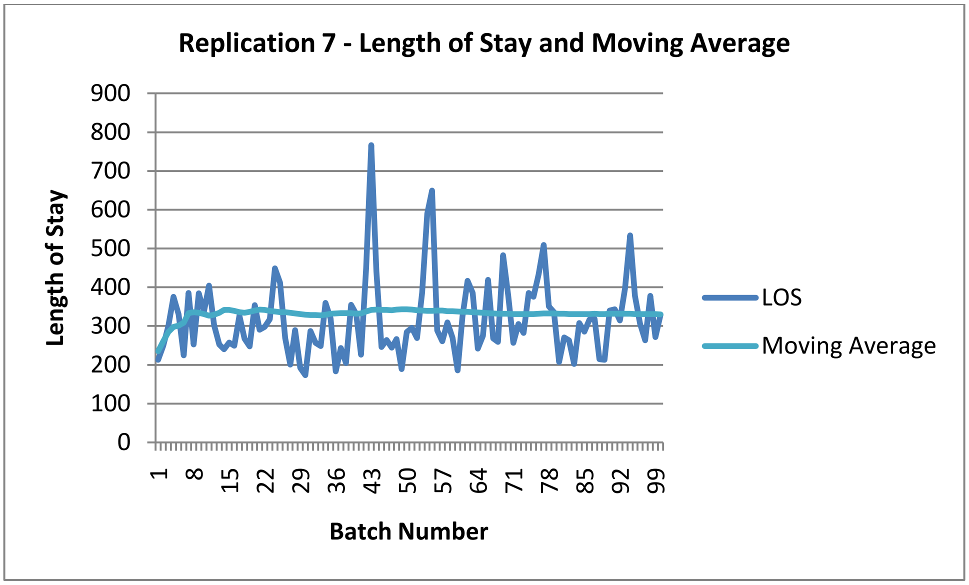
1200
1000
800
600
400
200
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average



Replication 7 - Length of Stay and Moving Average
Length of Stay
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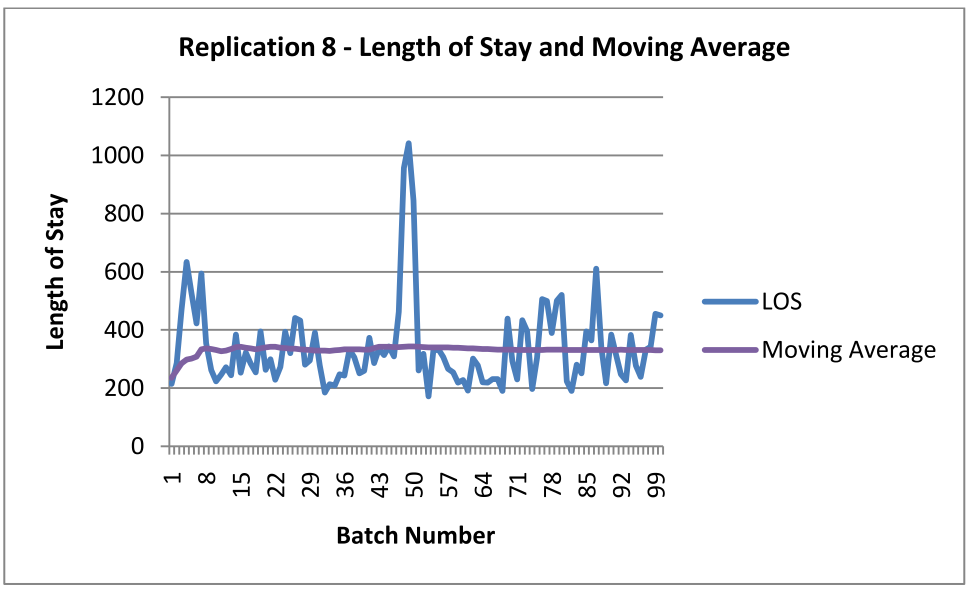
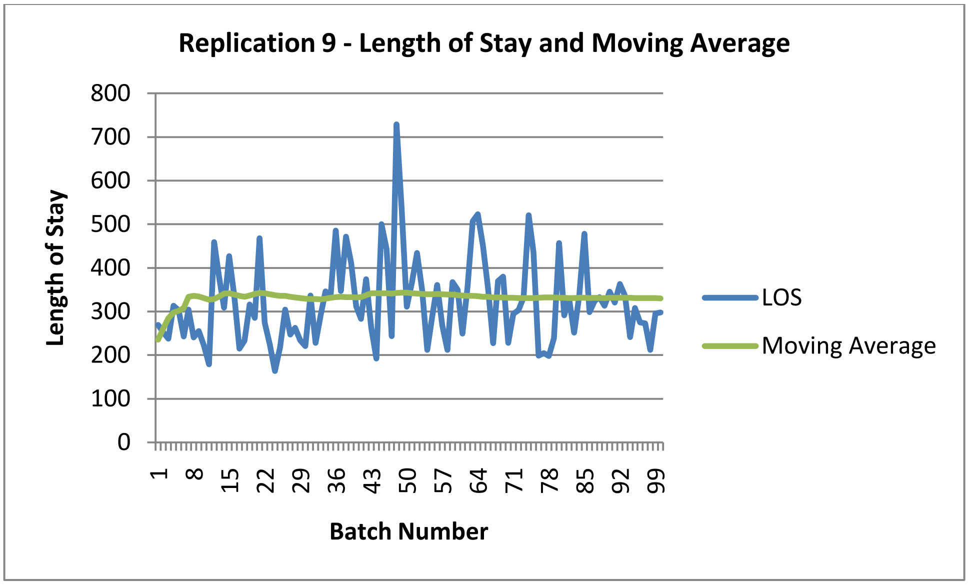
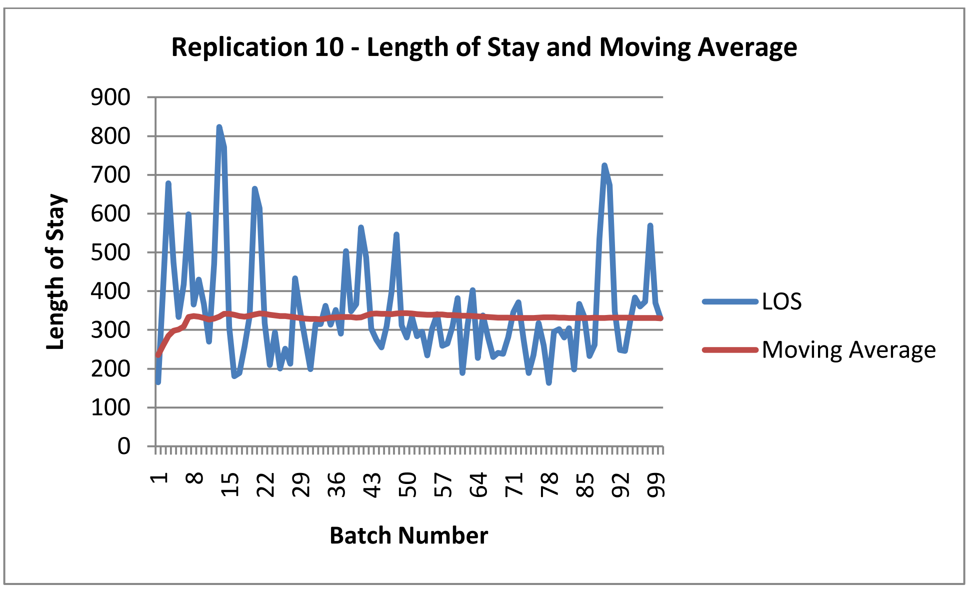
800
700
600
500
400
300
200
100
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average



Replication 8 - Length of Stay and Moving Average
Length of Stay
1200
1000
800
600
400
200
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average


Replication 9 - Length of Stay and Moving Average
800
700
600
500
400
300
200
100
0
Length of Stay
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average


Replication 10 - Length of Stay and Moving Average
900
800
700
600
500
400
300
200
100
0
Length of Stay
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Batch Number
LOS
Moving Average

Appendix H

Output Results – Observations of Each Replication for Each Scenario

Scenario 1	Replication									
Day	1	2	3	4	5	6	7	8	9	10
1	255.18	267.78	364.60	225.70	289.10	236.56	267.08	445.77	225.69	619.89
2	266.91	234.16	312.44	336.63	337.77	183.63	321.84	544.17	297.92	442.20
3	313.62	241.98	176.62	431.22	273.23	225.69	248.14	497.03	275.45	350.32
4	416.09	362.43	578.98	373.10	409.39	262.94	258.34	472.80	241.57	433.11
5	488.03	326.38	948.77	367.47	585.79	513.87	410.80	613.74	340.72	610.19
6	481.59	322.47	586.44	285.70	511.02	234.73	265.56	334.32	278.89	484.86
7	192.22	259.04	434.38	235.25	363.56	402.34	362.42	216.17	260.67	307.05
8	289.22	313.95	349.19	285.68	283.14	255.20	322.63	253.44	275.43	260.95
9	358.67	303.91	333.33	289.66	316.72	192.35	399.90	219.17	202.55	267.85
10	355.65	378.32	379.51	259.59	319.96	327.34	249.39	277.19	294.46	431.09
11	511.07	284.16	464.65	510.58	305.27	274.87	241.36	209.95	356.45	798.90
12	397.35	425.54	585.08	521.83	344.66	583.43	212.38	338.05	336.84	992.27
13	300.47	299.68	618.68	254.28	336.44	551.16	211.90	229.71	405.46	359.95
14	216.79	263.29	432.68	255.89	231.26	607.95	266.44	305.24	386.03	197.54
15	236.26	212.23	595.91	247.93	244.71	678.65	330.77	233.28	199.52	237.71
16	254.48	217.31	402.68	341.30	366.34	645.00	272.49	295.12	263.13	299.22
17	405.57	278.26	734.81	410.93	392.04	495.32	282.21	437.75	268.88	299.40
18	474.66	327.72	427.77	336.33	480.76	866.78	387.33	318.10	268.79	573.13
19	322.24	293.09	281.22	326.24	356.88	725.71	353.09	323.35	395.96	420.40
20	334.15	315.15	255.72	246.32	420.71	505.48	326.17	230.38	300.91	309.74
21	268.72	287.48	191.19	332.95	269.73	530.87	281.52	235.01	258.60	165.97
22	213.48	343.66	191.77	248.41	466.03	428.75	366.34	404.24	181.79	292.47
23	259.30	210.95	333.25	321.03	298.24	415.38	352.80	294.42	218.73	198.96
24	325.23	366.94	503.87	305.33	293.09	364.71	342.62	470.43	276.73	264.97
25	370.71	249.18	256.16	284.83	278.22	263.72	204.74	443.35	323.65	298.39
26	236.17	272.92	376.62	280.94	215.17	243.00	226.02	205.94	262.76	422.54
27	315.61	229.52	258.17	460.82	237.65	198.05	222.21	272.34	209.39	373.50
28	349.64	342.78	218.12	385.74	199.16	258.57	203.91	338.78	207.37	301.44
29	362.63	441.90	412.83	367.56	332.96	358.81	321.75	320.00	341.52	179.02
30	541.34	342.20	346.13	368.83	282.95	343.49	285.79	188.62	233.67	268.27
31	486.80	549.43	223.83	208.18	240.31	343.74	257.67	192.97	279.28	290.85
32	726.76	735.49	186.08	252.54	315.61	269.66	259.24	268.70	318.76	277.14
33	1143.27	297.95	197.39	327.65	445.58	362.81	214.92	275.50	340.35	320.54
34	1000.99	210.66	269.30	250.71	507.08	245.60	188.59	258.48	493.10	345.78
35	962.90	154.49	366.29	238.65	486.87	167.24	266.96	364.84	379.56	230.27
36	358.61	347.34	293.65	232.58	415.48	164.20	277.20	234.19	446.42	368.66
37	284.60	251.26	283.93	312.65	472.30	339.88	314.97	262.47	393.44	457.04
38	258.41	198.32	246.25	262.45	283.51	320.94	233.12	255.44	356.22	378.57

39	339.98	251.51	585.75	235.85	224.81	463.42	205.07	374.55	296.65	516.88
40	305.55	365.90	1323.12	221.11	350.74	1014.25	459.51	256.97	399.42	529.30
41	573.36	207.09	1099.08	198.76	200.37	882.65	863.85	354.01	336.20	333.80
42	664.65	224.49	448.45	237.02	242.93	548.39	456.37	283.54	199.53	307.14
43	281.77	392.53	189.09	325.20	310.78	407.54	219.62	289.64	482.55	247.34
44	437.13	291.16	270.23	265.43	204.65	309.69	206.48	324.04	465.74	277.63
45	410.17	221.16	206.00	232.24	335.85	275.33	269.05	503.66	294.77	328.95
46	269.30	210.60	245.29	316.00	276.29	350.74	224.51	914.51	702.37	654.89
47	331.93	322.12	325.57	240.67	231.50	273.21	236.30	1032.58	518.20	448.92
48	284.87	439.58	292.03	218.78	234.05	264.05	260.46	797.55	283.12	298.44
49	308.90	291.93	284.13	203.09	206.65	264.10	228.88	328.26	344.33	311.90
50	413.20	218.86	194.60	182.03	214.63	372.32	216.08	272.58	390.25	362.45
51	300.04	250.25	251.08	216.33	168.04	416.64	247.13	150.46	318.74	289.83
52	308.66	263.19	229.81	335.01	247.44	257.86	429.19	274.69	232.25	248.07
53	426.49	290.97	255.13	292.46	244.10	333.23	509.26	330.47	303.89	249.88
54	483.67	325.56	623.36	249.08	425.80	386.72	283.37	302.69	396.63	268.77
55	281.91	368.85	550.20	225.07	226.08	210.00	200.41	228.85	280.44	255.05
56	209.66	292.30	514.05	273.84	192.32	283.63	314.69	214.43	205.37	272.15
57	292.99	585.53	576.81	257.80	218.61	429.27	267.92	217.08	286.54	320.38
58	259.63	292.82	457.73	240.48	254.69	273.74	223.83	340.90	337.42	372.83
59	265.42	238.79	330.60	276.71	354.14	234.52	340.09	228.12	308.92	194.33
60	275.51	294.90	313.09	311.06	275.02	370.10	217.23	260.24	403.25	317.00
61	261.85	321.88	245.52	240.16	297.42	280.10	205.42	300.34	554.73	383.87
62	252.48	246.21	258.28	165.11	205.60	262.30	280.25	305.86	541.31	197.23
63	231.22	219.48	296.42	196.95	274.54	310.01	234.40	202.89	434.47	404.74
64	239.09	265.86	289.43	293.38	267.49	325.50	378.85	206.28	317.62	233.61
65	249.40	325.93	301.41	272.41	266.24	348.99	286.40	233.76	216.75	215.05
66	229.24	326.54	245.05	267.51	327.16	491.58	314.31	220.23	357.74	269.75
67	267.49	255.82	291.81	317.77	326.19	287.86	514.45	361.28	428.82	242.43
68	435.53	297.48	301.43	274.44	296.37	469.96	377.32	242.89	247.95	290.22
69	249.15	192.63	217.34	339.08	285.31	616.06	248.83	233.03	304.21	285.96
70	274.67	347.85	329.04	270.43	351.79	308.20	283.65	432.94	287.21	361.96
71	264.63	473.20	247.49	216.51	319.97	383.82	288.55	387.77	323.25	303.78
72	321.24	428.45	457.00	261.20	323.31	363.82	243.59	246.05	466.42	182.36
73	290.47	471.48	368.02	321.77	284.59	287.40	329.81	261.25	415.07	274.97
74	437.69	404.96	538.25	219.19	257.43	245.44	445.72	379.23	229.60	398.83
75	619.78	313.79	569.09	255.78	260.80	383.27	581.43	278.48	191.60	315.95
76	294.40	331.06	470.25	279.08	341.20	493.26	238.34	299.04	226.36	176.97
77	318.00	343.71	338.71	267.52	343.05	342.33	345.97	378.62	229.80	270.79
78	205.17	229.71	246.04	247.90	309.57	262.07	272.73	555.42	516.98	298.68

79	282.08	246.04	294.99	326.73	228.27	482.59	276.05	229.31	264.24	386.37
80	281.09	253.51	262.34	358.03	290.87	428.59	227.23	174.73	337.67	348.31
81	278.28	448.34	263.65	335.48	434.87	489.57	298.71	278.30	249.90	224.44
82	389.33	586.36	171.93	325.74	315.52	582.42	357.88	254.71	360.63	287.59
83	264.12	239.61	374.38	326.41	264.47	362.34	322.74	348.25	445.73	361.55
84	254.24	237.58	496.58	281.29	354.29	275.65	264.66	344.57	276.73	307.57
85	335.95	334.03	444.54	249.54	258.65	314.09	203.32	686.39	313.15	263.89
86	181.85	297.05	397.88	185.76	161.79	513.81	206.95	405.43	325.62	462.79
87	217.25	216.07	353.32	227.03	389.17	417.45	170.07	209.01	312.64	740.18
88	240.52	394.13	278.16	299.98	349.67	279.93	320.71	384.05	347.99	663.17
89	250.30	276.31	302.10	308.90	317.18	372.32	392.02	242.10	328.89	366.19
90	493.47	265.64	634.46	314.63	334.90	282.12	192.64	273.11	363.06	179.12
91	229.44	324.40	429.54	237.79	276.13	261.47	347.05	210.14	319.96	224.99
92	238.31	263.85	357.24	233.44	251.43	338.09	451.69	333.35	226.81	298.42
93	261.99	217.47	262.54	334.73	173.70	250.82	488.92	297.06	271.64	353.56
94	280.23	291.24	334.48	260.05	238.47	358.29	384.96	197.28	337.00	384.16
95	416.87	342.95	273.99	263.32	243.11	452.38	268.54	338.70	264.07	457.70
96	291.04	315.12	349.07	361.89	413.69	310.49	398.19	436.54	259.17	548.51
97	253.09	259.31	198.45	388.32	238.86	260.87	252.83	375.57	327.44	319.55
98	169.60	237.05	206.46	347.36	232.90	506.29	257.86	307.78	252.19	508.65
99	314.54	408.56	363.28	255.63	271.16	608.71	245.45	243.50	435.95	347.30
100	411.61	308.04	233.38	197.94	257.49	229.64	157.54	241.02	428.72	362.74

Scenario 2	Replication									
Day	1	2	3	4	5	6	7	8	9	10
1	260.71	229.83	351.96	216.27	285.11	219.15	247.76	397.50	228.36	501.13
2	271.26	228.79	314.57	311.17	325.73	192.72	293.60	289.48	285.49	434.18
3	309.12	242.61	170.91	406.14	270.22	239.14	215.38	333.28	264.50	344.44
4	324.69	282.32	341.07	310.93	398.55	248.76	249.31	299.90	236.83	322.52
5	394.36	279.83	363.10	304.25	446.08	304.81	381.99	268.45	276.55	299.91
6	430.78	274.43	383.95	266.45	457.82	236.60	249.31	245.32	245.68	342.39
7	199.97	246.98	382.08	226.37	344.81	409.56	381.19	208.70	250.62	268.88
8	294.57	313.41	357.15	278.28	254.03	260.53	345.33	252.93	262.45	220.02
9	292.63	291.35	334.04	282.18	318.26	191.55	458.52	213.77	179.24	255.94
10	308.06	349.03	386.72	258.02	319.03	278.50	266.00	262.70	296.15	349.55
11	310.50	255.36	367.61	421.46	317.88	224.53	225.39	211.34	303.53	338.72
12	300.41	341.63	310.36	398.12	314.97	556.91	191.02	291.17	280.26	318.60
13	267.41	232.72	327.76	253.69	279.10	545.29	243.00	231.49	384.55	271.82
14	211.45	227.63	324.91	261.56	243.84	550.72	246.57	279.05	384.08	196.15
15	223.67	195.14	408.87	250.35	220.86	612.51	308.87	223.99	206.39	237.29
16	228.97	210.83	353.67	270.23	340.64	603.62	270.95	264.96	248.43	268.24

17	355.91	272.09	504.57	253.43	378.06	475.76	280.92	355.73	269.21	300.82
18	398.00	291.82	326.15	212.99	337.28	685.00	349.58	278.71	218.25	272.14
19	296.62	263.91	273.83	231.59	318.79	667.02	313.77	276.58	289.21	298.68
20	281.94	304.38	240.13	233.78	404.94	435.96	267.49	175.75	275.76	241.84
21	239.90	288.49	188.70	325.25	268.13	525.68	284.65	234.19	224.55	163.72
22	204.03	347.70	182.58	242.97	422.51	370.46	348.64	289.43	182.76	244.72
23	242.87	207.18	331.00	322.73	279.70	393.84	287.79	273.15	221.26	190.15
24	308.54	369.15	452.72	310.95	279.08	297.05	285.82	337.98	271.34	256.49
25	341.00	220.93	231.58	281.10	238.48	292.71	197.10	297.95	330.22	280.08
26	234.36	233.99	322.84	262.83	201.25	199.91	207.87	216.16	232.84	282.63
27	269.65	243.28	263.31	395.36	236.07	192.43	207.40	248.70	222.86	300.55
28	265.81	340.22	217.53	384.04	191.84	255.22	171.68	342.36	201.51	254.86
29	356.70	430.07	383.02	342.52	284.07	363.18	261.88	289.96	286.97	178.18
30	435.99	357.95	286.03	351.98	233.80	321.65	268.21	178.71	215.22	264.48
31	396.85	484.45	221.80	210.40	242.53	339.96	248.93	182.12	264.32	295.18
32	428.47	489.15	169.19	235.69	309.12	274.59	285.78	212.24	279.14	257.76
33	314.64	261.35	196.65	285.46	435.31	301.00	219.68	205.40	282.32	214.53
34	273.08	198.83	442.33	237.78	509.13	234.96	184.47	229.71	418.40	336.85
35	371.69	162.49	412.24	240.79	474.78	168.78	270.60	357.00	326.36	206.03
36	293.32	319.38	260.64	187.63	355.51	152.34	291.03	231.25	362.27	352.44
37	290.91	232.05	284.06	300.91	447.81	304.46	311.13	262.75	307.89	456.42
38	259.23	190.45	241.99	252.17	266.45	308.26	254.71	207.41	339.44	369.30
39	290.93	257.99	298.24	239.13	206.90	364.01	204.41	278.13	272.67	474.02
40	279.35	336.91	383.24	235.25	313.78	455.03	413.70	229.84	258.53	436.06
41	402.10	206.41	419.78	181.01	194.84	358.84	626.41	216.36	297.21	322.41
42	429.40	245.32	325.99	242.91	231.25	274.36	331.40	221.51	191.86	299.46
43	298.31	274.16	184.21	314.08	292.36	336.94	218.40	266.73	341.92	244.36
44	415.82	331.13	258.38	273.44	184.98	348.57	213.53	294.12	398.29	266.51
45	352.33	211.18	205.56	219.94	334.74	284.90	272.03	423.08	270.88	337.16
46	246.91	211.18	235.68	286.13	228.36	321.57	235.08	445.17	505.87	505.29
47	203.02	238.49	231.53	246.49	219.91	252.33	231.10	262.82	408.13	409.62
48	280.00	374.67	298.57	200.82	221.95	256.85	268.69	307.14	272.78	295.47
49	294.11	291.47	229.30	206.67	190.02	251.43	248.29	298.08	299.46	309.59
50	385.02	218.27	191.65	197.86	231.38	352.34	216.43	219.52	307.02	328.02
51	278.35	234.15	249.12	187.54	165.40	366.89	218.06	138.39	311.36	292.93
52	280.51	255.38	217.95	347.25	222.17	245.51	401.98	260.32	232.46	248.73
53	306.37	262.20	245.13	261.67	223.36	250.11	455.53	277.23	295.52	205.49
54	400.26	278.83	573.35	212.41	341.22	314.33	279.16	236.83	352.97	247.75
55	273.49	387.42	526.66	222.96	197.85	195.95	213.64	215.74	282.52	251.71
56	210.58	290.55	458.49	258.71	181.32	229.78	298.55	197.36	211.29	272.36

57	292.71	402.83	510.29	255.22	213.09	356.59	245.96	193.93	283.28	328.73
58	249.30	265.16	435.26	233.53	236.70	268.92	198.26	327.69	330.21	329.33
59	267.72	229.23	296.02	231.47	360.90	242.39	362.12	197.36	282.47	190.74
60	255.63	293.48	276.93	260.45	246.06	279.24	211.40	230.82	364.56	263.58
61	178.09	333.00	221.68	231.10	295.14	217.23	193.28	198.06	374.56	290.40
62	247.05	254.99	249.40	154.14	202.94	248.00	261.85	288.64	356.93	171.72
63	238.27	219.67	261.63	190.00	267.38	299.70	230.74	179.86	382.76	336.58
64	233.85	243.51	255.50	288.71	251.15	358.56	336.19	201.03	287.37	223.91
65	247.32	297.04	234.38	268.81	268.33	380.79	289.82	255.78	215.13	217.83
66	223.69	304.98	206.43	233.38	307.41	489.00	277.95	218.99	365.96	217.44
67	236.22	187.56	236.29	258.28	296.36	282.31	354.57	323.21	395.30	195.33
68	258.75	317.76	291.66	263.23	282.18	461.84	316.78	186.04	199.04	243.39
69	235.40	191.41	197.68	308.49	256.47	414.99	226.54	221.68	279.72	288.43
70	255.99	349.47	311.97	199.27	294.66	302.40	283.29	301.48	278.04	309.72
71	254.82	399.25	264.38	199.10	322.05	294.97	251.04	285.07	317.49	300.97
72	312.94	358.17	456.81	242.71	322.86	354.90	200.10	194.62	287.23	176.36
73	293.49	375.67	275.30	320.70	301.58	278.53	263.93	243.05	299.64	283.93
74	281.21	347.37	328.13	208.05	211.02	223.57	388.20	325.13	212.01	288.65
75	274.50	303.56	234.74	223.42	267.00	246.08	353.05	296.25	169.68	210.64
76	289.76	321.94	320.31	246.57	330.43	391.42	225.51	233.78	234.92	166.05
77	286.01	327.84	282.94	269.52	276.25	277.71	344.86	316.04	241.55	248.28
78	209.34	224.02	240.70	205.70	308.74	249.94	246.39	310.13	431.42	300.29
79	262.22	239.66	275.96	445.15	245.23	450.99	260.63	207.61	248.71	377.68
80	262.37	223.84	246.86	384.88	291.47	391.07	236.45	166.15	312.99	261.44
81	262.75	221.06	262.31	305.68	397.64	435.20	300.77	261.72	220.04	211.28
82	380.12	267.79	174.50	289.59	246.07	395.14	307.43	262.24	340.01	203.78
83	234.95	223.50	348.81	312.10	245.35	261.35	292.35	238.92	337.32	255.74
84	252.44	238.96	372.80	265.45	265.54	244.22	224.91	282.67	261.64	261.10
85	319.42	327.28	356.52	238.04	256.75	326.53	225.40	408.91	308.77	259.16
86	177.18	316.54	305.54	167.19	160.08	521.01	223.16	309.85	299.41	389.25
87	213.36	215.60	239.65	225.14	399.45	410.78	161.23	204.42	278.61	362.45
88	222.47	314.90	243.81	298.03	331.24	241.31	298.04	276.26	349.47	281.13
89	212.28	253.67	268.82	303.13	315.19	303.35	399.70	230.33	319.97	305.66
90	336.44	257.40	312.90	276.93	325.66	231.11	207.45	270.03	311.71	177.76
91	230.55	236.20	371.74	229.53	270.05	266.01	352.07	208.04	300.91	222.01
92	228.98	233.27	359.56	232.23	227.85	329.59	399.49	278.45	214.29	246.78
93	260.12	217.51	252.44	321.96	170.66	234.20	430.44	288.10	258.74	291.27
94	265.70	284.95	316.11	251.35	305.60	303.81	387.47	200.78	330.96	344.03
95	341.74	289.90	206.68	238.97	231.38	328.75	232.34	290.04	266.54	335.56
96	261.95	270.95	325.68	243.68	304.69	253.52	305.44	323.78	254.08	471.73

97	240.16	242.26	187.70	296.45	197.65	263.88	252.14	290.94	256.02	309.02
98	169.97	236.66	201.91	257.72	220.90	477.98	240.06	304.10	239.09	527.12
99	315.06	400.26	362.43	251.85	270.72	525.76	251.67	198.15	342.38	325.39
100	397.99	309.99	209.66	185.22	259.81	214.12	153.60	251.06	292.17	341.54

Scenario 3 Replication

Day	1	2	3	4	5	6	7	8	9	10
1	250.32	236.29	356.70	294.93	310.49	244.21	254.06	507.95	226.44	628.50
2	247.73	223.79	308.83	352.78	328.25	179.68	362.99	556.54	296.74	459.00
3	299.08	245.84	176.58	439.18	267.82	240.42	243.74	497.35	272.94	376.83
4	411.08	369.89	491.74	365.18	382.50	267.18	256.23	474.92	264.14	435.02
5	504.48	331.15	805.53	364.20	529.42	539.46	327.41	627.94	340.72	557.41
6	481.05	322.45	558.45	271.59	501.09	238.29	268.70	347.23	271.51	404.52
7	186.44	256.65	426.00	220.21	364.21	407.92	324.32	209.52	259.70	311.56
8	291.25	309.66	357.73	278.48	291.39	256.87	410.79	257.90	266.97	270.92
9	372.29	299.71	323.95	290.14	316.01	176.63	442.72	213.45	183.98	266.41
10	358.97	372.62	346.62	280.72	318.70	318.98	293.15	278.53	371.88	431.74
11	481.48	267.39	454.96	521.62	319.47	267.19	243.64	222.10	398.60	740.80
12	414.88	420.13	593.61	512.79	350.64	558.59	207.56	352.66	319.02	970.64
13	304.83	293.93	682.20	255.38	335.38	507.61	237.92	234.44	406.31	343.55
14	213.05	242.28	447.63	261.46	238.01	551.17	276.40	283.30	398.71	193.47
15	235.76	191.30	589.63	258.29	236.14	648.25	333.54	236.76	202.08	243.35
16	255.87	216.60	425.02	330.17	345.12	598.06	280.93	293.30	258.08	297.35
17	386.70	274.50	703.18	391.87	370.65	495.77	276.79	447.33	271.27	300.45
18	470.50	317.47	436.46	334.90	484.28	815.93	387.90	315.80	270.22	568.91
19	337.32	293.84	286.98	337.75	310.51	677.76	349.09	314.07	398.41	395.99
20	327.18	306.38	253.66	262.04	421.46	502.50	318.31	188.31	300.79	295.83
21	253.63	277.66	195.14	337.07	262.17	590.23	295.35	237.12	224.85	170.66
22	189.05	340.51	193.28	260.64	425.37	410.74	363.83	408.09	182.08	279.08
23	236.73	204.20	333.39	322.84	299.97	383.97	344.70	291.89	215.10	194.96
24	313.30	371.63	504.01	305.25	294.65	364.50	325.90	490.50	277.51	261.66
25	376.58	211.04	239.50	283.41	265.03	258.79	205.87	456.26	314.19	297.10
26	238.29	275.78	382.32	278.14	214.71	229.64	235.92	213.75	270.38	404.55
27	273.64	227.20	255.78	446.49	235.68	198.96	217.34	283.68	209.83	370.10
28	277.26	341.95	200.14	384.78	199.36	256.47	198.89	335.71	193.14	315.79
29	346.86	439.56	351.43	368.82	301.67	352.89	320.59	286.24	345.96	179.68
30	536.31	359.74	319.19	349.12	260.06	338.98	264.33	178.48	226.75	268.84
31	469.88	604.69	223.13	206.52	252.49	346.58	230.41	200.39	260.55	303.25
32	672.29	738.73	177.12	256.93	348.89	275.40	250.77	262.03	297.12	312.94

33	1072.38	289.19	202.34	330.40	474.99	353.88	203.13	257.06	340.67	314.84
34	936.13	206.88	266.27	245.65	470.71	242.79	185.18	242.05	509.06	351.49
35	954.84	152.95	377.15	239.79	479.08	162.21	279.80	355.05	377.28	233.89
36	354.09	354.61	270.24	195.82	423.16	167.43	276.83	242.95	417.95	349.74
37	289.53	244.92	269.38	323.40	485.17	323.88	300.97	272.47	402.99	431.51
38	255.80	203.80	247.86	282.68	284.44	321.69	260.78	227.10	351.32	376.75
39	339.97	259.82	562.99	227.52	217.04	460.52	200.37	374.85	292.10	519.17
40	310.09	350.79	1315.27	224.91	349.90	1030.58	457.56	277.11	408.08	549.62
41	602.21	202.73	1113.15	186.46	200.40	851.89	889.81	372.65	328.53	355.96
42	651.90	224.40	435.73	239.59	246.14	553.55	446.94	285.62	186.09	304.95
43	285.39	432.61	190.46	332.95	264.44	415.12	215.28	275.10	516.54	246.99
44	450.01	316.27	272.75	300.58	181.41	339.94	209.93	335.72	471.40	259.32
45	428.22	211.85	203.93	234.13	341.44	274.27	281.58	505.74	278.87	316.81
46	269.27	208.21	252.32	332.03	267.49	361.95	231.34	930.65	729.36	638.51
47	316.15	309.25	295.07	257.54	226.20	278.33	243.04	1105.11	500.66	435.95
48	266.36	433.37	302.49	219.86	237.56	270.13	260.00	829.46	283.54	301.41
49	306.53	297.67	247.20	201.49	213.40	273.64	211.73	329.37	358.81	319.39
50	403.95	216.99	184.00	179.09	215.41	380.52	224.80	268.88	381.32	352.60
51	307.77	259.82	250.96	202.79	173.14	429.11	266.67	149.56	318.73	302.51
52	301.07	253.53	244.68	343.45	235.39	259.29	432.21	274.75	235.17	240.28
53	426.96	285.33	253.21	275.37	240.82	344.20	539.66	319.77	300.47	256.20
54	463.57	311.31	612.92	247.56	419.61	394.08	286.25	348.26	388.34	266.59
55	272.54	401.55	576.42	227.07	275.32	211.71	209.86	230.00	285.22	253.30
56	210.78	304.20	525.01	274.38	209.49	264.61	310.01	204.78	224.18	272.17
57	294.34	590.15	522.08	252.08	214.91	411.69	273.80	216.41	287.60	319.31
58	255.70	300.78	403.93	245.83	255.24	255.87	196.86	317.40	354.05	380.97
59	259.96	238.81	341.98	261.18	335.32	239.05	374.83	220.74	301.28	191.06
60	279.45	287.90	278.61	304.94	275.08	364.34	229.92	260.45	394.84	315.55
61	256.61	337.31	251.24	241.77	280.98	281.07	196.58	311.40	511.41	391.19
62	248.44	247.95	259.63	169.64	215.38	258.15	271.68	302.05	501.04	180.04
63	245.00	218.12	303.39	194.18	268.75	311.89	246.81	205.68	431.48	420.17
64	226.90	264.29	270.66	287.29	250.37	350.33	347.79	206.38	351.79	224.57
65	251.26	306.90	296.75	276.33	274.35	362.03	294.66	232.52	224.28	215.73
66	221.59	293.94	231.20	265.21	334.33	479.06	330.39	211.66	358.83	260.05
67	243.25	258.14	274.30	304.64	329.43	295.38	508.84	364.19	468.97	236.16
68	411.69	299.35	324.08	276.26	288.80	462.02	381.56	233.95	253.65	289.61
69	244.92	198.48	211.74	351.35	275.34	576.62	248.09	241.46	304.57	299.11
70	281.28	362.86	322.59	264.10	358.86	310.22	272.56	435.49	300.33	369.43
71	254.98	455.23	253.95	240.80	315.05	370.30	278.43	389.57	348.75	303.34
72	310.92	422.61	475.67	250.36	354.11	377.31	245.67	245.37	562.72	185.84

73	300.16	457.31	361.69	318.33	351.46	282.75	316.77	254.17	465.20	267.95
74	486.29	413.63	551.04	200.28	294.81	233.48	459.40	402.64	238.34	373.89
75	606.74	333.88	538.64	252.90	264.99	349.14	569.81	288.71	194.85	303.17
76	305.45	352.57	451.70	274.04	326.16	476.22	231.03	285.50	246.71	172.25
77	311.92	336.58	326.42	251.56	348.22	342.65	355.14	362.59	230.70	241.25
78	226.74	217.74	241.52	240.75	335.24	260.24	258.07	523.48	460.92	289.65
79	283.01	257.17	273.13	305.75	236.03	480.96	261.83	227.40	267.41	359.81
80	278.32	218.38	268.10	352.64	289.70	427.16	232.70	166.93	346.83	270.36
81	274.95	427.40	257.37	331.40	455.41	504.24	314.97	278.43	233.45	218.16
82	381.09	632.94	176.78	317.76	295.01	625.64	363.24	243.47	340.02	319.34
83	251.58	238.57	344.61	321.74	243.39	369.57	319.77	317.12	404.75	376.13
84	249.57	237.99	479.34	279.44	317.47	267.29	263.68	336.58	278.48	289.28
85	335.41	364.92	434.87	259.64	255.32	310.52	268.43	688.31	312.25	246.30
86	190.21	302.95	406.09	178.77	159.28	508.05	239.27	400.73	338.34	515.98
87	209.71	221.74	346.21	219.06	393.85	433.04	159.93	199.86	350.34	748.91
88	239.00	361.80	198.72	286.83	350.21	281.43	316.42	374.70	340.20	670.81
89	237.38	251.31	283.22	304.46	318.71	394.16	394.17	236.90	321.41	362.16
90	490.15	263.84	544.02	297.39	298.08	279.11	188.91	273.29	367.70	180.92
91	245.91	314.65	420.28	237.96	270.47	287.36	347.47	205.18	311.46	220.04
92	234.90	249.44	380.44	233.00	234.01	341.69	440.78	315.46	221.14	284.48
93	262.36	211.93	266.04	325.51	167.32	232.62	451.63	275.12	268.65	361.86
94	279.65	306.17	352.30	244.41	274.26	376.66	384.74	197.81	323.76	445.98
95	403.31	351.67	254.62	248.00	251.35	475.96	266.13	317.21	213.36	415.77
96	289.13	305.92	335.71	346.81	401.77	319.37	356.35	404.74	250.06	532.68
97	269.06	254.54	194.19	392.92	217.92	273.69	252.32	355.24	322.47	319.26
98	183.18	234.34	204.28	333.75	238.75	486.48	255.41	303.78	250.34	529.89
99	301.47	389.21	361.17	256.31	273.19	599.37	264.79	237.66	429.82	348.39
100	402.21	304.92	221.22	184.73	254.45	223.14	161.22	242.88	442.47	360.56

Scenario 4	Replication									
Day	1	2	3	4	5	6	7	8	9	10
1	256.14	209.46	320.52	210.91	310.90	219.84	234.24	379.90	218.24	482.83
2	263.38	228.87	298.87	310.65	375.95	177.35	290.39	244.77	287.49	408.59
3	302.48	239.67	161.35	403.90	281.31	213.86	205.11	317.55	265.47	341.82
4	328.83	285.33	334.29	303.55	398.01	225.38	242.00	307.13	236.40	299.61
5	377.84	276.77	366.82	292.12	409.03	308.32	354.71	272.69	267.90	373.10
6	425.58	274.07	379.26	263.59	465.06	233.42	235.96	244.26	251.00	335.95
7	195.67	253.20	395.13	218.99	339.53	415.61	342.31	209.68	251.91	276.80
8	288.85	297.48	349.28	273.82	253.78	259.59	321.30	237.78	254.91	225.01
9	282.55	291.89	371.20	282.63	309.93	175.29	400.94	214.99	181.47	258.77
10	308.71	350.35	372.95	271.26	309.96	298.05	250.44	265.37	294.02	333.61

11	293.99	271.47	370.72	413.85	319.22	218.14	226.43	205.90	316.36	316.77
12	287.36	328.37	298.79	360.05	326.41	538.94	190.22	282.85	265.70	303.41
13	254.58	240.99	344.80	237.32	288.62	540.28	187.71	224.69	355.95	252.16
14	210.50	226.81	339.20	247.44	228.22	577.61	226.12	278.36	392.81	192.26
15	227.21	185.06	386.89	244.83	222.37	586.81	304.01	218.34	206.74	234.84
16	237.03	209.06	336.36	267.82	343.00	566.24	274.52	247.73	251.05	274.53
17	363.07	266.24	500.22	250.40	374.65	473.54	273.80	324.58	266.46	297.33
18	408.46	306.06	304.40	220.08	332.92	726.72	353.58	264.62	210.47	269.38
19	295.14	251.50	273.50	228.87	319.23	686.28	314.55	267.41	282.97	280.61
20	279.60	305.83	230.57	233.16	406.17	481.88	270.82	179.73	275.15	254.75
21	223.98	288.87	195.04	321.94	263.81	567.19	267.93	236.37	229.53	161.62
22	197.25	344.42	188.24	241.16	408.33	361.73	334.55	287.14	174.08	224.80
23	247.01	201.51	324.23	328.09	279.45	355.12	279.04	289.08	214.81	192.88
24	313.30	359.43	450.60	307.27	286.67	281.85	325.73	333.23	266.67	260.82
25	340.63	210.64	230.46	265.86	227.58	269.98	194.24	276.75	300.90	265.60
26	236.48	225.98	310.36	265.90	199.88	220.62	223.53	200.29	254.38	295.62
27	346.08	235.37	246.40	427.20	227.91	183.64	211.96	251.99	234.97	313.32
28	340.44	312.49	197.15	410.10	201.90	256.10	197.64	314.95	208.05	250.02
29	331.40	426.24	343.18	340.01	295.59	338.14	297.31	281.40	274.48	177.42
30	451.28	330.65	263.23	358.41	236.87	334.21	268.42	177.50	216.50	268.96
31	395.17	469.75	220.68	203.63	233.07	336.84	234.00	171.63	289.84	289.11
32	416.04	504.11	155.87	239.01	302.13	274.33	219.38	207.30	311.79	243.00
33	294.09	300.87	183.49	286.93	422.03	299.18	205.28	203.27	289.82	209.25
34	261.69	203.52	249.62	245.79	492.22	241.20	180.83	226.92	415.25	319.04
35	375.06	158.30	361.94	241.61	467.76	163.81	268.64	344.98	318.87	213.24
36	297.47	303.39	263.29	205.93	396.94	153.85	293.33	228.61	342.75	354.36
37	279.82	230.13	268.03	288.47	446.89	310.82	284.48	258.47	315.32	438.87
38	236.96	197.47	246.91	245.91	253.16	312.53	229.51	212.90	341.91	373.31
39	286.37	254.95	299.79	231.51	195.83	390.98	192.27	286.88	269.53	452.19
40	272.80	303.08	384.84	192.86	285.28	463.30	385.14	231.19	257.30	420.99
41	405.70	201.06	418.78	173.75	194.28	343.49	578.95	214.17	310.41	327.97
42	404.79	230.58	331.14	226.87	244.96	257.17	321.75	208.66	183.32	286.02
43	307.26	260.50	182.54	303.28	250.50	324.97	216.44	265.08	326.77	242.83
44	402.74	261.16	255.51	253.48	171.28	317.31	204.92	320.09	412.29	259.99
45	321.05	194.29	216.45	216.23	345.98	278.10	276.18	429.76	266.79	324.05
46	233.29	201.67	230.41	289.49	227.79	314.37	234.71	460.39	503.33	504.98
47	200.08	246.31	237.66	233.37	221.76	256.28	225.27	261.87	386.00	405.59
48	274.51	394.15	290.56	207.32	231.96	252.94	263.49	286.41	273.15	299.75
49	297.33	278.24	227.04	206.34	191.08	268.02	237.80	303.49	309.12	322.67
50	391.64	212.06	184.54	197.72	207.92	329.23	224.67	223.75	330.83	328.95

51	277.49	230.32	251.56	199.76	167.12	367.08	218.49	138.83	313.89	306.16
52	283.69	260.36	227.95	345.34	219.29	236.72	418.30	256.29	230.10	249.71
53	303.65	264.58	236.73	252.49	219.18	230.34	389.78	258.74	290.29	202.98
54	387.89	279.76	578.01	209.14	330.93	290.65	281.62	228.24	350.44	217.88
55	261.33	380.32	522.73	223.36	204.84	197.06	192.74	216.20	287.67	252.45
56	215.83	290.44	487.93	240.78	175.08	244.54	298.64	192.62	200.75	260.66
57	289.17	382.79	529.51	228.77	208.47	344.67	242.65	195.80	278.94	317.61
58	235.92	252.74	408.63	229.49	255.03	269.23	200.02	309.02	311.26	294.75
59	268.05	231.94	304.71	237.53	310.77	240.48	375.94	200.16	292.90	189.74
60	252.95	291.01	245.87	246.96	247.99	278.52	196.59	238.96	346.83	270.22
61	183.02	332.40	227.99	233.06	259.42	224.85	193.98	197.72	345.22	293.94
62	249.79	250.20	259.73	157.19	207.78	242.70	263.76	299.85	355.90	174.23
63	241.92	214.76	252.94	187.10	257.85	301.35	228.00	174.19	374.11	354.39
64	219.47	245.32	238.98	293.90	233.26	353.97	337.33	193.70	263.84	219.03
65	252.81	304.18	215.56	261.13	269.34	380.49	288.82	207.62	198.63	215.20
66	222.94	303.79	230.34	237.50	323.87	501.33	270.62	200.32	340.69	210.10
67	237.47	193.89	239.90	255.96	298.06	270.59	352.32	327.69	409.50	195.16
68	260.95	278.39	302.24	273.58	288.76	522.72	340.32	191.86	196.01	251.27
69	238.08	183.79	198.58	296.35	272.74	432.39	237.60	228.59	278.41	274.08
70	273.37	338.67	307.51	179.27	293.37	293.51	269.17	290.01	280.94	295.12
71	256.06	386.81	250.58	216.13	321.97	278.20	239.46	280.34	310.36	292.00
72	293.77	326.55	436.54	259.79	306.51	358.89	215.54	235.92	289.28	191.68
73	278.20	379.77	280.63	318.80	274.08	274.85	260.56	228.31	297.75	273.93
74	278.59	338.63	292.86	190.28	201.77	228.22	385.49	315.22	206.76	271.58
75	277.00	296.39	227.99	225.67	249.67	243.02	366.36	264.38	172.27	191.47
76	295.43	329.46	322.69	243.09	311.87	369.55	228.74	243.73	243.28	161.68
77	281.65	309.56	294.65	262.40	259.15	293.33	346.78	318.13	218.92	248.75
78	207.16	218.09	237.56	197.06	266.20	242.89	243.58	315.13	405.78	282.22
79	257.34	244.88	276.18	300.00	222.22	464.52	247.38	214.23	257.87	379.75
80	272.22	215.38	269.25	366.47	286.05	410.47	227.15	164.19	315.24	235.58
81	259.35	223.12	258.83	302.70	388.79	435.03	275.87	306.91	222.35	211.64
82	376.59	254.68	177.02	254.18	241.55	385.94	279.48	233.40	298.93	202.99
83	248.80	216.74	353.90	301.25	237.17	259.30	302.37	215.78	345.77	251.69
84	243.45	241.68	372.17	271.02	278.21	248.05	223.13	281.58	268.29	259.75
85	314.82	347.09	344.36	231.48	259.77	300.61	184.64	413.03	306.13	229.50
86	189.65	308.86	295.82	171.31	162.41	480.38	212.92	313.23	309.25	372.97
87	201.99	210.62	258.32	211.68	383.21	390.15	156.22	197.29	288.57	354.86
88	219.60	317.86	184.24	303.81	333.16	245.52	301.70	269.64	343.29	292.27
89	213.64	257.93	258.92	304.07	304.90	303.78	316.68	211.33	315.09	320.10
90	347.01	254.10	302.53	254.59	304.21	231.53	190.67	282.73	324.05	182.10

91	230.40	241.83	364.68	222.61	242.79	252.92	360.73	209.13	302.00	231.09
92	238.60	247.33	355.57	238.78	226.63	339.74	414.64	295.47	221.11	233.71
93	264.09	213.41	253.66	317.37	171.50	222.86	444.44	287.89	262.66	295.45
94	270.78	302.40	309.80	241.67	212.42	311.70	349.49	194.35	330.92	266.96
95	330.96	292.22	219.49	230.40	212.01	328.27	231.59	278.24	245.46	324.32
96	277.73	270.71	305.52	263.17	313.50	242.86	290.53	303.27	233.71	468.44
97	242.56	216.33	187.65	304.43	203.44	256.34	244.67	274.43	265.36	324.15
98	171.27	222.43	201.90	229.08	219.85	463.20	247.29	304.78	222.98	510.82
99	333.01	379.94	369.86	240.97	267.96	522.01	253.48	199.33	344.99	321.18
100	406.77	292.19	195.26	190.59	251.84	218.27	143.78	250.22	300.89	350.91

Scenario 5	Replication									
Day	1	2	3	4	5	6	7	8	9	10
1	248.83	245.66	321.97	222.81	288.28	251.54	252.57	442.04	214.80	549.21
2	246.98	228.30	310.70	339.56	318.69	177.52	327.50	516.46	305.37	360.65
3	309.99	234.02	167.68	413.03	273.75	235.02	247.74	439.20	276.12	378.79
4	316.03	310.06	459.42	292.72	388.53	243.17	252.53	382.82	226.48	371.98
5	460.53	328.23	490.44	366.23	558.81	475.73	326.25	453.01	350.08	511.78
6	485.68	296.51	368.49	276.19	513.10	236.95	265.68	218.62	276.92	393.94
7	198.49	246.35	371.69	218.17	359.24	407.40	340.21	208.11	256.35	281.79
8	288.01	313.91	348.24	284.45	274.34	255.68	376.16	252.89	268.53	261.73
9	347.65	298.18	326.07	299.34	317.96	192.87	425.88	214.36	179.59	264.15
10	371.07	348.36	368.94	259.56	309.58	312.33	268.18	276.30	301.42	453.95
11	321.25	280.31	412.59	457.85	291.83	230.03	236.88	205.37	292.84	580.06
12	199.73	416.78	599.69	451.11	338.54	556.63	204.12	353.87	243.83	522.24
13	253.51	294.37	437.04	249.76	349.35	515.01	251.17	219.65	369.28	219.49
14	238.47	272.68	378.00	255.26	232.04	585.81	247.03	279.50	381.86	197.28
15	251.80	196.63	498.21	253.55	240.35	635.65	341.53	228.42	205.52	237.24
16	241.34	213.95	335.84	338.85	344.91	583.95	285.00	276.37	257.82	303.65
17	397.41	282.75	520.98	418.77	390.99	482.09	282.23	411.34	271.12	302.99
18	511.62	300.47	292.09	218.62	395.92	709.94	350.75	267.03	247.74	451.13
19	375.32	298.00	281.36	302.33	314.41	704.57	364.65	311.89	404.70	295.10
20	326.58	307.63	236.43	256.97	412.67	507.26	309.63	223.34	293.65	277.28
21	232.69	288.20	183.07	342.06	275.43	526.63	296.61	237.30	241.98	170.09
22	210.51	343.53	184.02	249.98	459.36	397.59	353.32	380.02	184.02	271.12
23	263.40	212.44	297.78	324.92	294.98	387.89	329.10	282.99	218.70	196.59
24	309.79	372.30	424.65	308.71	272.56	346.78	296.44	420.47	275.11	254.55
25	353.48	214.61	234.70	306.92	239.21	257.99	198.15	307.32	331.52	273.23
26	233.94	274.90	388.13	276.17	214.74	241.71	223.34	210.64	259.86	415.06

27	309.94	243.13	261.94	455.79	229.67	193.29	223.44	266.87	214.72	385.07
28	350.27	337.65	215.17	363.69	193.59	258.43	205.34	323.92	209.81	281.79
29	336.85	431.54	393.35	382.33	310.08	359.37	313.68	299.66	304.61	180.14
30	545.95	368.36	322.08	366.20	247.84	342.60	276.80	186.32	209.18	269.21
31	479.34	577.57	223.52	206.84	253.56	339.63	238.93	196.64	377.02	283.35
32	776.97	559.19	172.94	243.19	271.59	276.01	219.18	263.09	334.35	248.08
33	1027.32	260.96	200.43	345.36	449.70	352.87	206.17	261.36	376.80	260.23
34	615.02	207.91	464.91	255.28	492.40	265.35	183.96	249.62	517.61	337.89
35	616.04	154.23	418.21	240.05	491.27	169.43	278.34	364.30	366.02	224.16
36	253.10	339.20	248.98	188.69	423.23	163.53	286.72	229.46	438.50	328.94
37	284.19	231.36	289.56	317.27	460.13	322.35	263.12	270.44	377.37	439.81
38	256.29	199.63	258.93	277.81	282.50	289.86	227.97	243.22	355.43	374.38
39	323.67	250.23	544.33	238.70	182.85	353.54	205.69	311.45	284.84	511.12
40	325.23	360.59	695.13	213.41	348.66	878.62	444.48	284.53	404.01	535.84
41	708.04	209.57	680.08	181.31	202.01	681.34	773.48	425.06	327.63	333.68
42	671.17	243.17	318.20	228.71	241.52	284.24	369.86	306.85	189.28	311.07
43	275.92	447.86	185.20	304.25	298.46	330.44	220.19	263.55	621.18	243.93
44	424.67	367.85	258.69	227.69	184.34	314.28	217.16	314.72	518.81	248.88
45	387.42	217.40	220.51	232.57	354.83	294.86	282.05	444.14	284.90	321.58
46	272.72	209.88	242.43	289.62	245.14	339.28	239.29	595.17	560.07	547.85
47	316.98	334.31	317.86	247.29	227.76	283.05	243.86	667.59	441.00	439.44
48	273.21	430.46	288.49	209.43	236.98	264.41	252.03	623.41	267.92	298.91
49	311.39	286.86	238.28	211.56	205.25	249.38	224.97	297.91	315.66	313.97
50	409.10	218.01	189.11	196.63	206.16	364.04	217.47	232.86	442.30	395.27
51	280.57	241.39	253.91	216.08	172.67	386.95	241.33	149.11	326.09	252.93
52	287.32	249.53	234.90	355.62	235.28	260.56	423.64	265.90	233.15	255.91
53	328.91	252.99	247.05	215.80	218.79	245.82	461.50	307.25	309.27	196.34
54	441.55	311.59	613.43	242.42	426.48	310.74	297.82	343.01	403.48	256.22
55	292.00	376.59	597.99	226.86	210.29	212.62	192.04	237.55	283.90	273.62
56	231.17	306.71	545.71	281.05	179.39	271.01	310.33	205.35	207.59	279.13
57	306.35	526.27	534.15	248.82	215.10	406.10	276.43	206.40	289.17	292.78
58	261.81	267.08	448.54	241.62	235.01	269.52	222.13	338.50	324.05	340.40
59	265.13	232.48	310.68	254.90	369.73	244.99	370.28	209.64	298.50	201.47
60	215.36	288.65	282.30	280.42	243.11	287.59	195.48	251.71	345.16	315.94
61	260.64	349.02	251.29	238.51	311.67	266.80	209.68	298.29	489.54	381.28
62	245.86	251.54	264.06	177.07	214.33	249.33	277.17	292.20	445.23	174.85
63	230.34	220.70	326.28	195.33	251.66	345.78	246.20	200.50	419.17	402.74
64	236.35	261.12	264.67	283.82	250.75	355.74	340.54	198.05	307.74	206.54
65	247.90	331.01	287.49	271.49	271.78	389.02	290.84	211.05	202.29	214.15
66	224.51	328.05	209.90	247.82	359.88	480.17	288.83	215.59	369.72	250.19

67	243.54	202.72	252.00	255.81	307.12	256.92	384.04	339.39	454.60	206.40
68	345.00	324.03	312.03	257.45	290.41	512.76	374.73	237.30	271.74	298.12
69	253.83	194.05	219.78	309.76	269.34	596.42	249.16	233.54	306.04	307.59
70	280.17	364.36	321.76	273.20	337.26	300.25	293.90	367.23	291.75	373.15
71	263.63	450.03	242.15	203.82	325.48	356.32	278.42	313.73	358.91	298.83
72	317.01	439.91	460.31	243.75	300.04	343.78	247.87	193.85	598.22	187.75
73	298.45	463.72	310.27	312.69	289.85	280.29	307.24	241.27	400.26	286.75
74	402.31	365.81	437.61	201.96	187.52	227.19	439.18	285.27	222.30	311.82
75	427.87	313.89	482.16	256.06	222.24	337.78	465.95	264.23	197.28	330.91
76	279.33	329.28	386.87	260.60	329.12	467.97	221.13	309.83	229.53	178.24
77	309.90	339.79	276.53	256.63	329.58	313.68	348.62	358.71	252.33	260.25
78	211.63	224.94	244.71	239.28	334.04	257.54	258.77	506.02	508.68	294.73
79	294.72	235.14	277.18	427.48	233.67	482.19	266.43	215.27	250.39	376.82
80	264.13	222.07	270.75	412.72	290.76	413.23	216.13	172.50	334.23	270.81
81	271.89	259.50	264.69	305.31	404.53	470.52	274.35	263.00	220.19	207.05
82	387.94	356.35	170.95	329.22	296.04	617.31	343.07	255.82	354.92	294.82
83	248.17	209.53	377.69	329.94	245.36	362.93	309.60	303.00	432.14	365.07
84	252.85	239.05	461.80	274.53	302.51	259.36	258.79	313.96	271.94	300.18
85	340.26	325.54	431.28	243.15	257.64	311.44	210.93	627.33	311.67	243.01
86	174.34	299.21	390.66	193.25	162.32	520.91	213.87	333.95	320.19	438.92
87	222.18	215.10	297.85	218.75	426.20	402.04	165.52	213.29	277.88	666.12
88	220.42	344.22	179.74	274.86	333.11	246.98	296.79	313.69	336.60	403.80
89	239.65	272.59	284.98	315.24	311.06	373.91	427.13	207.26	300.55	375.21
90	462.11	261.11	629.89	278.26	321.37	254.91	219.14	267.28	332.55	187.09
91	224.95	269.67	410.71	235.93	278.43	268.17	343.28	215.38	312.89	229.07
92	241.69	219.22	373.60	248.21	232.97	327.26	466.79	334.18	218.57	326.15
93	256.83	226.26	251.21	347.73	169.25	244.67	503.26	301.35	258.61	375.84
94	268.73	284.31	345.48	248.67	224.16	309.19	401.34	204.63	329.69	334.26
95	368.36	329.66	241.89	250.03	252.22	333.37	246.04	289.87	252.84	318.30
96	288.14	323.63	338.54	370.91	396.21	305.33	405.80	411.20	250.54	491.04
97	245.97	216.30	188.07	378.42	209.72	276.65	248.95	370.28	299.31	322.06
98	176.84	241.00	193.43	340.32	236.82	501.56	254.23	321.50	237.33	502.50
99	343.37	409.76	363.76	252.97	269.94	605.67	256.77	229.59	452.51	316.50
100	413.58	313.71	218.70	199.49	254.70	224.07	158.75	253.60	360.22	361.46

Scenario 6 Replication

Day	1	2	3	4	5	6	7	8	9	10
1	259.12	236.55	324.85	214.56	288.80	224.05	238.05	379.90	216.59	435.54
2	253.28	227.96	299.76	310.60	334.50	178.00	296.02	282.41	290.57	356.05
3	299.07	241.07	171.21	399.95	272.41	217.34	206.20	328.63	264.45	350.08
4	319.64	297.20	383.89	287.81	397.86	225.05	242.03	330.26	228.56	317.44

5	400.74	278.16	348.54	288.22	440.34	300.15	382.97	260.43	270.19	298.81
6	445.06	253.52	358.27	273.47	477.64	242.48	236.46	214.82	250.44	349.91
7	195.96	250.69	364.65	216.80	361.24	400.73	359.45	205.14	249.62	243.85
8	291.75	304.07	338.74	280.63	257.71	261.08	368.88	250.57	266.37	200.82
9	320.77	288.87	343.11	291.00	319.12	194.11	413.92	213.73	170.26	230.40
10	342.44	352.86	369.02	260.40	316.14	284.10	246.18	266.84	385.95	310.29
11	267.90	264.65	370.62	408.63	299.34	209.59	229.72	212.89	317.44	339.25
12	260.87	346.36	300.76	360.94	318.26	533.43	190.96	291.76	230.33	270.74
13	246.47	245.60	333.78	247.43	291.62	502.97	258.69	214.09	351.94	231.24
14	212.10	234.78	329.50	254.38	228.60	536.22	241.61	264.57	350.73	192.82
15	233.06	181.55	462.55	246.97	227.07	615.76	300.47	220.50	207.35	231.94
16	227.66	213.96	346.77	272.58	327.16	606.71	274.81	269.98	250.12	262.57
17	358.43	265.53	463.33	262.82	375.59	469.87	275.71	336.45	273.99	313.61
18	408.39	289.61	275.89	210.35	344.22	670.15	351.33	261.55	249.74	301.38
19	300.38	252.96	269.38	229.83	316.98	651.89	308.92	278.88	286.81	280.83
20	282.07	300.78	251.62	233.00	409.66	430.37	267.55	188.94	292.80	234.53
21	227.73	297.01	187.61	332.98	269.80	516.68	270.04	232.94	234.25	163.14
22	204.10	343.41	189.11	232.40	426.22	363.64	326.25	291.98	175.17	220.95
23	240.80	202.81	271.13	315.56	287.26	337.70	291.13	279.58	219.48	192.37
24	307.11	353.05	405.52	314.63	278.09	283.71	273.23	323.08	274.63	256.57
25	335.76	222.63	232.07	263.84	214.66	255.87	182.26	271.15	308.38	262.79
26	226.52	233.29	338.01	266.78	211.47	211.88	229.23	211.25	241.36	292.77
27	271.77	240.89	264.04	417.85	232.20	195.62	214.34	255.63	209.24	314.77
28	253.48	326.44	218.91	372.95	190.04	256.47	252.69	303.15	205.16	295.13
29	349.25	416.75	377.89	331.83	296.24	359.11	289.91	266.94	279.08	179.56
30	416.26	368.14	272.14	331.39	236.36	332.38	276.46	173.76	211.54	261.49
31	402.22	484.38	215.18	200.57	242.25	341.34	232.67	184.18	295.46	286.75
32	440.06	487.39	168.50	225.32	299.53	266.46	208.26	252.72	298.69	245.56
33	325.51	258.63	179.47	292.21	428.35	315.28	211.25	240.72	286.75	203.88
34	244.15	200.00	220.13	257.58	461.00	242.58	184.20	242.32	410.85	309.87
35	354.33	156.35	365.49	235.85	472.86	165.99	261.22	355.88	326.10	215.67
36	231.36	319.78	259.58	211.38	406.89	158.37	300.39	232.45	349.04	344.57
37	278.75	235.85	263.14	310.23	441.28	303.44	291.34	262.55	314.69	458.85
38	248.28	198.21	255.89	248.29	257.87	291.84	221.01	200.53	342.33	374.74
39	270.91	252.86	346.03	232.91	177.67	342.64	203.49	267.91	277.45	495.19
40	263.85	340.90	377.34	201.62	293.57	460.62	411.26	250.73	250.46	427.75
41	397.32	204.95	411.44	176.86	193.78	339.24	623.00	222.10	302.12	334.13
42	424.55	236.43	324.63	235.50	244.28	229.15	314.56	202.81	194.12	283.83
43	257.13	264.78	198.32	295.41	291.04	305.80	220.00	250.89	364.42	248.54
44	405.06	332.04	256.85	252.43	183.75	325.10	212.55	303.81	407.11	257.35

45	352.48	207.85	204.84	216.19	324.39	277.54	277.07	434.81	282.12	317.09
46	266.18	208.40	234.92	277.84	239.93	311.56	222.20	477.78	499.09	533.24
47	206.36	209.56	237.64	232.76	230.72	251.43	223.40	273.52	386.85	403.03
48	284.24	371.02	295.26	195.02	224.30	269.93	263.93	310.75	257.64	275.76
49	294.98	294.19	243.91	205.63	194.42	247.50	212.66	288.84	279.58	318.60
50	409.94	211.44	188.69	179.16	221.60	340.99	219.84	233.54	309.11	317.49
51	272.80	239.90	255.92	191.45	167.31	385.25	218.93	134.11	281.82	234.91
52	270.80	256.16	220.72	338.17	224.00	259.88	400.90	261.34	191.28	231.43
53	290.57	267.99	247.02	239.91	210.76	225.70	451.72	293.93	289.62	206.32
54	386.19	282.10	573.72	209.79	335.52	284.28	280.29	229.71	345.40	247.22
55	271.80	358.34	511.95	222.92	260.58	195.58	214.29	217.76	287.50	257.95
56	234.64	295.27	490.06	273.13	198.08	227.61	299.90	187.20	193.07	266.62
57	290.19	403.77	526.51	242.19	214.37	352.73	252.03	201.06	290.57	309.88
58	246.46	243.66	414.91	232.44	248.21	257.94	196.19	329.63	302.04	293.41
59	262.21	237.67	272.04	249.59	377.99	241.99	373.71	206.15	289.04	192.54
60	213.69	284.51	266.11	239.14	237.76	274.15	196.46	234.05	365.44	284.44
61	186.52	319.40	225.41	242.17	293.30	214.98	194.12	194.33	373.98	307.88
62	251.02	258.77	260.80	168.74	204.86	252.08	266.61	290.47	328.92	161.78
63	240.55	227.41	243.83	186.71	253.86	265.08	225.46	181.36	395.49	326.85
64	228.94	250.17	237.95	285.32	252.93	352.34	318.86	197.34	255.75	201.95
65	245.30	292.44	229.66	254.70	278.97	345.93	293.09	205.32	197.75	213.47
66	230.26	315.07	218.82	225.43	318.43	483.38	275.04	206.79	356.93	220.56
67	226.18	185.21	237.59	255.07	312.67	257.30	374.56	324.86	439.00	192.23
68	237.06	295.02	297.57	275.90	289.13	512.62	333.00	189.38	199.93	250.54
69	235.59	190.85	209.10	301.84	258.41	412.16	228.46	225.40	301.28	299.73
70	270.23	326.83	313.58	206.24	294.75	275.55	297.49	298.35	284.14	310.40
71	250.07	378.74	255.44	188.15	324.83	292.90	263.95	274.49	322.53	288.89
72	308.31	334.01	455.98	244.26	341.78	340.87	209.55	196.60	283.37	177.58
73	302.03	387.76	281.55	327.56	302.65	278.11	259.45	231.69	262.13	309.54
74	286.02	338.82	302.40	189.81	178.61	226.29	373.64	274.22	207.45	311.48
75	255.45	287.33	229.62	233.51	217.40	247.87	331.49	238.65	175.82	210.88
76	268.66	341.16	311.69	246.14	318.38	371.90	222.04	246.82	225.79	165.14
77	277.86	312.18	275.28	266.63	270.22	284.34	336.69	329.57	225.38	255.66
78	196.94	213.81	233.19	205.57	279.14	252.00	243.19	304.89	409.04	286.41
79	260.59	225.66	266.54	445.98	231.05	442.65	247.97	198.84	259.38	365.96
80	262.14	219.61	233.90	390.95	283.68	414.02	219.72	161.41	317.38	238.45
81	268.15	201.49	259.84	304.96	386.28	448.76	260.19	273.97	214.82	202.99
82	380.71	266.86	184.37	290.04	240.43	370.51	279.39	232.80	319.42	205.65
83	237.39	209.21	347.10	306.18	248.52	254.89	284.74	216.68	352.61	277.86
84	243.34	238.59	369.75	275.17	285.60	252.54	218.11	279.40	257.62	273.43

85	314.31	349.61	350.81	240.78	260.00	301.08	178.39	418.92	300.23	238.68
86	175.47	321.62	291.93	170.20	160.40	511.12	207.26	284.09	316.65	352.39
87	209.77	214.24	248.75	217.41	409.43	401.83	165.44	190.95	271.84	352.99
88	219.41	336.90	178.79	266.50	333.29	226.84	291.28	253.73	343.59	267.41
89	215.34	263.97	262.94	309.61	314.42	325.35	331.11	188.82	314.16	318.68
90	333.39	258.17	305.04	256.83	300.76	221.86	187.04	282.22	297.90	185.12
91	192.46	226.39	334.34	216.39	255.37	255.78	356.85	209.07	300.59	227.50
92	243.99	205.36	335.66	244.01	227.73	351.02	378.34	279.42	212.55	249.70
93	256.11	222.74	251.90	322.85	170.63	225.53	424.62	291.23	253.72	301.50
94	269.06	286.35	316.91	268.59	215.94	301.10	378.12	200.43	311.86	260.43
95	343.95	292.89	219.03	240.89	235.61	333.26	224.29	259.99	201.80	302.86
96	271.94	285.84	319.25	265.67	322.08	233.29	315.96	307.43	241.95	447.04
97	248.32	215.21	186.49	290.18	227.75	248.55	232.40	301.56	302.46	302.62
98	164.68	233.67	207.63	258.61	228.04	464.60	253.16	303.92	235.57	510.22
99	329.45	410.56	369.79	247.06	266.54	532.41	255.06	204.22	358.22	328.41
100	407.47	310.05	201.67	186.98	260.74	227.06	154.10	250.16	271.21	352.39

Scenario 7	Replication									
Day	1	2	3	4	5	6	7	8	9	10
1	249.57	243.05	335.86	216.12	292.15	257.95	242.98	505.34	218.27	546.00
2	248.24	222.00	311.76	334.24	329.75	177.53	383.27	541.05	299.23	344.09
3	313.16	235.98	177.51	416.77	263.17	226.22	238.86	440.08	267.28	376.53
4	326.48	312.09	440.88	301.91	381.18	228.23	244.62	390.32	229.92	422.24
5	444.37	307.11	520.57	363.55	545.42	452.19	341.16	449.16	335.94	556.87
6	505.72	297.76	373.54	278.72	488.30	232.31	266.70	225.92	286.41	415.36
7	195.69	239.16	371.95	207.37	369.81	431.22	318.70	207.94	248.24	284.95
8	279.48	302.74	362.91	273.12	279.21	258.49	370.42	248.44	266.32	252.03
9	347.95	291.90	324.29	296.91	312.10	178.08	428.22	212.41	184.90	259.67
10	361.24	356.21	371.25	258.10	304.09	306.62	281.94	274.55	373.30	420.94
11	292.70	280.22	418.36	430.24	312.24	234.58	241.18	206.14	299.79	541.39
12	205.81	439.35	574.57	409.87	353.15	504.69	205.58	342.36	256.76	489.57
13	251.96	304.97	436.41	238.78	337.16	545.94	240.80	225.14	374.75	218.36
14	242.69	250.55	396.68	249.32	228.22	589.38	239.20	263.12	393.78	194.19
15	228.45	195.66	493.97	249.37	246.67	603.44	331.81	227.72	199.89	234.41
16	246.02	208.92	339.88	316.42	321.44	584.70	279.99	276.33	249.78	296.24
17	383.20	272.62	555.13	414.16	375.49	481.75	277.69	401.89	273.05	296.57
18	487.39	316.45	289.91	213.19	395.66	744.70	350.43	267.28	240.14	445.14
19	348.95	288.20	286.60	287.91	292.75	704.62	360.87	334.23	399.25	292.70
20	332.59	308.05	230.04	240.49	410.18	533.61	283.46	196.70	307.25	283.48

21	232.44	286.45	191.09	338.60	265.78	537.59	281.39	233.81	237.31	172.01
22	187.92	339.75	191.05	250.43	434.07	408.92	348.50	378.58	173.65	286.28
23	259.09	207.23	281.72	326.15	283.57	382.93	316.60	278.03	218.51	191.86
24	288.93	362.96	416.72	305.54	274.61	349.49	293.86	445.44	280.46	261.50
25	357.58	210.46	226.04	292.55	232.86	256.91	192.62	302.66	300.26	253.10
26	234.04	272.07	379.32	269.11	207.24	229.89	229.69	214.47	268.53	414.47
27	272.17	226.31	259.21	428.70	231.66	178.52	216.76	243.90	217.73	369.48
28	263.06	338.33	198.65	392.93	197.95	254.38	170.22	339.21	193.54	258.97
29	354.22	426.48	338.93	369.57	325.23	339.48	268.05	303.00	299.65	179.48
30	453.60	340.57	302.66	354.05	264.65	343.00	255.61	185.97	208.83	267.02
31	454.92	587.41	223.35	205.06	238.55	336.35	260.60	193.11	275.59	285.08
32	677.96	539.10	170.51	236.89	283.57	263.19	276.53	215.54	290.60	246.38
33	993.57	269.01	201.20	313.82	447.28	349.63	221.43	223.09	362.87	257.88
34	625.15	205.93	274.96	247.50	500.18	242.60	174.07	233.01	509.24	332.14
35	598.19	155.56	374.60	237.24	481.00	164.78	285.95	358.12	363.39	231.86
36	262.42	344.48	254.21	195.59	444.47	162.94	274.65	229.79	418.60	337.62
37	282.31	232.08	267.58	307.55	472.17	316.88	297.84	263.06	379.18	430.78
38	243.66	196.58	249.67	260.87	281.49	295.50	242.15	252.48	344.55	370.22
39	299.09	256.26	534.13	233.68	183.63	367.39	198.40	305.71	282.91	489.08
40	297.97	358.76	665.17	243.29	350.93	807.73	457.27	261.27	410.51	532.01
41	597.48	209.93	727.85	179.12	207.55	647.85	747.03	408.00	333.13	335.82
42	622.67	245.86	325.63	237.79	252.94	256.55	347.66	263.68	183.98	311.07
43	267.35	435.48	185.00	309.94	259.31	300.96	216.48	267.04	556.98	245.10
44	423.48	362.69	262.08	257.55	172.26	335.28	211.68	304.83	459.30	261.87
45	389.88	224.44	225.17	224.34	360.23	275.46	262.37	456.66	269.16	327.50
46	261.66	207.89	233.65	271.84	246.19	319.30	224.95	549.05	527.96	542.63
47	324.02	327.86	312.65	245.46	223.24	306.98	238.05	652.73	442.08	434.72
48	283.41	444.86	309.00	214.66	226.57	263.84	254.95	573.39	277.09	306.90
49	304.73	298.13	249.52	197.71	210.98	251.74	217.83	287.00	338.00	321.68
50	388.38	218.18	190.55	196.12	215.12	359.61	227.07	226.28	453.44	406.61
51	274.41	239.83	255.96	223.18	166.80	400.50	251.11	143.27	316.35	258.04
52	286.92	249.11	217.68	354.89	237.06	250.34	441.62	266.02	234.19	246.04
53	355.72	263.01	243.86	220.56	224.23	237.57	450.90	310.62	306.39	202.30
54	437.32	302.18	652.81	244.47	412.84	303.35	298.95	317.14	405.22	255.68
55	274.49	380.61	625.06	224.11	344.75	207.29	189.96	228.40	285.73	273.92
56	202.41	287.74	505.42	248.54	206.97	254.36	309.90	201.17	226.30	272.08
57	292.38	545.47	544.48	233.71	209.17	413.08	273.04	201.13	294.72	287.14
58	253.62	272.43	439.58	234.58	239.11	266.03	197.60	323.32	340.53	319.10
59	257.50	230.17	305.65	269.57	353.09	230.41	384.42	203.42	297.76	195.35
60	222.76	291.61	272.92	293.04	235.66	278.07	199.85	239.10	330.18	323.36

61	245.37	337.47	256.82	238.21	268.14	267.90	214.81	286.76	485.83	372.91
62	254.83	231.94	259.48	168.82	201.48	251.01	273.21	300.91	495.63	172.07
63	231.80	202.48	257.66	194.73	256.48	330.68	230.75	187.34	422.99	371.72
64	231.42	261.09	261.35	286.10	249.54	371.77	354.64	206.60	331.99	205.16
65	247.27	311.59	274.86	267.22	266.64	380.86	288.61	215.85	216.54	226.71
66	233.15	303.45	188.63	270.44	353.62	474.64	276.07	212.44	351.31	243.69
67	244.94	205.96	244.73	255.91	309.41	275.81	384.24	326.08	466.51	199.03
68	378.73	320.62	313.92	268.39	274.21	533.01	368.38	214.73	250.44	276.09
69	245.28	188.36	198.94	314.92	260.75	615.86	244.89	241.89	286.91	342.67
70	280.99	363.86	316.07	271.22	343.09	293.74	271.76	374.26	288.70	394.12
71	260.43	472.94	268.12	222.78	318.70	339.50	262.26	305.46	331.69	308.62
72	312.11	437.39	467.51	254.75	352.97	353.49	229.92	227.60	578.64	179.83
73	307.53	465.48	312.73	309.11	339.29	273.55	305.51	234.99	391.64	285.40
74	406.51	375.59	439.10	192.16	190.03	227.86	455.71	287.01	228.48	304.32
75	437.71	295.85	480.39	258.26	233.64	396.95	488.09	286.31	191.60	300.89
76	271.91	323.83	381.11	255.80	333.81	499.27	213.33	299.64	234.96	165.53
77	304.32	330.21	269.97	253.65	344.51	320.53	346.57	324.88	226.90	250.66
78	205.50	215.12	237.12	240.86	332.73	263.85	262.49	461.27	509.37	281.65
79	299.32	242.49	276.41	342.37	235.67	477.40	277.91	210.29	257.96	386.07
80	272.74	228.47	257.97	353.94	296.90	429.79	213.53	168.05	341.27	299.49
81	264.58	251.73	256.42	306.92	407.12	478.95	299.47	253.45	231.44	209.24
82	358.58	357.55	171.74	343.40	296.79	597.13	373.24	245.93	372.27	327.70
83	246.90	212.76	349.61	323.32	240.66	359.90	313.80	289.97	428.53	406.72
84	253.09	234.91	492.92	276.52	314.39	256.15	256.96	317.14	268.50	280.28
85	355.12	322.00	418.97	244.85	261.23	292.30	245.24	640.59	307.44	272.85
86	184.39	306.78	356.93	198.64	159.00	474.86	233.10	324.37	306.35	451.03
87	213.21	214.80	296.67	219.21	395.73	389.73	164.76	204.05	277.88	674.74
88	216.68	344.76	181.95	264.95	335.73	231.34	295.56	308.69	341.42	413.03
89	242.23	265.31	285.22	315.10	313.45	380.91	403.37	206.08	319.72	319.92
90	460.52	258.12	634.43	290.68	302.48	239.61	184.49	280.62	379.06	175.09
91	202.68	253.96	414.90	230.86	255.22	258.03	354.58	203.48	312.16	233.44
92	234.38	208.08	371.55	229.69	245.45	317.53	466.91	336.05	218.00	311.71
93	262.09	208.15	248.82	338.88	169.36	234.50	510.76	286.41	254.85	376.67
94	273.55	285.02	316.66	262.29	272.60	321.12	414.19	200.59	309.08	401.14
95	358.53	324.14	235.84	241.87	253.91	334.62	247.07	252.29	236.84	333.35
96	285.94	323.50	331.58	376.54	405.22	307.37	410.30	387.42	244.98	461.60
97	254.40	227.15	186.89	387.71	207.06	270.81	247.39	372.48	299.85	316.80
98	186.71	236.68	197.19	342.11	242.83	515.60	258.05	308.29	242.22	521.90
99	299.96	394.15	374.96	241.16	265.70	571.78	250.60	222.67	374.24	319.02
100	433.35	300.43	223.18	194.88	253.86	228.71	158.55	243.37	337.02	366.92

Scenario 8 Replication

Day	1	2	3	4	5	6	7	8	9	10
1	256.34	227.39	318.00	210.94	288.69	229.28	236.35	379.15	216.01	430.81
2	248.07	223.11	304.87	311.21	339.21	174.64	290.99	295.35	289.10	331.22
3	292.83	237.15	158.31	402.44	270.60	199.62	198.41	321.34	266.09	375.92
4	319.17	283.27	341.59	298.10	393.71	221.99	242.32	315.01	229.09	318.12
5	383.38	283.46	349.03	292.83	426.97	313.26	381.98	262.33	267.67	308.33
6	430.50	263.69	353.87	266.54	455.29	233.16	238.31	217.15	246.53	343.49
7	198.83	249.99	373.42	204.19	351.69	409.85	343.12	206.82	251.71	247.78
8	281.39	304.04	352.19	272.82	246.44	258.47	324.68	232.92	256.03	215.27
9	295.08	284.90	329.23	281.19	313.86	165.45	385.22	211.67	176.24	246.04
10	312.88	334.74	356.83	259.85	312.89	288.08	242.88	264.02	292.18	328.76
11	271.47	270.39	371.89	387.43	317.91	212.60	224.95	212.59	283.19	343.28
12	259.18	329.03	318.41	344.04	313.88	498.46	190.87	282.87	208.40	267.01
13	235.47	238.73	337.84	223.76	281.62	500.40	189.61	210.19	344.28	228.82
14	208.31	222.86	331.92	239.55	227.59	530.23	230.13	266.51	383.63	204.65
15	229.30	182.03	438.13	251.43	216.95	593.12	292.98	213.32	204.21	238.50
16	225.88	208.83	339.72	276.02	322.81	623.45	272.47	256.45	243.46	269.53
17	361.73	260.46	469.32	263.04	374.76	482.71	275.20	330.08	270.15	312.55
18	422.28	307.46	270.29	198.73	332.37	716.76	353.09	258.06	232.10	291.76
19	292.46	254.77	275.49	218.80	278.78	655.22	317.87	272.01	286.72	274.36
20	282.86	301.53	217.05	233.67	405.72	464.85	260.17	184.46	274.09	229.80
21	247.51	291.41	195.13	326.59	259.31	531.20	264.39	236.63	225.15	154.91
22	212.25	343.11	191.93	227.95	399.28	375.69	330.81	266.42	173.52	222.43
23	245.42	211.58	277.03	329.69	282.08	377.03	278.48	269.00	217.97	191.61
24	289.66	341.24	393.53	310.11	274.63	283.46	309.68	318.15	271.45	246.86
25	330.96	218.34	220.64	278.01	216.95	252.83	180.89	259.87	294.70	241.08
26	223.46	222.25	317.89	252.99	205.36	209.51	226.46	207.42	250.46	295.75
27	271.14	229.58	243.09	409.10	230.77	179.95	218.46	238.33	226.51	301.71
28	256.56	307.39	198.97	391.25	196.41	256.99	200.08	300.06	204.98	248.07
29	346.63	421.78	333.02	349.42	295.72	358.49	309.49	286.89	272.27	177.29
30	422.37	346.83	267.58	331.90	228.84	328.54	267.00	173.79	212.22	264.09
31	392.06	469.10	216.59	201.67	229.66	327.35	223.73	184.72	323.51	285.17
32	412.21	485.51	169.39	214.95	260.47	272.94	206.57	208.94	298.15	230.24
33	303.34	243.37	177.48	272.02	434.40	297.79	207.23	207.88	298.17	202.71
34	260.24	201.92	430.93	244.91	497.79	228.71	177.96	234.06	416.16	308.70
35	348.67	157.45	413.05	240.42	477.69	163.42	251.63	353.69	321.16	205.42
36	232.14	319.75	272.49	190.29	389.33	150.80	302.33	235.38	348.82	330.03
37	285.91	236.42	283.84	275.08	444.33	296.22	254.93	262.20	343.16	451.08
38	248.21	197.30	260.44	226.77	253.16	283.52	213.84	209.65	338.94	382.76

39	273.32	254.45	354.99	232.85	174.48	343.47	196.66	273.87	276.06	461.48
40	278.21	293.24	383.93	228.32	282.50	439.69	391.66	225.52	256.71	448.82
41	395.03	198.48	436.15	175.87	191.46	340.71	577.29	213.75	295.55	334.42
42	428.83	233.66	318.92	252.75	239.95	238.14	300.36	198.53	185.64	298.87
43	249.49	260.30	183.91	289.94	242.91	294.02	218.30	261.99	373.51	242.27
44	388.32	241.33	256.26	237.18	170.38	323.61	210.14	293.22	400.84	263.93
45	354.41	202.83	204.00	209.42	345.89	269.39	274.03	407.76	259.73	329.39
46	245.59	205.20	233.79	287.04	246.66	308.10	217.95	459.43	499.76	535.35
47	201.75	221.41	244.55	242.47	211.51	253.77	224.58	262.17	391.57	409.58
48	279.28	375.20	283.18	207.79	237.32	261.96	259.19	273.59	255.74	305.39
49	290.41	266.02	233.74	207.02	183.10	243.71	209.21	276.36	300.44	317.32
50	380.60	206.35	186.16	184.77	224.25	332.07	229.01	226.30	313.93	320.85
51	273.28	219.25	247.79	187.06	168.71	375.68	218.28	137.61	291.25	255.10
52	276.06	254.52	232.52	311.70	205.93	254.57	413.60	244.06	232.55	248.39
53	297.50	262.98	242.96	235.58	209.87	245.63	426.59	274.88	290.74	196.30
54	383.89	278.46	573.92	203.57	332.64	285.04	288.81	230.52	350.52	238.37
55	257.52	352.86	514.54	226.20	207.58	194.08	196.83	219.87	286.34	254.11
56	208.09	307.87	489.01	265.57	165.31	245.95	294.24	179.96	213.70	274.37
57	291.98	404.51	528.67	241.68	212.18	370.21	253.35	192.00	290.24	290.03
58	236.73	249.13	405.79	242.10	237.07	258.18	193.24	319.69	298.70	292.57
59	261.21	243.16	268.87	252.37	311.92	233.04	385.38	210.72	288.02	183.07
60	253.21	291.24	247.77	249.38	235.28	266.80	192.71	238.82	337.80	286.44
61	177.20	330.88	233.51	229.92	269.89	215.26	194.02	195.52	352.19	304.43
62	251.76	243.08	258.09	160.55	205.03	250.32	267.79	292.70	355.61	166.95
63	230.09	203.80	247.43	190.12	258.24	276.63	218.78	182.36	384.44	326.11
64	224.88	244.68	230.93	290.18	234.01	348.87	327.87	197.40	261.12	195.19
65	249.74	302.46	220.88	255.01	259.88	373.50	289.47	237.94	192.61	214.50
66	227.09	312.68	231.68	236.80	305.15	480.63	269.06	219.90	338.84	205.24
67	234.56	188.72	237.49	255.81	303.98	260.28	362.82	314.24	409.71	191.96
68	246.28	320.68	286.73	266.69	278.63	518.30	335.81	185.36	203.67	246.88
69	235.50	192.47	205.29	304.62	262.99	432.52	228.66	219.39	280.44	308.52
70	299.13	331.11	316.06	207.81	300.61	274.43	273.77	288.46	278.91	314.77
71	252.90	361.86	268.11	211.78	322.88	294.43	236.36	270.01	322.16	288.56
72	289.12	318.42	441.99	260.69	358.99	342.67	216.30	227.63	283.64	187.94
73	267.50	386.34	289.32	339.63	314.04	272.12	250.38	230.39	273.52	287.03
74	255.15	345.76	282.61	194.03	172.05	225.38	381.02	277.38	203.67	293.12
75	305.53	262.76	235.29	231.83	206.66	241.07	349.73	242.61	168.35	198.64
76	274.84	320.43	314.09	234.09	303.56	369.34	199.05	243.46	249.21	162.44
77	275.05	315.92	274.74	260.62	257.62	282.76	351.84	322.35	212.74	239.47
78	189.36	214.53	240.92	200.69	303.12	247.60	265.04	304.49	402.20	294.06

79	270.47	232.58	263.43	399.70	213.83	478.35	246.72	193.08	250.63	390.46
80	263.38	219.98	251.74	363.64	283.91	402.88	220.86	164.26	313.12	234.44
81	263.12	215.04	266.43	306.67	368.61	449.78	267.81	270.97	219.32	204.47
82	378.99	247.01	176.12	288.63	236.09	371.56	271.41	227.89	329.16	211.68
83	254.35	207.62	350.95	302.98	255.59	249.77	269.56	201.32	326.18	259.51
84	239.46	233.06	368.48	270.42	273.49	245.28	216.78	282.34	254.61	250.74
85	310.84	323.34	337.99	234.70	270.06	282.07	176.90	430.50	293.22	239.37
86	185.65	306.65	300.24	163.02	158.75	522.31	205.94	289.83	302.57	371.00
87	211.08	218.72	243.82	213.43	388.73	399.11	153.94	201.24	282.57	356.80
88	221.50	338.02	234.80	261.77	338.93	218.98	294.48	255.49	350.33	269.06
89	205.56	260.53	272.52	309.45	309.65	326.78	376.67	194.51	326.69	340.10
90	341.17	259.78	313.29	254.37	312.61	222.73	192.83	268.14	296.97	188.32
91	191.21	231.22	343.38	214.47	240.60	275.81	343.45	202.61	305.30	224.69
92	231.56	214.56	362.75	248.96	233.10	329.61	381.14	292.32	211.74	246.41
93	256.91	210.15	259.01	316.92	169.99	227.18	502.97	276.77	252.79	280.07
94	262.24	293.71	318.00	253.87	209.52	286.61	348.56	193.71	319.52	248.17
95	333.10	287.27	228.44	230.45	209.21	299.34	243.47	255.61	238.19	299.93
96	276.05	281.05	313.00	253.36	316.83	244.99	303.31	306.77	227.68	439.11
97	248.16	255.61	184.98	283.49	226.75	258.21	246.63	291.76	281.80	297.68
98	166.37	235.83	197.10	241.44	238.18	469.64	243.94	294.46	258.67	512.16
99	298.24	381.39	368.52	239.92	310.14	519.24	256.88	176.12	308.94	324.79
100	419.73	295.01	201.79	197.19	259.99	215.63	147.50	250.46	271.25	353.52

Appendix I

Simulation Model