# Simulation modeling for the impact of Triage Liaison Physician on Emergency Department to reduce overcrowding

By

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# Abstract

Emergency department (ED) overcrowding has been a common complaint in Emergency Medicine in Canada for many years. Its adverse effects of prolonged waiting times cause patient dissatisfaction and unsafety. Previous studies indicate that adding a physician in triage (PIT) can increase accuracy and efficiency in the initial process of patient evaluation. However, the scientific evidence of the PIT impact on ED is far away from sufficient before its widespread implementation. This research is to search solutions using PIT to identify areas of improvement for the ED patient flow, based upon a validated discrete-event simulation (DES) model. As an efficient decision-making tool, the DES model also helps to develop an understanding of the current ED performance and quantitatively test various design alternatives for ED operations.

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# Dedication

To my parents, my husband, and my son.

# Contents

# Glossary

| | |
|---|---|
| ED | Emergency Department |
| SBGH | St. Boniface General Hospital |
| WRHA | Winnipeg Regional Health Authority |
| EDIS | Emergency Department Information System |
| DES | Discrete-event simulation |
| CTAS | Canadian Triage and Acuity Scale |
| LOS | Patient length of stay in the ED |
| WTBS | Patient status when he/she is waiting to be seen by a doctor |
| TIP | Patient status when treatment is in progress |
| PIT | Physician in triage |
| PIT Strategy | The strategy of adding one physician in triage with corresponding changes to the current ED patient flow |

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# Chapter 1

# Introduction

## 1.1 Research Background

Hospital emergency departments (EDs) provide the emergency medical treatment for patients of all ages, facing a variety of illness from minor to life threatening problems. In 2014 – 2015, more than 16 million ED visits in Canada were reported by National Ambulatory Care Reporting System (NACRS), while within the Winnipeg Health Region, each year there are over 300, 000 visits to one of the six EDs ("Emergency Department Reports | Emergency Department & Urgent Care Wait Times | Winnipeg Health Region" 2016; CIHI 2015).

EDs are the gatekeepers to hospitals in Canada; 10% of the patients are admitted to the hospital through EDs according to a report recently released by the Canadian Institute for Health Information (2015). Most patients spend approximately 7.5 hours in the ED from registration/triage to departing after treated; but for the 10% of patients who need to be admitted, their stays in the ED can be much longer, with an additional time (can be more than 28 hours) waiting for an appropriate inpatient bed to become available (CIHI 2015).

Canada's overall waiting time to see an ED physician has been steadily falling from 3.6 hours to 3.2 hours during 2008-2013 ("Find Your Hospital or Province's ER Wait Times to See a Doctor" 2016). However, not all provinces are seeing such improvements. In Manitoba, patients commonly wait up to 5.6 hours before their initial assessment by an ED physician. Compared to other provinces in Canada, Manitoba has the highest waiting time in the ED during 2009 - 2013.

*Brief review of current knowledge on ED overcrowding*

A popular term ED overcrowding is often used when studying waiting times in EDs, which refers to a situation where the ED service cannot meet care demands within reasonable time frames (Affleck et al. 2013). Overcrowding in EDs has been a common complaint in Emergency Medicine in Canada for more than 20 years (Affleck et al. 2013). Considering its adverse effects on patient satisfaction and safety (Bond et al. 2007; Guttmann et al. 2011; Carter et al. 2014), improving ED operations to alleviate ED overcrowding becomes crucial and urgent.

ED overcrowding is a complex public health concern, whose leading factors penetrate in almost every level of the health care system (Affleck et al. 2013). But overall, the mismatch between the supply and demand in health care systems devotes its major contribution to this issue (Hoot et al. 2008). In the past decades, researchers have made great efforts in attempt to define a single universal standard to quantify the ED crowdedness, such calculators as NEDOCS (National emergency Department Overcrowding Study) and EDWIN (Emergency Department Work Index) (Weiss et al.

2004; Bernstein 2003). But multi-center studies are needed to test whether these scales can provide a good reflection of the overcrowding at other EDs before they are determined to be universal standards (Bernstein 2003; Weiss et al. 2006). Another ED overcrowding measurement system called "International Crowding Measure in Emergency Department" (ICMED) is also waiting to be formally validated (Boyle et al. 2015).

Nevertheless, Simulation modeling, as one of the common operation research techniques, has significantly helped the EDs in various issues to improve their performance gauging metrics, such common ED issues as forecasting, capacity planning, resource allocation, staffing and scheduling, measuring performance metrics, geographic optimization, and supply chain management (Kolker 2012). By designing a virtual model of a real ED system, the process performance can be investigated, and various strategies of the ED operation can be evaluated through groups of experiments for a better operating policy (Shannon 1998). Without disturbing the actual system, the simulation model is proved an efficient decision-making tool in improving the system performance.

*Bridging the gap in current knowledge*

Previous studies indicate that one of the main factors causing ED overcrowding is the process inefficiency within the ED. To improve the process/patient flow within the ED, multiple strategies have been offered as potential solutions, such as ED floor plan modifications, changes in workflows, and resources adjustments. Physician in triage (PIT) is one of these interventions to increase accuracy and efficiency in the initial process of patient evaluation by gaining more accurate information upfront, and issuing discharge or appropriate tests early by adding a physician in triage (Oredsson et al. 2011).

Theoretically the PIT method can be beneficial to all types of patients regardless of their acuity levels.

But unfortunately, the recent PIT related studies are mainly grounded on either the survey or limited data analysis. The scientific evidence of the PIT impact on EDs is far away from sufficient before its widespread implementation (Rowe et al. 2011). More research is required to examine these preliminary findings using a robust decision tool to determine its application and limitations (Kaushal et al. 2015).

Due to the complexity of the ED system, decisions need to be much more evidence-based and made in near-real-time conditions. Simulation model proposed in this research will help analyzing and identifying these types of variability in EDs. Few research publications are found using the simulation model to evaluate the PIT effect on EDs, where one presented a team triage method (using a receptionist, a nurse and a physician in triage) which reduced the patient average throughput time by 26% using the simulation (Ruohonen et al. 2006).

## 1.2 Research Objectives

This research is undertaken at St. Boniface General Hospital (SBGH) in Winnipeg, Manitoba. The hospital management considers implementing some changes to reduce patient waiting time and throughput time in their emergency care process, and to improve the overall service delivery and system throughput.

Since simulation allows an analyst to create a virtual environment of a real or proposed system in order to examine its reactions to various conditions, it is favored over analytical solutions when studying complex dynamics systems such as an ED (Jurishica

2005). Using the computer simulation, it is proposed to achieve success of modeling the emergency care process and determining the impact of key resources on key performance measures (patient waiting times and length of stay).

A list of the detailed objectives of this research is as follows:

1) To develop a validated DES model that can be used to study bottlenecks in the current patient flow;
2) To design and test alternatives around these bottlenecks to reduce WTBS and LOS based on a validated DES model;
3) To search solutions using PIT to reduce LOS and WTBS based on a validated DES model.

## 1.3 Thesis Overview

This thesis research is organized as follows: Chapter 1 introduces the thesis background and research objectives; Chapter 2 presents the literature review of ED overcrowding and simulation modeling for improving the ED patient flow; Chapter 3 provides a detailed description of the current ED patient flow at St. Boniface General Hospital; Chapter 4 introduces research milestones and overall methodology to conduct a DES simulation study, and specifies the processes within the model development; Chapter 5 identifies the bottlenecks within the current ED patient flow and evaluates various operating alternatives for the ED improvement; Chapter 6 concludes the major findings from this research and suggests opportunity for future research.

# Chapter 2

# Literature Review

## 2.1 Emergency Department Overcrowding

*Background*

Emergency department (ED) overcrowding refers to a situation where the demand for emergency services exceeds the ability of an ED to provide the quality care within appropriate time frames (Affleck et al. 2013). It is a significant world-wide problem; many research activities have been conducted in this field. In Canada, ED overcrowding has been a critical issue in Emergency Medicine for more than 20 years (Affleck et al. 2013). A national level survey conducted by the Canadian Agency for Drugs and Technology in Health in 2006, reported that 62% of ED directors regarded overcrowding as a severe problem (Bond et al. 2007). Some researchers also determined that ED overcrowding was associated with a great risk in patient safety and mortality (Guttmann et al. 2011; Carter et al. 2014).

*Measurements of ED overcrowding*

Although there is close attention to ED overcrowding by the public, there are currently no national standard definitions in Canada to measure it, and this fundamental weakness applies to many other countries too (Ospina et al. 2006; Higginson 2012; Affleck et al. 2013). Boyle et al. (2015) in their research mentioned an international Delphi-based standard which was composed of eight-point measures of ED crowding, called "International Crowding Measure in Emergency Department" (ICMED). Higginson (2012) in his review of ED crowding mentioned ICMED as well where the eight-point measures were grouped into three categories with specified operational definitions: input, throughput, and output measure (*Table 2-1*).

*Table 2-1: International Crowding Measure in Emergency Department (ICMED) (Boyle et al. 2015)*

| **Measure** | | **Operational Defination** |
|---|---|---|
| Input Measure | 1. Ambulance offload time | An ED is crowded when the $90^{th}$ percentile time between ambulance arrival and offload > 15 mins. |
| | 2. Patient LWBS | An ED is crowded when number of patients LWBS ≥ 15%. |
| | 3. Time until triage | An ED is crowded when there is a delay > 5 mins from patient arrival to begin their initial triage. |
| Throughput Measure | 4. ED occupancy rate | An ED is crowded when the occupancy rate > 100%. |
| | 5. Patient total LOS | An ED is crowded when the $90^{th}$ centile patient total LOS > 4h. |
| | 6. Time to a physician first assesses | An ED is crowded when a Triage level 1 or 2 patient waits > 30 min to be seen by a physician. |
| Output Measure | 7. ED boarding time | An ED is crowded when less than 90% of patients have left the ED 2h after the admission decision. |
| | 8. Number of patients boarding in ED | An ED is crowded when there is > 10% occupancy of boarders in the ED. |

However, the operational definition of ICMED has not yet been formally validated. Some researchers (Boyle et al. 2015) attempted to validate ICMED in a domestic/international sample of EDs, but substantial variations in the performance of ICMED were observed in different countries and different centers. Future work is required to validate the ICMED definition before it can be advocated widespread use in order to have the standard definition in the evaluation of ED overcrowding in place (Boyle et al. 2015; Ospina et al. 2006).

Although there is no single standard definition of ED overcrowding, researchers' interest in this field seems never fade away. In 2004, Weiss et al. (Weiss et al. 2004) generated a Web-based NEDOCS calculator (i.e. National Emergency Department Overcrowding Study) to determine the congestion in ED with scores from 0 to over 180, where 0 indicates ED is not busy at all while score over 180 indicates ED is dangerously overcrowded. The greater the NEDOCS value, the greater the degree of ED congestion (Weiss et al. 2004). The index formula is as follows:

$$\text{NEDOCS} = \left(\frac{N}{B}\right) \times 85.8 + \left(\frac{W}{H}\right) \times 600 + T \times 5.64 + L \times 0.93 + R \times 13.4120$$

Where,

- $N$ is the total number of patients in ED at time $t$;
- $B$ is the total number of beds in ED at time $t$;
- $W$ is the total number of patients waiting in hospital at time $t$;
- $H$ is the total number of bed in hospital at time $t$;
- $T$ is the time of patients in ED waiting for available bed at time $t$;
- $L$ is the longest time of emergency patients waiting to be hospitalized at time $t$;

– $R$ is the number of emergency patients which use inhale apparatus at time $t$.

Another relatively common ED overcrowding calculator is named EDWIN (i.e. Emergency Department Work Index). Bernstein et al. (2003) created EDWIN to quantitatively measure the ED crowding and busyness. It is defined as:

$$\text{EDWIN} = \sum \frac{n_i t_i}{N_a(B_T - B_A)}$$

Where,

– $n_i$ is the number of patients present in the ED in triage category $i$;

– $t_i$ is the trage category (ordinal scale 1-5, 5 being the most acute);

– $N_a$ is the number of attending physician on duty at a given time;

– $B_T$ is the total number of beds, or treatment bays, available in th ED;

– $B_A$ is the number of admitted patients in the ED.

The EDWIN score characterizes ED status as three zones – active, busy, and crowded: a score less than 1.5 indicates an active but manageable ED; a score between 1.5 and 2 indicates a busy ED; and a score greater than 2 indicates a crowded ED (Bernstein 2003).

Both NEDOCS and EDWIN have been developed for a few years, while NEDOCS seems relatively more extensive in the health care system. Both of them are reasonably good tools to quantify the subject feeling of ED overcrowding (Anneveld et al. 2013; McCarthy et al. 2008). However, common limitations exist as well. Weiss et al. (2006) stated that both scales were designed and validated on the basis of opinions from ED experts; the scales tended to be local based since opinions could be various from different experts in different ED centers. Another limitation is regarding the scale validation. A multi-center study is needed to test whether these scales can provide a good reflection of the overcrowding at other EDs before they are determined to be universal standards (Bernstein 2003; Weiss et al. 2006).

*Causes of overcrowding*

As noted by many researchers (Affleck et al. 2013; Asplin et al. 2003; Schull et al. 2002; Hoot et al. 2008), ED overcrowding is a complex, multi-dimensional health service system problem which cannot be solved by examination of the ED in isolation. Although factors causing overcrowding penetrate in almost every level of the health care system, the mismatch between the supply and demand in health care system devotes its major contribution to this issue (Asplin et al. 2003).

To identify the system-origin of the ED overcrowding problem, several publications have recommended to examine ED overcrowding in the context of the entire health service delivery system which could be conceptualized using the input-throughput-output model (*Figure 2-1*) (Asplin et al. 2003; Affleck et al. 2013; Higginson 2012; Ospina et al. 2006). This model allows most factors related to overcrowding to be categorized into one of the three interdependent criteria: input, throughput, and output.

The input component of this conceptual model refers to factors that contribute to the demand for ED services (i.e. sources of patients seeking ED care); the throughput component looks internally at the ED operation, specifically in associated with the ED efficiency, workload, and capacity; finally, the output component defines bottlenecks that cause delay in patient disposition such as patient boarding in the ED (i.e. a situation where a patient supposed to be admitted hospital remains in the ED due to certain factors) (Asplin et al. 2003; Ospina et al. 2006). Moreover, Hoot and Aronsky (2008), Hwang et al. (2011) and Schull et al. (2002) illustrated some of the factors causing overcrowding more deeply to clarify the conceptual framework of ED overcrowding. The well-studied causes of ED overcrowding are generally non-urgent visits, "frequent-flyer" patients, influenza season, inadequate staffing, inpatient boarding, and bed shortages, with the bed shortage and inpatient boarding the most influenced (Hoot et al. 2008; Bond et al. 2007; Ontario Hospital Association 2006; CIHI 2007).

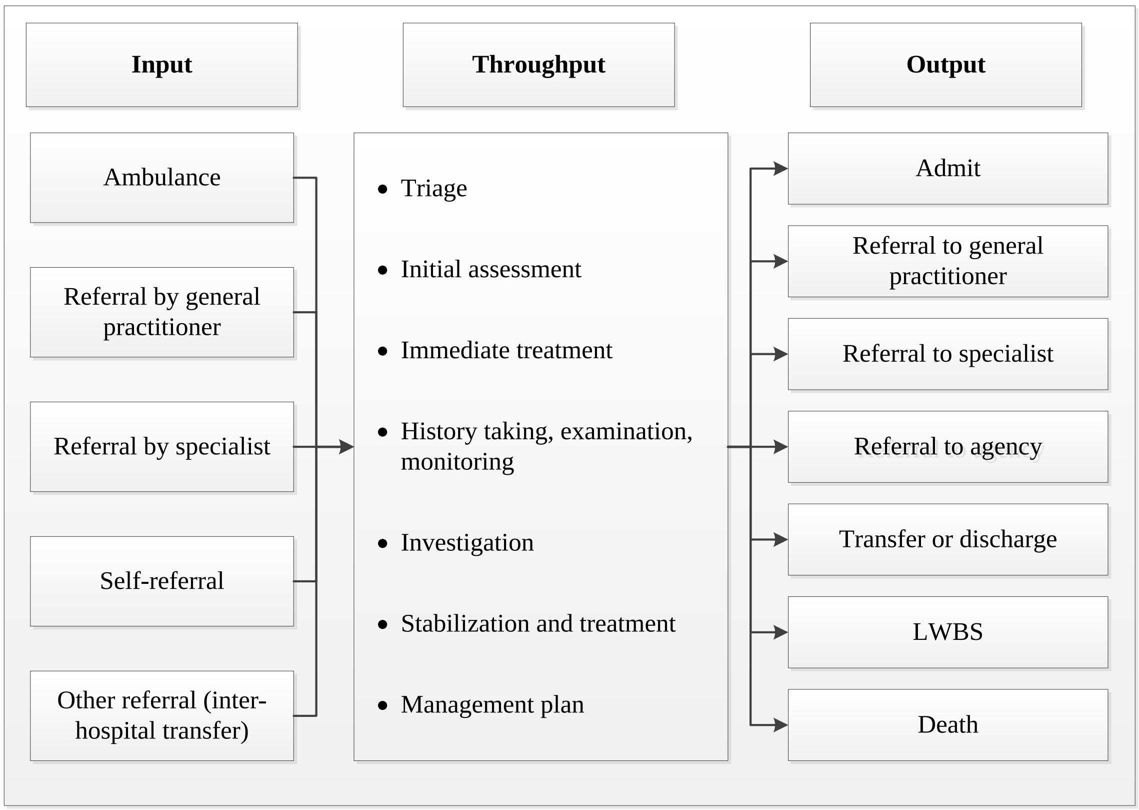



*Figure 2-1: Input-throughput-output conceptual model of ED overcrowding (Ospina et al. 2006)*

### *Effects of overcrowding*

There is extensive literature on a variety of potential effects of overcrowding. Most of the papers demonstrate a negative effect of overcrowding on the patient care and nurse/physician satisfaction. A comprehensive structured review done by Hoot and Aronsky (2008) concluded that the common effects of overcrowding included the patient mortality, transport delays, treatment delays, ambulance diversion, patient elopement, and financial effect. Similar conclusion was mentioned by Higginson (2012) too in his review of ED crowding.

Even though there is currently no universal standard to measure the ED crowdedness, a reliable alternative seems well accepted by the public, which is to measure the ED crowdedness by monitoring outcome measures. Some of the commonly studied outcome measures are (Hoot et al. 2008): patient wait times; patient length of stay (LOS); patient throughput; left without being seen (LWBS); bed occupancy; ambulance diversion rate; and resource utilization. A Canadian national survey conducted in 2006 (Bond et al. 2007) demonstrated that these outcome measures could be a good projection of the ED crowdedness because their impact on ED crowding was obvious.

*Solutions to overcrowding*

Multiple solutions to alleviate ED crowding have been studied in the literature, and generally can be grouped as (Hoot et al. 2008): the demand management in non-urgent patient referrals, ambulance diversion and destination control; additional resources either physical or human; finally, operation research to provide business intelligence (i.e. the patient flow optimization).

## 2.2 Simulation Modeling for Improving ED Patient Flows

Simulation modeling is one of the most common operation research techniques, whose contributions to the ED patient flow optimization have been remarkably extensive, generally in associated with the ED patient flows (i.e. the physical movement of patients through a set of locations). In this section, literature is reviewed regarding optimizing patient flows inside the ED, in particular using simulation modeling.

*Benefits of Simulation Application in ED*

Simulation modeling has been used for improving the ED performance with a growing popularity. By designing a virtual model of a real ED system, the process performance can be investigated, and various strategies of the ED operation can be evaluated through groups of experiments for a better operating policy (Shannon 1998). Without disturbing the actual system, the simulation model is proved an efficient decision-making tool in improving system performance.

*Overview of Simulation in ED*

There is a great volume of in-depth research on the ED patient flow optimization using simulation to understand causes of ED overcrowding and to test various interventions to alleviate the effects of overcrowding. Simulation shows the great impact on ED processes at care-team, organizational, and environmental levels (Paul et al. 2010). Most research in the ED simulation falls in one of these four motivations: costs and competition, efficiency, re-engineering, and quality of the service (Paul et al. 2010). The primary goals amongst most simulation publications are to identify bottlenecks within the ED, detect areas of improvement, and test various “what if” strategies. Its commonly studied outcome measures generally are: patient wait times; patient length of stay (LOS); patient throughput; left without being seen (LWBS); bed occupancy; ambulance diversion rate; and resource utilization.

*Simulation Applications in ED*

Different research has been conducted to examine patient flows/ED processes for improvement. Simulation becomes indispensable in addressing common ED issues, generally with respect to: forecasting; capacity planning; resource allocation; staffing and scheduling; measuring performance metrics; geographic optimization; and supply chain management as summarized in *Table 2-2* (Kolker 2012).

*Table 2-2: Simulation research in addressing common ED issues (Kolker 2012)*

| **Simulation research on ED issues** | **Objectives/Methods** |
|---|---|
| Forecasting | Projecting the future patient volumes (demand) for short- and long-term budget planning and other planning purposes |
| Capacity planning | Determining the maximum amount of resources that are required for a unit or service (such as beds, operating rooms, pieces of equipment etc.) |
| Resource allocation | Defining how to deploy resources in an efficient manner (ex. specialized resources VS pooled resources) |
| Staffing and scheduling | Estimating the number of care providers (i.e. nurses, physicians etc.) needed for a particular shift in a unit in order to best achieve operational and service performance objectives |
| | Optimizing staff schedules that help not only in delivering a safe and efficient care for patients, but also take into account staff preferences and convenience |
| Measuring performance metrics | Monitoring outcome measures such as patient waiting time to help achieving the system throughput goal |
| | Defining and measuring staff utilization |
| Geographic optimization | Optimizing geographic location of facilities and facility layout |
| | Design of facility optimized workflow |
| Supply chain management | Optimizing a supply chain and inventory management |

*Methods for improving ED patient flows*

As Hopp et al. (2012) noted, adding resources is the most direct way to reduce crowding but it is also the most expensive method without the preferred option. Rather than focusing on the level of resources that the ED deserves, it sounds more reasonable to consider how to ensure the ED resources direct to those who need them – the patients in the waiting room.

There are multiple interventions offered as potential solutions to improve the patient flow in the ED, while "front-end" interventions become an important area of the focus (Oredsson et al. 2011; Wiler et al. 2010). Wiler et al. (2010) defined front-end operations as "the patient care processes that occur from the time of a patient's initial arrival to the ED to the time an ED health care provider formally assumes responsibility for the comprehensive evaluation and treatment of the patient". Typically, these front-end operations include the initial patient presentation, registration, triage, bed placement, and medical evaluation although they may vary in different EDs (Wiler et al. 2010).

The time spending generated by completing the front-end operations has influence on the ED total length of stay; patients would have to wait in a queue because of their non-succession occurring (Wiler et al. 2010). This sheds light on the need for scientific research in front-end interventions. According to Oredsson et al. (2011), these front-end (or triage-related) interventions can be generally grouped into: the team triage; patient streaming; fast track; point-of-care testing; and nurse requested X-ray as shown in *Table 2-3*.

*Table 2-3: Front-end interventions to improve the patient flow in the ED (Saghafian et al. 2015; Oredsson et al. 2011; Wiler et al. 2010)*

| **Front-end interventions** | **Description** | **Rationale** | **Pros** | **Cons** |
|---|---|---|---|---|
| Team triage | Defined as triage handled by a team that includes a physician. | Increase accuracy and efficiency in the initial process of patient | Reduce LWBS rates, patient | Adding physician is an expensive cost of triage. |

| | | | | |
|---|---|---|---|---|
| | | evaluation: gaining more accurate information upfront, and issuing discharge or appropriate tests early on. | waiting times, LOS, and ambulance diversion levels. | |
| Patient streaming | Refers to routines where patients, following triage or brief evaluation, are divided into different streams based on a prediction of their disposition (admit or discharge). | Process non-urgent patients in First-In-First-Out (FIFO) manner to achieve fast discharge; remain traditional prioritization methods on admitted patients. | Reduce patient waiting times, and LOS. | Only beneficial to discharged patients; inpatient care is not adversely affected. Its effect is supported by only limited scientific evidence. |
| Fast track | A dedicated stream of resources to process lower acuity patients more quickly. | The majority of ED visits are non-urgent; the use of a fast track lane is a great aid in serving lower acuity patients and reducing overcrowding. | Reduce LWBS rates, patient waiting times, and LOS. | The institution of a fast track depends on having sufficient lower acuity patients; a decision tool to determine this threshold population volume is unknown. |
| Point-of-care testing | Refers to moving laboratory analysis to the ED. | To increase the speed of diagnosis in the ED. | Reduce turnaround time for the laboratory analysis and patient LOS. | Its effect is supported by only limited scientific evidence. |
| Nurse-requested X-ray | Nurse requests X-ray for a patient at triage if the patient shows the evidence that he/she needs an X-ray. | X-ray examination is a time-consuming process in the ED. In many cases, it is evident at first presentation that the patient needs an x-ray. | Reduce patient waiting times, and LOS. | May have an increased risk of needing additional x-rays following the physician's examination. Its effect is supported by only limited scientific evidence. |

In addition to the methods discussed above, there are also some other strategies to improve ED front-end processing. Wiler et al. (2010) presented some additional strategies such as immediate bedding, bedside registration, tracking systems and whiteboards, wireless communication device, kiosk self-check-in and personal health record technology. Some publications even seek to modify the traditional/current triage protocols in order for a smoothing patient flow in the ED (Saghafian et al. 2015; Wiler et al. 2010). Resource allocation and staffing schedules are also major concerns in some research publications.

*The potential of adding a physician in triage*

In terms of the five interventions as displayed in *Table 2-3*, they all present some potentials to improve the ED performance, but only with methods of the fast track and team triage having relatively strong scientific evidence (i.e. the scientific evidence for the other three interventions is insufficient) (Oredsson et al. 2011). Fast track is the most studied intervention; the use of a fast tract lane helps to process lower acuity patients more quickly. The advantage of the fast track is significant for patients in non-urgent situations, whereas its effects on urgent patients are unclear (Oredsson et al. 2011; Ardagh et al. 2002). Team triage is designed theoretically for all types of patients regardless of their acuity level. Compared to the fast track, urgent patients may be better handled by the team triage (Oredsson et al. 2011).

There are a few studies in the literature that have investigated the use of a physician in triage (or team triage) and its impact on ED patient flows. Surprisingly, most of these studies come to conclusions that adding a physician in triage improves the overall emergency care services and mitigates the effects of ED overcrowding (Shea et al. 2012; Subash 2004; Choi 2006; Holroyd et al. 2007; Rowe et al. 2011). The current traditional “nurse triage” model of managing patient arrivals often creates barriers to the process of efficiently evaluating patients (Shea et al. 2012). By adding a physician in triage (PIT), EDs will increase accuracy and efficiency in the initial process of patient evaluations by gaining more accurate information upfront, and issuing discharge or appropriate tests early; meantime patients will benefit from the immediate assessment by a physician

(Oredsson et al. 2011). The introduction of a PIT to the team may also enable inexperienced staff to extend their knowledge and practice to a senior level with the mentorship and guidance from the physician (Richardson et al. 2004; Oredsson et al. 2011); thus further advance on efficiency in triage can be expected due to experienced staff.

But more research is required before PIT can be widely implemented (Rowe et al. 2011). The recent PIT related studies are mainly grounded on either the survey or limited data analysis, such as using the interventional study with retrospective data to evaluate the effect of a PIT on the ED throughput. The scientific evidence of the PIT impact on EDs is far away from sufficient before its widespread implementation. A decision tool is required to examine the application and limitations of these preliminary findings (Kaushal et al. 2015).

*The potential of using simulation to evaluate the physician in triage*

Due to the complexity of the ED system, decisions need to be much more evidence-based and made in near-real-time conditions. Simulation model proposed in this research will help analyzing and identifying these types of variability in EDs. There are few research publications found in using the simulation model to evaluate the PIT effect on EDs. Ruohonen et al. (2006) presented a team triage method (using  a receptionist, a nurse and a physician in triage) which reduced the patient average throughput time by 26% based on the simulation.

## 2.3 Summary of Literature Review

Based on the literature review above, the physician in triage (PIT) is proposed in this research as a method for the ED improvement. This research will search solutions using PIT to identify areas of improvement for the ED patient flow, based upon a validated simulation model. Using the proposed simulation model to examine the PIT operation, the difference of ED performance will be measured based on using and without PIT. Factors potentially causing overcrowding will be detected to understand details that impact ED operations. Various scenarios of the ED improvement will be proposed and tested incorporating both resource utilization and process optimizations.

Since simulation allows an analyst to create a virtual model of a real or proposed system in order to examine its reaction to various conditions, it is favored over analytical solutions when studying complex dynamic systems such as an ED (Jurishica 2005). It is the "what if" analysis (i.e. the ability to test various "what if" scenarios within a minimum amount of time) that has made simulation a widespread tool in the ED (Saghafian et al. 2015; Kolker 2008). Comparing to the other methods applied in the ED, simulation seems to be much more flexible and versatile: it allows free assumptions of the input data (i.e. the arrival pattern and service time); the system structure can be of any complexity; and the custom action logic can be built in to mimic the real system behavior in a great level of details (Kolker 2008).

However, the simulation application in EDs has limitations: it is the ED specific, and not generalizable (Günal et al. 2010; Paul et al. 2010). Substantial diversity exists among such studies in terms of the objective, scope, level of details and calibrations. Rather than a generically available tool, simulation is more of a case-by-case approach (Saghafian et al. 2015).

# Chapter 3

# ED Patient Flow Description

## 3.1 ED Background

St. Boniface Hospital is a general hospital in the St. Boniface Neighbourhood of Winnipeg, Manitoba. It has been providing multiple healthcare services to Manitobans since it was first established in 1871. Located at the fork of the Red and Assiniboine Rivers, it is the first hospital in Western Canada and second largest hospital in Manitoba. Its healthcare service generally consists of community outreach programs, ambulatory care programs and inpatient services through 554 beds and 78 nursing bassinets ("Facts and Figures" 2016).

The Emergency Department at St. Boniface Hospital is a 24-hour/7-day emergency care facility with approximately 42,000 patient visits annually (~120 patients per day). There are a total of 40 spots (beds/seats) for patient care divided into six distinct care areas: Resuscitation Room (2 beds), Stretcher Bay (11 beds), ERooms (8 spots; Seat 8 is a ENT Room for patients searching care for ear, nose, throat & eyes), Minor Treatment Area (3 spots), Reassessment Unit (14 beds; 12 of them are used on a day-to-day basis while the remaining 2 beds are only used in a busy period), and Psych Rooms (2 spots; the one called "Family Room" is only used as a Psych exam/holding room when required). *Figure 3-1* presents the floor plan of the ED at St. Boniface Hospital.

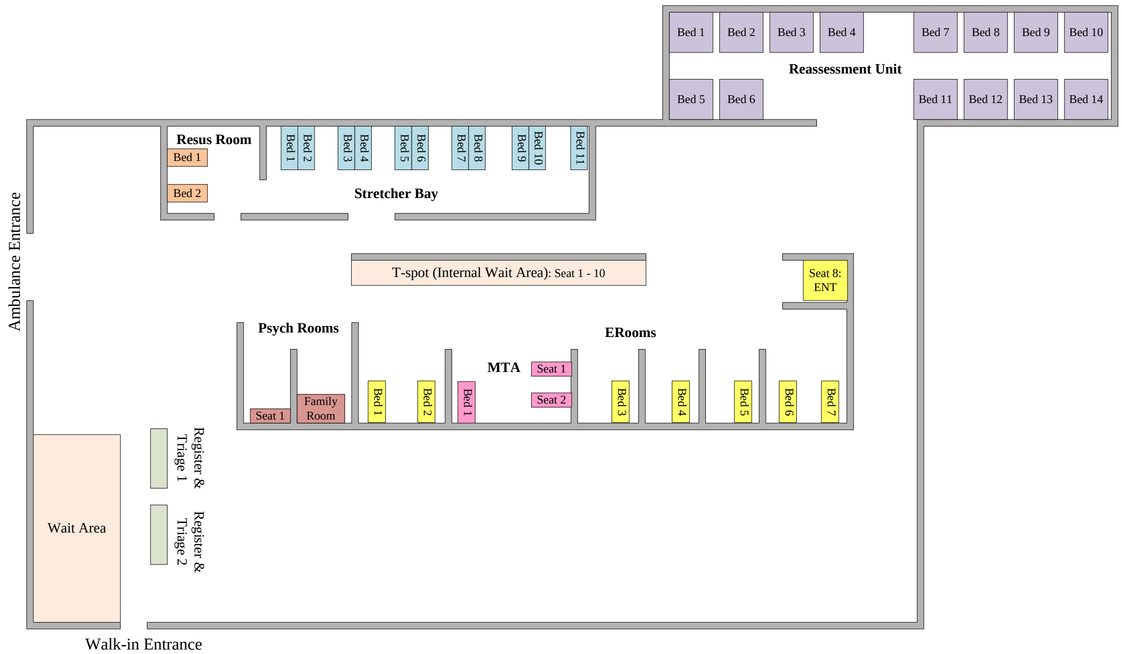



*Figure 3-1: A simplified SBGH ED floor plan*

## 3.2 Patient Flow Description

A visit to the ED usually involves a various series of decisions, activities, and interactions with ED and hospital staff. Patient flows can vary from patient to patient based on the acuity level and diagnosis, and thus it is impossible to classify all ED patient flows exactly. However, a general ED patient flow can be determined, which involves most common decisions, activities, and interactions that a patient will experience in the ED. Based on the information provided by the ED staff, a general patient flow chart can be constructed as shown in *Figure 3-2*. A typical visit to the ED usually involves: pre-bed service, on-bed service, and departing the ED. The remaining of this section gives a brief overview of each activity in the general patient flow process.

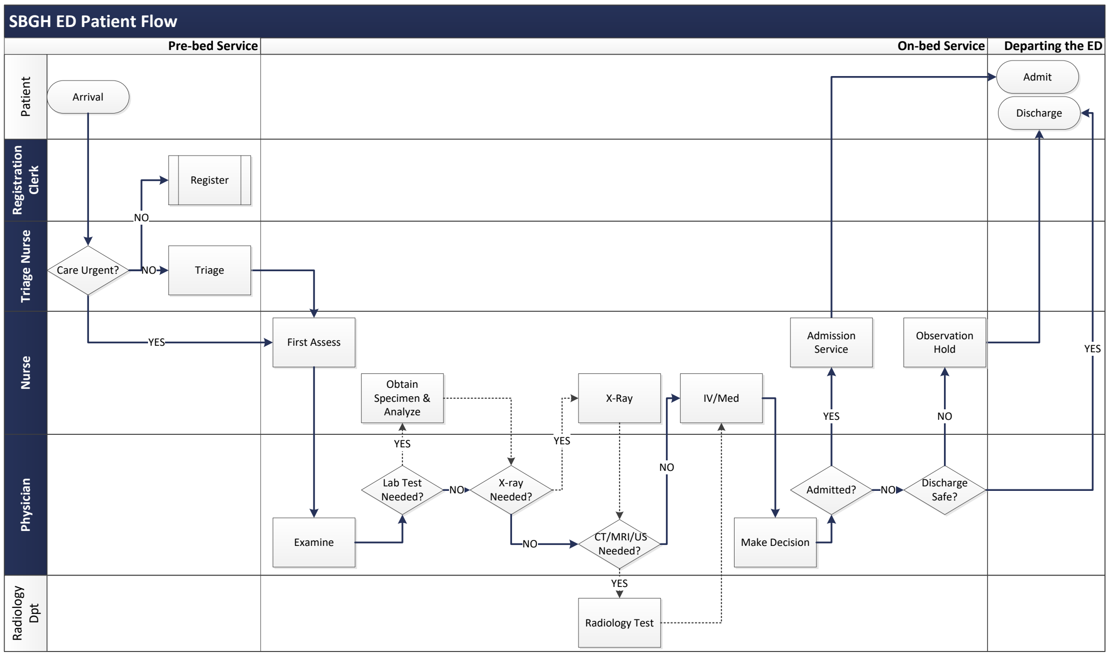



*Figure 3-2: A general patient flow in the ED*

*Pre-bed Service Process*

A patient enters the ED by one of two modes: walk-in or ambulance. When a non-critical patient (either walk-in or ambulance patient) arrives at the hospital and enters the ED, the patient first waits to be called for triage in the immediate front row in the waiting area. During the triage process, the triage nurse takes a full set of vital signs of the patient (i.e. temperature, heart rate, blood pressure, respiratory rate and oxygen saturation), assesses the patient's condition, and assigns the patient an acuity level and treatment unit. Simultaneously, a registration clerk registers the patient by creating a file for this specific visit. Basic information such as name, birth date, and social insurance number is collected during registration. At this point, the patient returns to the main waiting room to await availability to the designated treatment area within the ED. A critical patient with the life-threatening condition may bypass registration and triage, and be serviced directly by doctors and nurses.

The triage nurse classifies patients into five classes including CTAS 1, CTAS 2, CTAS 3, CTAS 4, and CTAS 5, according to Canadian Triage and Acuity Scale (CTAS) National Guidelines as shown in *Table 3-1* (Beveridge et al. 1998). CTAS 1 critical patients are seriously ill or injured, for example, stroke or heart attack, and they need immediate life-saving treatments. CTAS 2 are emergent patients, requiring a rapid medical intervention. CTAS 3 and 4 are assigned to urgent or semi-urgent patients, which account for a major percentage of the patients. CTAS 5 are those non-urgent patients who may go to clinics instead of the ED owing to their minor symptoms.

*Table 3-1: Canadian Triage and Acuity Scale categories and waiting times (Beveridge et al. 1998)*

| CTAS Level | Acuity of Patient Condition | Waiting Time |
|---|---|---|
| 1 | Resuscitation | Immediately |
| 2 | Emergent | Within 15 minutes |
| 3 | Urgent | Within 30 minutes |
| 4 | Semi-urgent | Within 60 minutes |
| 5 | Non-urgent | Within 120 minutes |

*On-bed Service Process*

The ED at St. Boniface Hospital is sectioned into six distinct treatment areas. These are the Resuscitation Room (Resus), Stretcher Bay (SB), ERooms (ERms), Minor Treatment Area (MTA), Reassessment Unit (RU), and Psych Rooms. Patients are assigned to one of these areas (except RU) based on age, acuity level, type of illness and some other determinants.

Once a patient is transported to a specific treatment area, an ED nurse initiates the patient care cycle by assessing the patient's condition. For those critical patients that are sent directly to the beds, the nurse also carries out triage and registration procedures. After the nurse completes the initial treatment process, an ED physician performs an assessment and continues treatments of the patient. Based on the type of illness and the severity of the patient's condition, the physician decides whether the patient requires additional care (i.e. lab test, radiology tests, or any combination of these). Lab test and X-ray are usually conducted by the nurse in the ED, while for other radiology tests such as CT, MRI and Ultrasound patients are sent to the Radiology Department of the hospital which is outside the ED. After the patient returns from the laboratory and radiology tests, additional medical treatment (i.e. IV/Med) is provided by the nurse. Typically, the patient may need to wait in the internal waiting area T-spot until all the testing results are ready. Then, the physician re-examines the patient's condition, and makes decision on whether to admit or discharge the patient. During this cyclical process although it happens rarely, a patient may receive multiple visits from ED physicians and nurses.

After each care activity is completed, the nurse either admits or discharges the patient followed by the physician's disposition instructions. If admitted, the patient may have to wait in the RU until an appropriate inpatient bed on the hospital floor becomes available. If discharged (i.e. non-admitted), the patient leaves the ED until reaching a stable condition. In other words, the discharged patient will be hold under observation in the RU until the physician says safe to discharge.

*Departing the ED*

Being admitted to the hospital, being discharged from the ED, leaving the ED before treatment, and death are the only four ways a patient may exit the ED. A patient will be officially released from the ED only after the physician is satisfied with the patient's overall assessment and treatment.

# Chapter 4

# Model Development

## 4.1 Research Milestones

This research introduces the method to conduct a discrete-event simulation (DES) study to simulate the behavior and performance of a real-life process or system.

There are generally three milestones to conduct this research:

1) Building a validated model to simulate the current ED patient flow;
2) Conducting the bottleneck analysis to identify limiting factors that prevent an efficient ED;
3) Designing and testing various ED operating alternatives to suggest improvements.

## 4.2 General Procedure of a DES study

Conducting a DES simulation study generally consists of the following steps: the problem formulation, setting study objectives, conceptual modeling, data collection, model design and building, model verification and validation, model analysis, and study documentation. *Figure 4-1* shows a flowchart of the step-by-step DES simulation procedure.

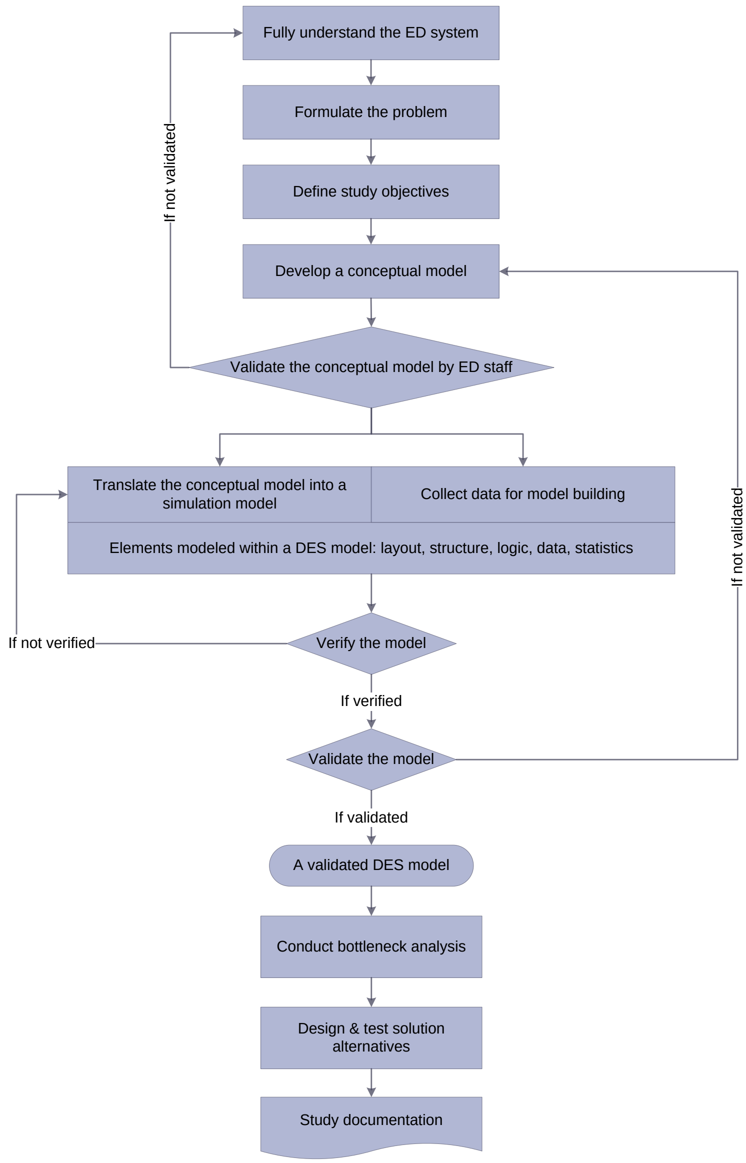



*Figure 4-1: General procedure for a discrete-event simulation study*

The first step of model building is to fully understand the ED function. Based on this understanding, formulate a problem statement that describes the problem which needs to be solved and defines an overall goal of the study with specifics of study constraints. Following of this, a conceptual model is then developed to abstract essential features of the ED system with consideration of the formulated problem and the objectives of the simulation study. Here it is important to note that the conceptual model may use a number of assumptions to simplify the modeling effort by eliminating any trivial. The conceptual model is then translated into a data-driven computer programmed simulation model of a sequence of ED operations.

Within a DES model, the layout, structure, logic, data and statistics of the real-world system are built. In this research, simulation software Witness 14.0 is used to simulate the current behavior of the ED system. The model built in Witness consists of a series of elements, which represents model physical components such as resources, flow lines, and infrastructure (Al-Aomar et al. 2015). In this ED model, major elements include patients, ED staff, service operations, and patient flows. The level of details put into model elements is mainly dependent on the system nature and modeling objectives.

The model undergoes the verification and validation during the entire model building process. Model verification is the first step of the quality control check to see if the simulation model is built and performed on the indented logical design. A successful verification reflects what the modeler has initially designed. Model validation is the second step of the quality control check before the model can be used to test various “what if” scenarios or predict future behavior. It is a process of checking the accuracy of the built model to determine if the model is a good representation of the real-world system. Here it should be realized that the model is only validated based on the project purpose; it is not and will never become a 100% representation of the real system. Once the built model is validated for the project purpose, it is ready to be used as a robust decision making tool to analyze the effects of different ED operating scenarios on the ED performance.

## 4.3 ED Modeling Basics

The main objective of the simulation model was to develop an understanding of the current ED performance and test design alternatives for ED operations. This was accomplished by modeling the general patient flow and ED processes for realistic operating conditions using the simulation software Witness 14.0. A typical visit to the ED usually involves three phases (i.e. pre-bed service, on-bed service, and departing the ED) as shown previously in *Figure 3-2*. Using the general patient flow description along with the flowchart as a guide, each phase of the patient flow process was translated into the model.

The model was built in Witness with a series of “elements”: parts, buffers, machines, labors, attributes, variables, and so on. There are three basic elements in the ED model: parts, buffers, and machines. Each one of the three has a certain representation for the emergency care process (*Table 4-1*).

*Table 4-1: Basic elements in Witness and their representation in the ED model*

| Element Name | Element Description | Element Representation in the ED Model |
|---|---|---|
| Parts | Entities which flow through the model | Patients who flow through the ED model |
| Buffers | Queues where entities can be held | Patient queues waiting in the wait area |
| Machines | Activities which pull entities in, process them, and push them to their | Service stations and treatment processes where patients receive care |

| | | |
|---|---|---|
| | next destination | service |

## 4.4 Model Assumptions

It is important to note that the model was developed using a number of assumptions to simplify the modeling effort by eliminating any insignificant parameters and/or events. A few of the most significant assumptions used in constructing the model were:

1) All patients remain at the same CTAS level throughout their stay in the ED. The CTAS level is assigned during triage for non-emergent patients or immediately after entering the ED for patients with emergent conditions.
2) The two psych rooms specific for mental health patients are not considered within the model, because there are no other types of patients competing for the psych rooms. Patients searching for service in the psych rooms can be regarded as a small isolated event in the ED. Comparing to a big majority of other types of patients, mental health patients represent a very small percentage of all patients seen in the ED, and their impact on the total resource utilization and treatment times is very limited and can be ignored.
3) All patients undergo triage and registration on arrival when the resource is available. Emergent patients who bypass triage and registration on arrival have a very tiny proportion (0.26%) according to the historical data, and ignoring this would not cause any pronounced effects on the model for the project purpose.

## 4.5 Model Control Logic

This section describes the general patient routing logics in the ED model. *Figure 4-2* shows how a patient is assigned to a specific treatment area when entering the ED. The process starts with the patient arrival. Each patient is assigned an attribute (i.e. the CTAS level) to characterize the patient type during triage. *Figure 4-3* describes the medical operation procedures for patients after being placed into a designated treatment area.

In the model, the bed placement decision is dependent on the bed availability, patient urgent level, and patient waiting time. When a bed in a designated treatment area comes available, the model picks and sends the most urgent patient with the highest waiting time to the available bed. The decisions to place a treatment location for a patient during triage, whether a patient requires additional care (i.e. lab test, radiology tests, or any combination of these) and to release a patient from the ED are based on two combined factors: 1) the patient CTAS level, and 2) the assigned treatment area. The decisions are analyzed using the historical data represented by probability percentages.

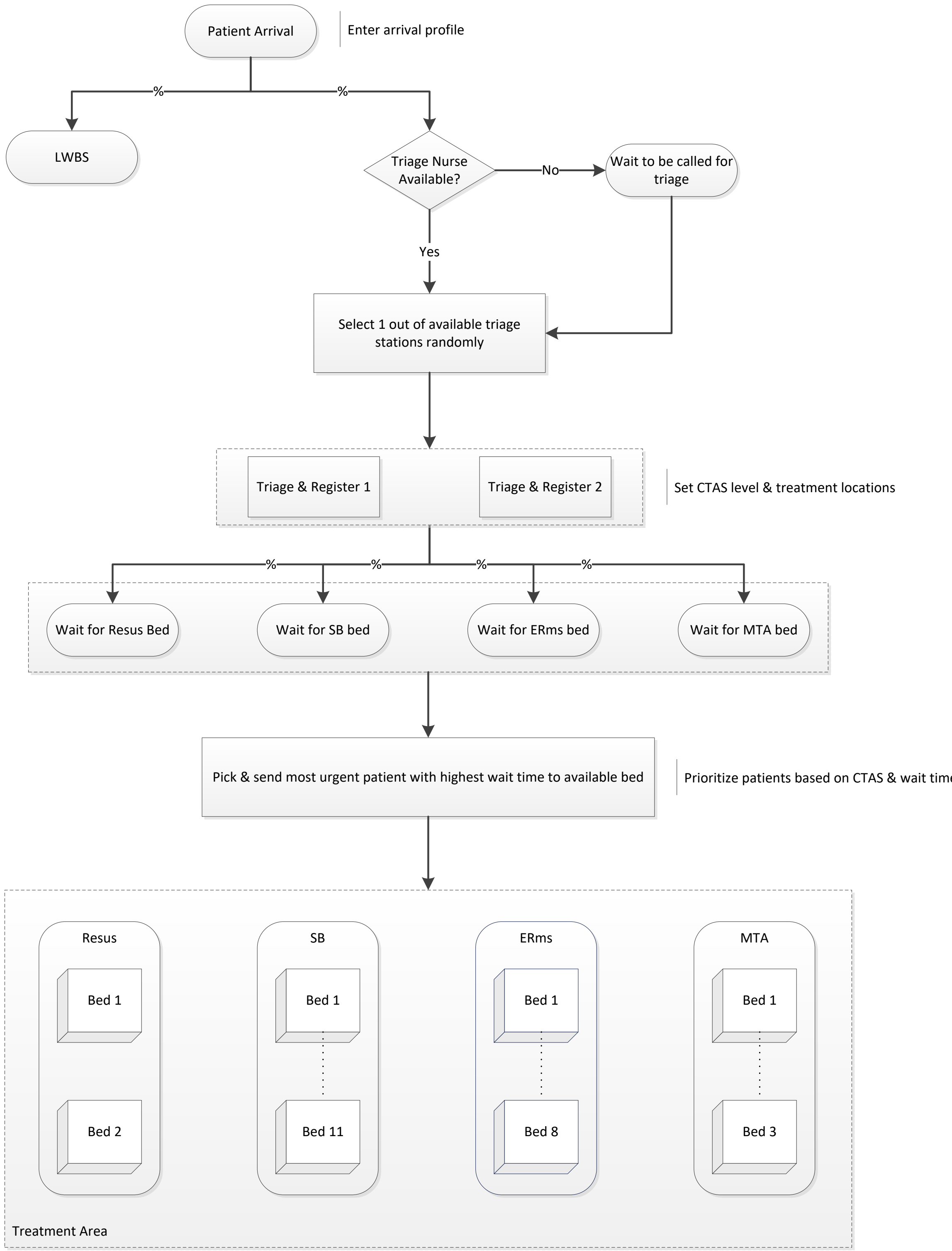



*Figure 4-2: Treatment area assignment for patient during triage on arrival*

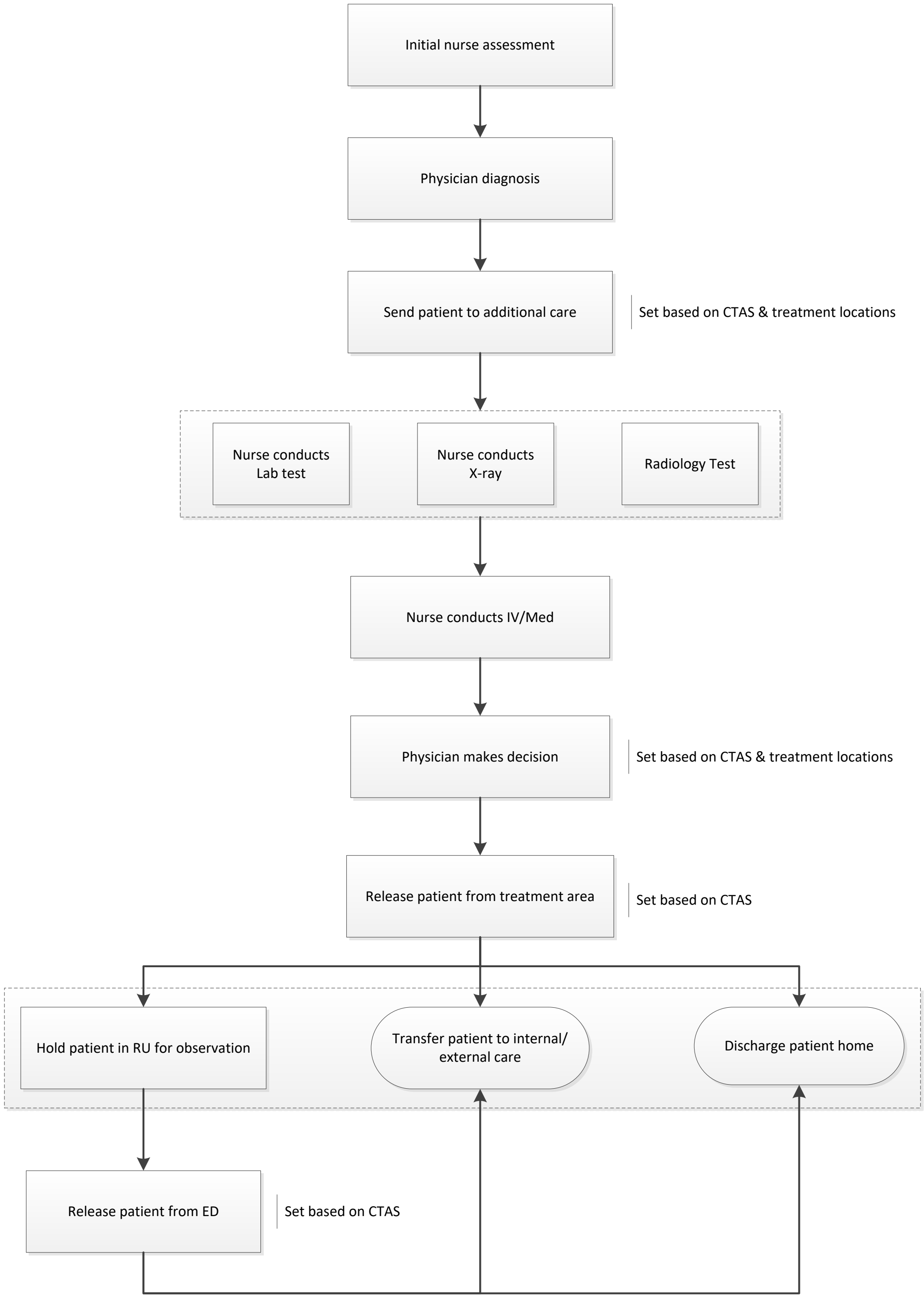



*Figure 4-3: Medical operation procedures for patients after being assigned into a designated treatment area*

## 4.6 Model Input Data Collection

Historical data of year 2015 were gathered from the ED information system provided by the regional health authority with a total of 39,525 anonymous patient records. Each patient record is described in time, location and status stamps in an excel sheet. In fact, not all collected data were used to build the model. Instead they were divided into two sets. The first set consists of data from the first six months of the total collected data, and it was used to build the model; the second set contains the remaining six months of the total data, and it was used to validate the model. Before they can be used to build the model, the first data set (i.e. model building data) has to be transformed in the format that compatible with the Witness software. The following of this section defines the input data that are required to build the model in Witness.

*1) Patient Arrival Profile*

Patient arrival profile is one of the most important data that are required to build the model. It is very useful for introducing patients into the model in an irregular pattern. *Figure 4-4* shows the average patient visits to the ED per hour of day based on the first six months of the collected data.

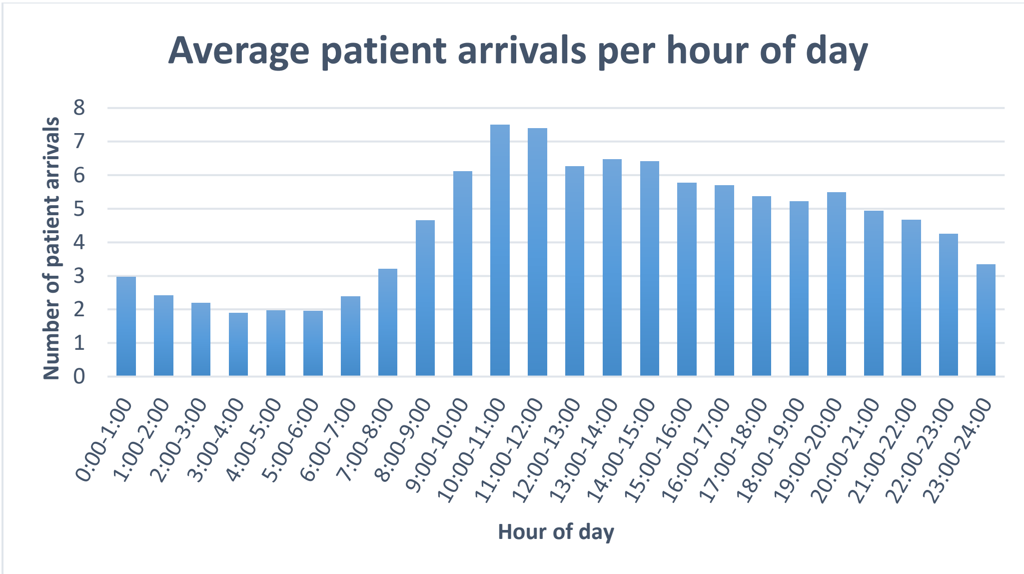



*Figure 4-4: Average patient arrivals per hour of day*

In terms of patient acuity levels, the occurrence of each CTAS follows a discrete distribution where the following pattern emerges (*Figure 4-5*):

1) On approximately 1.9 percentages, a patient with CTAS 1 enters the ED;
2) On approximately 25.7 percentages, a patient with CTAS 2 enters the ED;
3) On approximately 42.6 percentages, a patient with CTAS 3 enters the ED;
4) On approximately 21.1 percentages, a patient with CTAS 4 enters the ED;
5) On approximately 8.7 percentages, a patient with CTAS 5 enters the ED.

The CTAS level with higher weighting percentages is selected more frequently in Witness than one with the lower percentages.

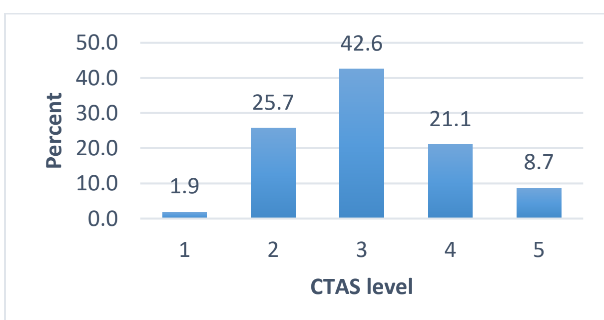



*Figure 4-5: The occurrence of CTAS 1 ~ 5 patients in the year of 2015*

*2) Resource Data*

The ED consists of several resources such as beds, physicians, and nurses etc. *Table 4-2* shows the bed resource and waiting area capacity in the ED. The current working schedules and treatment area assignments for both physicians and nurses are presented in detail in *Tables 4-3 and 4-4* respectively. Each physician or nurse is assigned to take care of the patients in a designated treatment area. As a rule of thumb in the ED, physicians in the subsequent shift take handover from colleagues in that area in proceeding shift, and same rule applies to nurses as well.

*Table 4-2: Bed resource and waiting area capacity*

| | | |
|---|---|---|
| **Wait Area** | Immediate Front Row | 6 chairs |
| | Main Wait Area | 30 chairs |
| **Bed/Spot** | Resus | 2 beds |
| | SB | 11 beds |
| | ERms | 8 spots |
| | MTA | 3 spots |
| | RU | 12 beds regularly |

*Table 4-3: Physician quantity, work shift hours and treatment area allocation*

| Physician # | Shift | Shift Hours | Treatment Area Allocation |
|---|---|---|---|
| 1 | Day | 8:00am - 16:00pm | Resus; SB |
| 2 | | 8:00am - 17:00pm | ERooms; MTA |
| 3 | Mid | 9:30am - 17:30pm | ERooms; MTA; occasionally SB |
| 4 | Evening | 16:00pm - 24:00pm | Resus; SB |
| 5 | | 17:00pm - 2:00am | ERooms; MTA |
| 6 | Night | 24:00pm – 9:00am | Entire ED |

*Table 4-4: Nurse type, quantity, work shift hours and treatment room allocation*

| Nurse # | Type | Treatment Room Allocation |
|---|---|---|
| *Day shift: 7:30am - 3:30 pm & Evening shift 3:30 pm - 11:30pm* | | |

| | | |
|---|---|---|
| 1 | Charge RN | Assist during a busy or high acuity period |
| 2 | Triage RN | Triage |
| 3 | Triage RN | Triage |
| 4 | RN | Resus |
| 5 | RN | SB 1,2 |
| 6 | RN | SB 3,4,5 |
| 7 | RN | SB 6,7,8 |
| 8 | RN | SB 9,10,11 |
| 9 | RN | ERooms 1,2,3; MTA |
| 10 | RN | ERooms 4,5,6,7,8 |
| 11 | RN | RU 1,2,3,4,5,6 |
| 12 | RN | RU 7,8,9,10,11,12 |
| 13 | Protocol RN | Assist during a busy or high acuity period |
| 14 | Flow RN | Assist during a busy or high acuity period |
| *Night shift: 11:30pm – 7:30 am* | | |
| 1 | Charge RN | Assist during a busy or high acuity period |
| 2 | Triage RN | Triage |
| 3 | RN | Resus; SB 1,2 |
| 4 | RN | SB 3,4,5 |
| 5 | RN | SB 6,7,8 |
| 6 | RN | SB 9,10,11 |
| 7 | RN | ERooms 1-8, MTA |
| 8 | RN | RU 1,2,3,4,5,6 |
| 9 | RN | RU 7,8,9,10,11,12 |
| 10 | Float RN | Assist during a busy or high acuity period |

*3) Service Times*

Operation times of the service procedures are collected if available from the historical data, and fitted into appropriate distributions. *Figure 4- 6* presents a sample to visually show the goodness to fit a distribution to a data set; the red curve is a distribution function curve that generated by a software tool based on the discrete historical data which are categorized in the format of a histogram. The p-value for this goodness-of-fit hypothesis test is 0.116, which implies the red curve is a good fit to this data set.

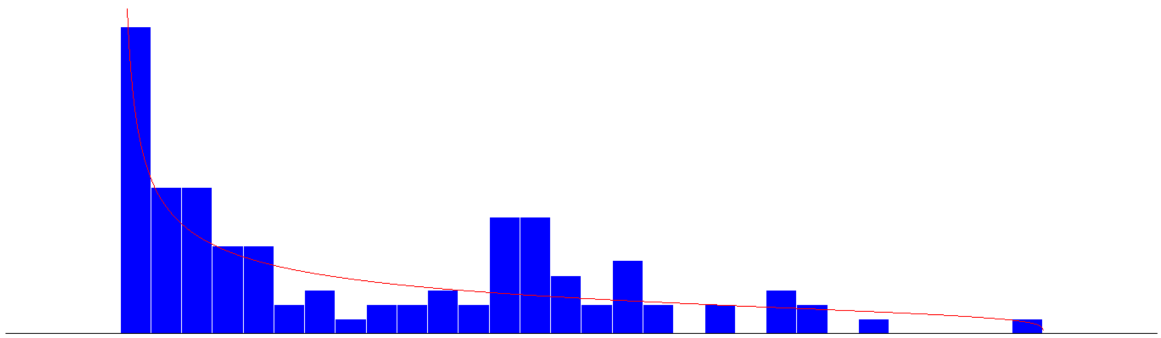


*Figure 4-6: Distribution function curve generated from discrete historical data*

However, the amount of the treatment time that a nurse or a physician spends with a patient is not recorded in the EDIS system and managerial estimates on the time are not provided either. *Table 4-5* displays the processing time inputs for the model on each service station. Since some of the data are no way to be collected, they have to be estimated on a reasonable basis before the model can be complete and run.

In order to make the best benchmarking of the treatment time by a nurse or a physician, great effort has been made to search these relative values in publications. However, very few publications have a clear identification of the exact numbers of the treatment time by a nurse or a physician, and it is even harder to find out these numbers as referrals in literature based on patient acuity levels.

The estimation of the amount of the treatment time that a nurse or a physician spends with a patient mainly comes from two sources: 1) a poster presentation in *Western Emergency Department Operations Conference (WEDOC) 2016* to investigate the effects of early inpatient discharge on ED waiting time; and 2) a published paper to reduce patient length of stay in a ED by simulation (Wang et al. 2012). Average treatment times by an ED physician based on CTAS levels are captured from the poster where two

Canadian ED centers are studied. Compared to the ED in SBGH, the EDs involved in those two sources have a very similar patient volume in average daily visits, which shows great similarity in care demand for ED service. The ED physicians in Canada also have similarity in either educational background or career training, although they may have great variability in individual skill set and decision making. But when the pre-existing data of the ED are not available for model building, benchmarking or best guesses will have to be sufficient (Jurishica 2005).

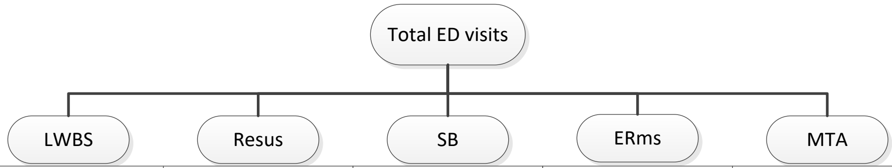
*Table 4-5: Service time inputs for the model*

<table>
<tr><th>Service Station</th><th colspan="6">Processing Time (Min)</th></tr>
<tr><td>Triage & Registration</td><td colspan="6">Triangle (0.88, 7.03, 55.8)</td></tr>
<tr><td rowspan="2">Initial Nurse Assessment</td><td>Resus</td><td>SB</td><td>ERms</td><td colspan="3">MTA</td></tr>
<tr><td>30</td><td>30</td><td>20</td><td colspan="3">20</td></tr>
<tr><td rowspan="2">Physician Diagnosis</td><td>CTAS 1</td><td>CTAS 2</td><td>CTAS 3</td><td>CTAS 4</td><td colspan="2">CTAS 5</td></tr>
<tr><td>35</td><td>35</td><td>15</td><td>11</td><td colspan="2">11</td></tr>
<tr><td rowspan="3">Nurse Lab Test</td><td>Resus</td><td>SB</td><td>ERms</td><td colspan="3">MTA</td></tr>
<tr><td rowspan="2">10</td><td>CTAS 1</td><td>CTAS 2</td><td>CTAS 3</td><td>CTAS 4</td><td>CTAS 5</td></tr>
<tr><td>3</td><td>5</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td rowspan="3">Nurse X-ray Test</td><td>Resus</td><td>SB</td><td>ERms</td><td colspan="3">MTA</td></tr>
<tr><td rowspan="2">10</td><td>CTAS 1</td><td>CTAS 2</td><td>CTAS 3</td><td>CTAS 4</td><td>CTAS 5</td></tr>
<tr><td>10</td><td>15</td><td>10</td><td>20</td><td>20</td></tr>
<tr><td rowspan="3">Radiology Test</td><td>Resus</td><td>SB</td><td>ERms</td><td colspan="3">MTA</td></tr>
<tr><td rowspan="2">10</td><td>CTAS 1</td><td>CTAS 2</td><td>CTAS 3</td><td>CTAS 4</td><td>CTAS 5</td></tr>
<tr><td>15</td><td>20</td><td>25</td><td>25</td><td>25</td></tr>
<tr><td rowspan="2">Nurse IV/Med</td><td>Resus</td><td>SB</td><td>ERms</td><td colspan="3">MTA</td></tr>
<tr><td colspan="2">30</td><td colspan="4">10</td></tr>
<tr><td rowspan="2">Physician Decision</td><td>Resus</td><td>SB</td><td>ERms</td><td colspan="3">MTA</td></tr>
<tr><td colspan="3">5</td><td colspan="3">1</td></tr>
<tr><td rowspan="2">RU Observation</td><td>CTAS 1</td><td>CTAS 2</td><td>CTAS 3</td><td>CTAS 4</td><td colspan="2">CTAS 5</td></tr>
<tr><td>4 + 2480 * BETA(0.514, 1.24)</td><td>3 + NegExp(899)</td><td>3 + NegExp(742)</td><td>3 + GAMM(1370, 0.643)</td><td colspan="2">UNIF(0.999, 209)</td></tr>
<tr><td>Discharging home</td><td colspan="6">15</td></tr>
<tr><td>Transferring to other care services</td><td colspan="6">40</td></tr>
</table>

*4) Percentages*

Percentages, such as the percent of patients who left without being seen by a physician or percent of patients who are sent to Resus/SB/ERms/MTA for treatment (*Figure 4-7*), are dedicated to tracking where patients go. This data collection is also significant in simulation input modeling to determine percentages where patients go. *Table 4-6* quantifies the patient percentages of discharging home, transferring to other internal/external care services, and holding in RU after patients being seen in one of the four treatment areas. *Table 4-7* further breaks down the percent of patients being hold in RU into two sub-percentages: the patient percent of discharging home or transferring to other types of care services. All these percentages are analyzed based on patient acuity levels.

Using percentages are more representative in DES model building because ED is such a dynamic environment with numerous rules in patient routing. For example, a patient with a higher acuity may be sent to a bed with a lower acuity due to scarcity of the bed resource, while a patient with a lower acuity may be placed to a bed with a higher acuity due to an emergent change in the patient condition. Rather than trying to manually write syntax for all the possibilities in patient routing although it is impossible, it sounds more reasonable and objective to statistically quantify the percentages where patients go. Statistics based on historical data are more evidence proved.




| | LWBS | Resus | SB | ERms | MTA |
|---|---|---|---|---|---|
| CTAS 1 (%) | 0.01 | 44.23 | 53.46 | 1.15 | 1.15 |
| CTAS 2 (%) | 4.59 | 6.51 | 58.60 | 24.08 | 6.22 |
| CTAS 3 (%) | 7.86 | 1.84 | 25.53 | 50.08 | 14.69 |
| CTAS 4 (%) | 11.43 | 0.84 | 10.44 | 46.61 | 30.68 |
| CTAS 5 (%) | 13.93 | 0.64 | 2.54 | 37.53 | 45.36 |

*Figure 4-7: Patient routing percentages to LWBS/Resus/SB/ERms/MTA based on CTAS*

*Table 4-6: Disposition percentages of patients after being seen in a treatment area based on CTAS*

| **Patient Disposition after Treatment (%)** | **CTAS** | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| Direct discharging home | 25 | 62 | 70 | 85 | 92 |
| Direct transferring to other care services | 43 | 17 | 5 | 1 | 2 |
| Direct routing to RU for holding | 32 | 21 | 25 | 13 | 6 |

*Table 4-7: Disposition percentages of patients being hold in RU based on CTAS*

| **Holding Area** | **Patient Disposition (%)** | **CTAS** | | | | |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| RU | Discharging home | 41 | 40 | 35 | 35 | 34 |
| | Transferring to other care services | 59 | 60 | 65 | 65 | 66 |

## 4.7 Model Verification and Validation

Model verification and validation investigates whether the model represents the real system for the project intended purpose (Law 2009). Any model is supposed to be an abstraction and simplification of reality. There is no such thing as absolute correct model that 100% represents the real system. In fact, a model that is valid for one objective may not be for another(Sargent 2011), and the validation process is often based on the model and project intended purpose.

Credible models can be used by analysts in several aspects such as the system design, problem solving, and continuous improvement, and are essential for analysts to arrive at the correct and realistic approaches to underlying issues (Al-Aomar et al. 2015). There are two general steps to achieve model credibility: model verification and model validation. In model verification, the model builder is to make sure the model is built as (s)he expects to, in model inputs, logic, structure, and outputs. In model validation, the model is further compared with historical validating data to ensure it correctly represents the behavior and outcomes of the real system.

As the goal of this research is to reduce patient waiting times to see a doctor (i.e. WTBS) and their length of stay in the ED (i.e. LOS), these two parameters need to be robustly validated for modelling intent. To generate more credibility of the model, the time spending for a patient from start of triage until the end of active treatment on an assigned room (i.e. WTBS + TIP) is also strictly validated as well as patient daily throughput, total patient arrivals to ED and total patients released from ED. *Figure 4-8* illustrates the patient journey from arrival to exit with motoring tags (i.e. WTBS, TIP, LOS etc.) clearly defined. The ED activities that direct add value to the patients are here named as value added activities.

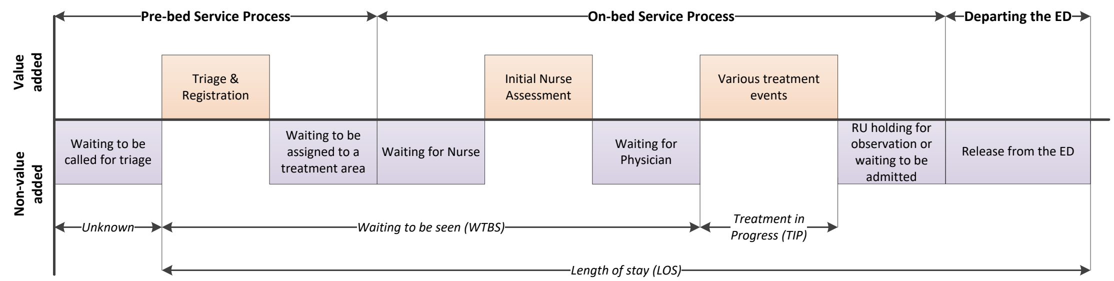



*Figure 4-8: Value stream mapping of the ED activities*

Since the ED is operating 24 hours/day and 7 days/week, it virtually never stops. Even if it is studied for a particular period, the ED will be loaded with patients at the beginning of that period. However, a simulated ED model usually begins without any patient in the system. This hence calls for a warm-up for the model to travel through the initial transient state, and to reach its steady state.

To determine the run time of the warm-up period, Welch's method is applied to visually indicate when the slope of the initial transient state approaches 0. At this point, the output measure of patient daily throughput has reached steady state. *Figure 4-9* demonstrates the built ED model reaches its steady state at day 10. Observations are made every 24 hours.

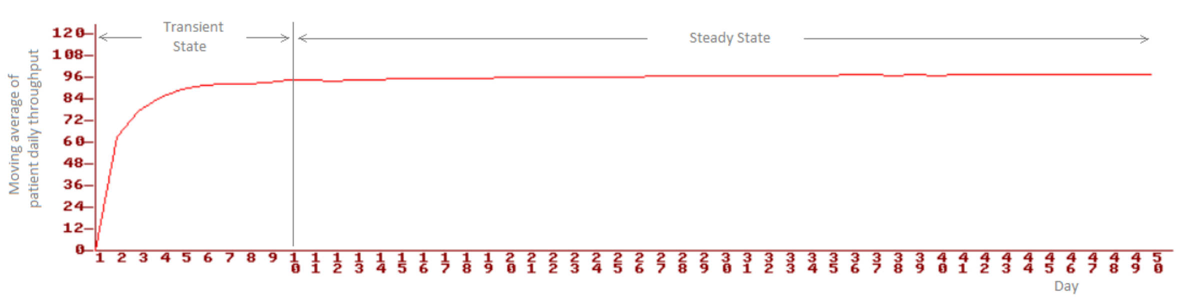



*Figure 4-9: Welch's method: plot of moving average of patient daily throughput*

To verify if the model is built as intended, animation is used to detect conceptual errors by seeing the animated entities through the model. Moreover, the first six months (i.e. data from January – June 2015) of the total collected historical data are used for the model verification. The results of comparison in *Table 4-8* demonstrate "building the model correctly".

*Table 4-8: Comparison of ED performance measures for model verification*

| **Performance Measures** | **Real ED Data (Mean)** | **Simulated Data (Mean)** | **Discrepancy (%)** |
|---|---|---|---|
| WTBS | 196 min | 207 min | 5.61 |
| WTBS + TIP | 382 min | 358 min | -6.28 |
| LOS | 595 min | 585 min | -1.68 |
| Patient daily throughput | 98 | 100 | 2.04 |
| Total patient arrivals | 19641 | 19700 | 0.30 |
| Total patients released from ED | 17821 | 18048 | 1.27 |

To validate the model, the model results with running of 6 months are compared with the system validation data which contain the historical data from July to December 2015. The general accuracy of model outputs proves "building a right model" (*Table 4-9*).

*Table 4-9: Comparison of ED performance measures for model validation*

| **Performance Measures** | **Real ED Data (Mean)** | **Simulated Data (Mean)** | **Discrepancy (%)** |
|---|---|---|---|
| WTBS | 204 min | 207 min | 1.47 |
| WTBS + TIP | 352 min | 358 min | 1.70 |
| LOS | 558 min | 585 min | 4.84 |
| Patient daily throughput | 101 | 100 | -0.99 |
| Total patient arrivals | 19883 | 19700 | -0.92 |
| Total patients released from ED | 18290 | 18048 | -1.32 |

Moreover, hypothesis testing is carried out to see whether there are statistically significant differences in LOS and WTBS for model output data and system validation data. The testing conducted is as follows:

1) Hypothesis testing for LOS

   *Null hypothesis ($H_0$):* There is no statistically significant difference in average LOS for model output data and system validation data.

   *Alternative hypothesis ($H_1$):* There is statistically significant difference in average LOS for model output data and system validation data.

2) Hypothesis testing for WTBS

   *Null hypothesis ($H_0$):* There is no statistically significant difference in average WTBS for model output data and system validation data.

   *Alternative hypothesis ($H_1$):* There is statistically significant difference in average WTBS for model output data and system validation data.

In the results of testing, the p-value for LOS hypothesis test is 0.074 while the p-value for WTBS hypothesis test is equal to 0.129. Since both p-values are greater than the significant level of 0.05, we fail to reject the null hypothesis. In other words, the model is sufficiently validated for the project purpose and is available for use of further analysis.

# Chapter 5

# Model Analysis and Solution Design

## 5.1 Bottleneck Detection

The model is designed for the evaluation of alternative strategies that could reduce patients waiting times to see a doctor and their length of stay in the ED. In order to achieve that, it is necessary to first identify the limiting factors that prevent a greater ED, commonly called bottlenecks. Knowing the bottlenecks within the current ED patient flow allows having a clear target on diagnosing specific components that cause blockage in the flow.

A method of evaluating "criticality indicator" for each service station and comparing the values to detect the critical station is applied to detect bottlenecks within the existing patient flow (Leporis et al. 2010). Criticality indicator for the *i*-th service station is calculated from simulation statistics considering the difference of individual rates for this service station (i.e. the average rates of utilization, starvation, blocking, waiting for labor) with respect to the whole system average of this rate by using the following the equation:

$$KR_i = \left(\frac{\sum_{i=1}^{n} B_i}{n} - B_i\right) + \left(I_i - \frac{\sum_{i=1}^{n} I_i}{n}\right) + \left(BL_i - \frac{\sum_{i=1}^{n} BL_i}{n}\right) + \left(L_i - \frac{\sum_{i=1}^{n} L_i}{n}\right)$$

Where,

- $KR_i$ is the criticality indicator for the *i*-th service station [%]
- $B_i$ is the average utilization rate for the *i*-th station [% Busy]
- $I_i$ is the average starvation rate for the *i*-th station [% Idle]
- $BL_i$ is the average blocking rate for the *i*-th station [% Blocked]
- $L_i$ is the average waiting rate for labor for the *i*-th machine [% Wait for labor]

The criticality indicators method allows a direct quantitative identification of the severity of each station (Leporis et al. 2010). The service station with the minimal value of $KR_i$ denotes a bottleneck station that may need capacity building, whereas the station with the maximal value of $KR_i$ denotes a station allowing a better utilization.

By using this method, criticality indicators are calculated for all service stations within the ED model, and the graphical results of the bottleneck analysis are shown in *Figure 5-1*. As indicated in *Figure 5-1*, criticality values for the stations of triage and reassessment unit are extremely low, which implies that the top priority should be given to these two stations in order to have a smoother patient flow. Focus of the improvement is given to MTA & ERms as well since the values for MTA & ERms are also relatively low.

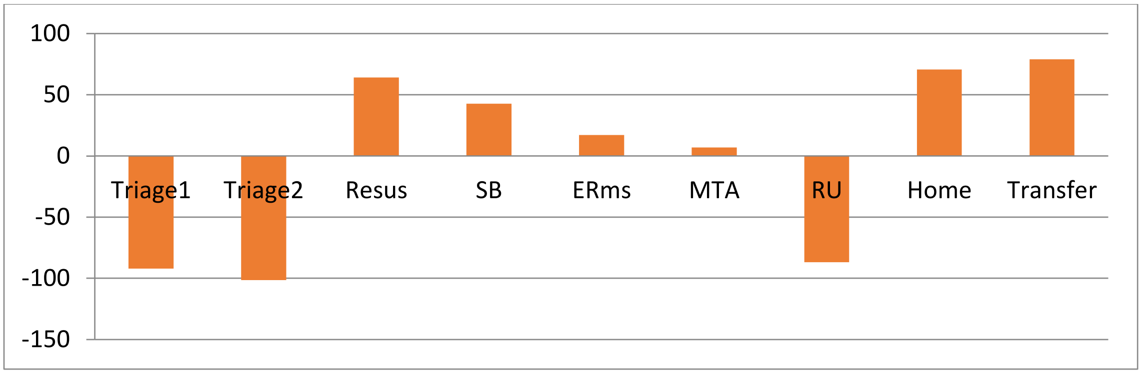



*Figure 5-1: Results of the bottleneck analysis on ED service stations using the criticality indicator based method*

Using the same method, criticality values are analyzed for all ED physicians and nurses to identify possible resources that cause blockage in the flow. *Figure 5-2* shows that physician #5, #6, #2 and #3 are potential limiting factors that delay the patient flow. *Figures 5-3 and 5-4* are graphs that display results of the bottleneck analysis on nurses. On day & evening shifts, nurses share a same room assignment rule whereas nurses on night shift have a different one. *Figures 5-3 and 5-4* indicate that triage nurse and nurses looking after patients in ERms & MTA could possibly lead to the blockage in the flow as well. Details on physician and nurse allocations can be referred back to *Section 4.6*. The following section is dedicated to search solutions by testing alternative strategies to alleviate patient waiting time and throughput time.

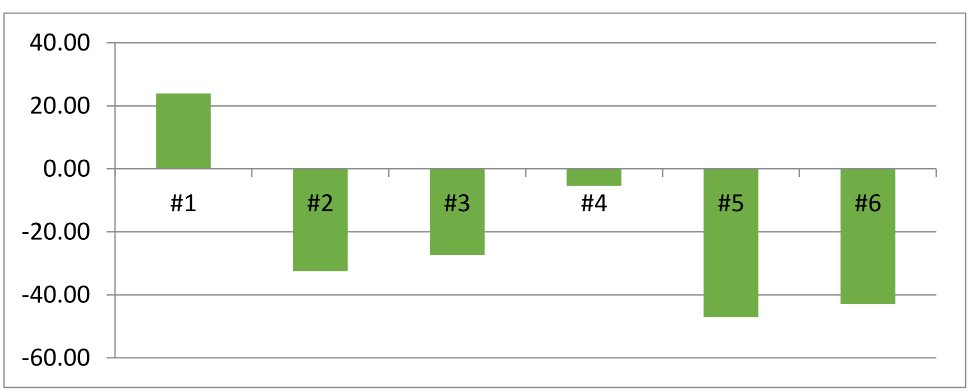



*Figure 5-2: Results of the bottleneck analysis on ED physicians using the criticality indicator based method*

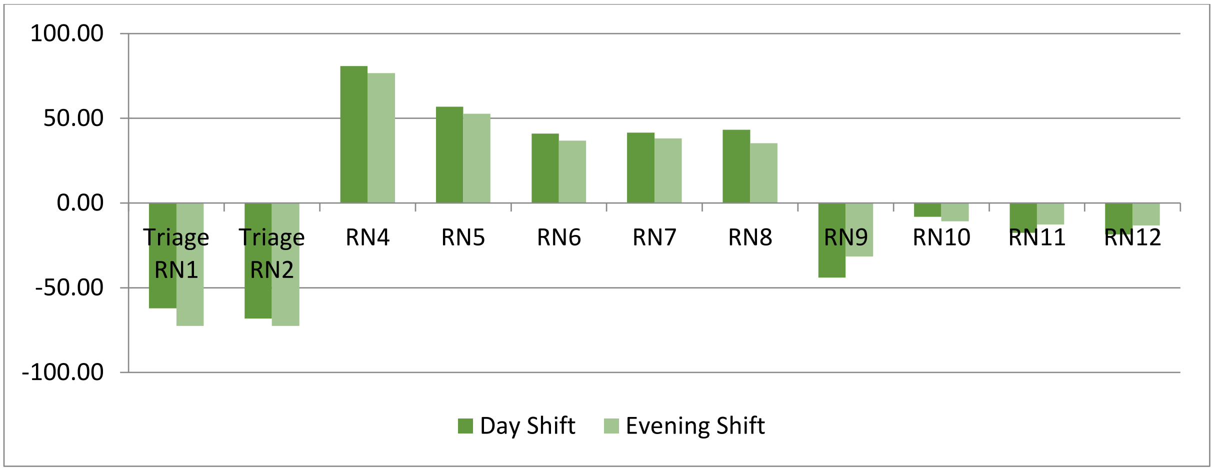



*Figure 5-3: Results of the bottleneck analysis on day & evening shifts nurses using the criticality indicator method*

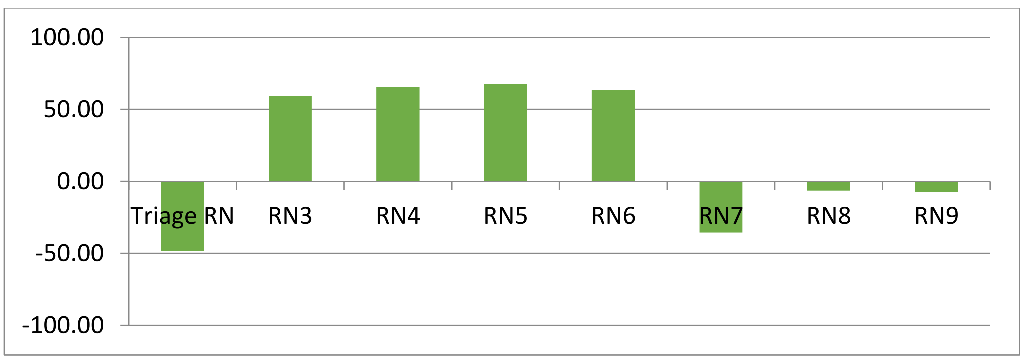



*Figure 5-4: Results of the bottleneck analysis on night shift nurses using criticality indicator based method*

## 5.2 Testing of Alternatives and Results

Strategies used in solution searching to help alleviating patient waiting time and throughput time generally fall into two groups: 1) strategies without the process redesign and 2) strategies with the process redesign.

Within strategies without the process redesign, several alternatives are tested, and can be grouped as: 1) building capacity for potential bottleneck stations without changing of their operation times; 2) reducing operation times of potential bottleneck stations without changing of their quantities; 3) increasing availability of potential limiting resources in physician and nurse. Within strategies with the process redesign, a specific solution of “adding one physician in triage” is considered. Details of this solution are discussed further in *Section 5.2.2*.

### 5.2.1 Strategies without the Process Redesign

*1) Building capacity for potential bottleneck stations without changing of their operation times*

The focus of the section is on the potential limiting stations of Triage, RU, MTA and ERms, with a purpose of quantitatively comparing the difference in LOS and WTBS by increasing their capacity. *Table 5-1* shows the results of patient average waiting time and throughput time due to the capacity growth in potential bottleneck stations. As shown in *Table 5-1*, it can be observed that:

a) Purely adding more triage stations (without adding more resources in triage) to the current ED system generally has very minor reduction in patient average throughput time, and does not have any improvement in patient average waiting time.

b) Adding two more beds in RU with each nurse serving 7 beds instead of the current 6 does not show much improvement in patient average waiting time and throughput time.

c) Building capacity in MTA causes the reduction in both patient waiting time and throughput time, and generally leads to a greater reduction in WTBS compared to LOS.

d) The capacity growth in ERms does not see a visible improvement in patient waiting time and throughput time.

*Table 5-1: The effect of capacity growth in potential bottleneck stations on patient average waiting time and through-put time*

| Criteria | Alternatives | LOS | | WTBS | |
|---|---|---|---|---|---|
| | | Baseline | Effect (%) | Baseline | Effect (%) |
| 1 | Add one Triage1 | 584 min | -6.68 | 207 min | 10.63 |
| | Add two Triage1 | | -5.48 | | -13.04 |
| | Add three Triage1 | | -1.37 | | 5.31 |
| 2 | Add one Triage2 | | 9.93 | | 62.32 |
| | Add two Triage2 | | -4.11 | | 70.05 |
| | Add three Triage2 | | -0.17 | | 42.03 |
| 3 | Add two beds in RU with each RU nurse serving 7 beds instead of 6 | | -1.54 | | 7.73 |
| 4 | Add one bed in MTA | | -4.79 | | -1.93 |
| | Add two beds in MTA | | -6.34 | | -27.54 |
| | Add three beds in MTA | | -6.51 | | -34.78 |
| | Add four beds in MTA | | -5.31 | | -38.65 |
| | Add five beds in MTA | | -6.16 | | -22.22 |
| 5 | Add one bed in Erms | | 4.79 | | 67.63 |
| | Add two beds in Erms | | 0.17 | | 0.00 |

*Note: All service stations run 24 hours a day except that Triage2 station is off-shift in the night from 11:30pm to 7:30am.*

*2) Reducing operation times of potential bottleneck stations without changing of their quantities*

This section presents different processing time scenarios for triage and RU observation so as to determine whether operation times in triage and RU have impact on the patient waiting time to see a doctor and their length of stay in the ED, and the level of influence. *Tables 5-2 and 5-3* display effects of the triage time (including registration) and RU observation time on average patient waiting time and throughput time respectively. By comparison, it is not hard to find out that:

a) Operation time reduction in triage has a positive influence on both patient waiting time and throughput time, especially with a greater reduction in WTBS compared to LOS;

b) Time reduction in RU observation does reduce the average patient length of stay in the ED; however, reduction in WTBS is rarely observed;

c) Operation time reduction in triage generally leads to a greater reduction in LOS compared to time reduction in RU observation.

*Table 5-2: The effect of triage time on average patient waiting time and throughput time*

| **Criteria** | **Alternatives** | **LOS** | | **WTBS** | |
|---|---|---|---|---|---|
| | | **Baseline** | **Effect (%)** | **Baseline** | **Effect (%)** |
| 1 | Reduce Triage & Registration time by 10% | 584 min | -14.55 | 207 min | -47.34 |
| | Reduce Triage & Registration time by 15% | | -19.18 | | -28.50 |
| | Reduce Triage & Registration time by 20% | | -23.97 | | -55.56 |
| | Reduce Triage & Registration time by 25% | | -24.14 | | -34.30 |
| | Reduce Triage & Registration time by 30% | | -24.66 | | -53.14 |
| 2 | If Triage & Registration is complete within [1,2] min | | -31.16 | | -76.33 |
| | If Triage & Registration is complete within [3,4] min | | -29.45 | | -59.90 |
| | If Triage & Registration is complete within [5,6] min | | -30.31 | | -48.79 |

| | | | | | |
|---|---|---|---|---|---|
| | If Triage & Registration is complete within [7,8] min | | -25.17 | | -60.87 |
| | If Triage & Registration is complete within [9,10] min | | -28.60 | | -57.00 |
| | If Triage & Registration is complete within [11,12] min | | -27.40 | | -76.33 |
| | If Triage & Registration is complete within [13,14] min | | -22.95 | | -63.29 |
| | If Triage & Registration is complete within [15,16] min | | -20.72 | | -62.80 |
| | If Triage & Registration is complete within [17,18] min | | -26.88 | | -44.93 |
| | If Triage & Registration is complete within [19,20] min | | -16.61 | | -45.89 |

*Table 5-3: The effect of RU observation time on average patient waiting time and throughput time*

| Criteria | Alternatives | LOS | | WTBS | |
|---|---|---|---|---|---|
| | | **Baseline** | **Effect (%)** | **Baseline** | **Effect (%)** |
| 1 | Reduce RU time by 10% | 584 min | -1.71 | 207 min | -13.04 |
| | Reduce RU time by 15% | | -5.31 | | 65.70 |
| | Reduce RU time by 20% | | -7.02 | | 56.04 |
| | Reduce RU time by 25% | | -7.53 | | 18.36 |
| | Reduce RU time by 30% | | -10.45 | | 10.14 |
| | Reduce RU time by 35% | | -10.45 | | 17.87 |
| 2 | Release patients in RU 60min in advance | | -3.60 | | 38.16 |
| | Release patients in RU 90min in advance | | -2.91 | | 52.66 |
| | Release patients in RU 120min in advance | | -4.45 | | 79.23 |
| | Release patients in RU 150min in advance | | -6.51 | | 27.54 |
| | Release patients in RU 180min in advance | | -6.68 | | 13.53 |

*3) Increasing availability of potential limiting resources in physician and nurse*

Adding additional human resources to the current ED system can be another way to resolve the overcrowding issue, but it is only true when you add the right one. *Table 5-4* shows the level of influence on the patient average waiting time and throughput time by adding potential bottleneck resources in either physician or nurse. Since the hospital is financially available to employ another physician to join the ED team, multiple alternatives are tested to search the best allocation for the physician. As turns out by the experimentation:

a) Without making changes in the current patient flow, the patient average waiting time and throughput time can be reduced if another physician is allocated to look after the patients in ERms and MTA;

b) Adding additional nurse resource in Triage, ERms and MTA does not show an effective improvement of the ED performance.

*Table 5-4: The results of patient average waiting time and throughput time by adding potential bottleneck resources in physician and nurse*

| Criteria | Alternatives | LOS | | WTBS | |
|---|---|---|---|---|---|
| | | **Baseline** | **Effect (%)** | **Baseline** | **Effect (%)** |
| 1 | Add one Physician #5 | 584 min | -13.53 | 207 min | -36.71 |
| | Add one Physician #6 | | -8.22 | | -35.27 |
| | Add one Physician #2 | | -4.62 | | -10.63 |
| | Add one Physician #3 | | -5.31 | | -32.37 |
| 2 | Add one triage nurse for 24 hrs | | 0.17 | | 0.00 |
| 3 | Add one RN9 & RN7 (i.e. nurses looking after patients in ERms & MTA) | | -5.31 | | 9.18 |

*4) Summary of effective alternatives without the process redesign*

This section is to conclude the most effective alternatives introduced above to relieve the bottlenecks within the current ED system. *Table 5-5* summarizes the possible ways that can be used to effectively reduce patient average waiting time to see a doctor and their length of stay in the ED without changes to the current ED patient flow. Their numerical degrees of influence on LOS and WTBS can be refereed back to the previous sections. Within these four summarized alternatives, reducing processing time in triage shows the greatest positive impact on both LOS and WTBS.

*Table 5-5: Summary of effective alternatives to reduce LOS & WTBS without changes to the current ED patient flow*

| **Index** | **Alternatives** | **Influence Level** | |
|---|---|---|---|
| | | **LOS** | **WTBS** |
| 1 | Building capacity in MTA | + | ++ |
| 2 | Reducing processing time in triage | ++ | ++ |
| 3 | Reducing observation time in RU (i.e. Releasing patients in RU faster) | + | - |
| 4 | Increasing availability of resource in physician in ERms & MTA | + | ++ |

*Note: "+" denotes a positive influence; "++" denotes a greater positive influence compared to "+"; "-" denotes a non-effective alternative.*

### 5.2.2 Strategies with the Process Redesign

*1) Description of PIT strategy*

This section specifically presents the solution of adding one physician in triage (i.e. *PIT strategy*), which involves a process redesign in the existing general patient flow. Traditionally, nurses take the responsibility to conduct triage for patients on their arrivals, and by the general protocol in the ED nurses cannot order any testing for patients in triage, leaving up to physicians to order necessary testing for patients during the treatment cycle. This may be one of the factors that prolongs the entire treatment cycle, and meantime adds additional workload to physicians when they can be more attentive to patients on diagnosis during treatment.

In the *PIT strategy*, as mentioned in the earlier section, by adding a physician in triage ED may increase accuracy and efficiency in the initial process of patient evaluation by gaining more accurate information upfront, and issuing discharge or appropriate tests early on; meantime patients will benefit from the immediate assessment by a physician without waiting for a long time.

To help understanding the process redesign within the *PIT strategy*, a mapping of the proposed patient flow is scoped out in *Figure 5-5*. Instead of the current nurse triage model, a team triage based model is proposed, which consists of a physician, a nurse, and a registration clerk within the team. The physician does the initial assessment during triage, and orders appropriate tests for patients depending on their needs. The nurse then conducts the tests for patients by following physician's prescription. Meantime when patients are waiting for results of testing, the registration clerk quickly collects their basic information for care needs.

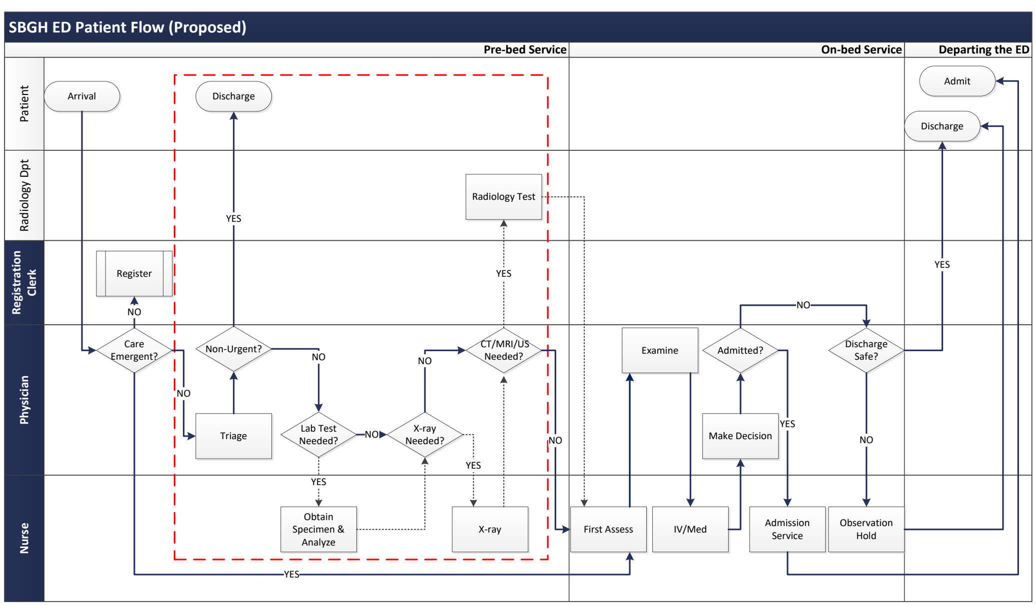



*Figure 5-5: A proposed general patient flow in the ED*

In the simulation model, it is assumed that emergent patients who sent to Resus will undertake a second run of testing during the treatment cycle because of the general complexity in their condition. But for patients who are sent to SB, ERms and MTA, they are assumed to take only one run of testing during triage based on their medical needs.

*2) Model experimental scenarios using PIT strategy*

*a) Step 1 of the PIT experimentation – Observing general efficacy of the PIT strategy*

Before jumping to search detailed solutions to implement the PIT strategy, it sounds more rational if we can build some evidence to see its potential efficacy on the ED performance. In order to achieve that, two interventions using PIT strategy are tested within the simulation model in comparison with the baseline model (*Table 5-6*) to see:

1) Whether there is a need to initiate a triage station with *PIT strategy* for 24 hours a day (i.e. replacing one nurse triage station which opens for 24 hours a day by a PIT enforced one);
2) What is the level of influence if only one PIT enforced triage station is open to function for 24 hours a day (i.e. cutting off the nurse triage station which only operates during day and evening shift);

*Table 5-6: Two interventions using PIT strategy that are tested within the simulation model in comparison with the baseline model*

| | | **PIT Strategy Enforced Triage** | **Current Nurse Triage** | |
|---|---|---|---|---|
| **Shift Hours** | | 24 hours a day | 24 hours a day | Day & Evening Shift |
| **Triage Station Qty** | **Baseline** | 0 | 1 | 1 |
| | ***PIT-1*** | 1 | 0 | 1 |
| | ***PIT-2*** | 1 | 0 | 0 |

*Note: "1" indicates that one triage station has applied the corresponding triage method; "0" denotes non-adoption of the corresponding triage method.*

Here it is important to note that in all three PIT interventions the triage time is reduced down to [1, 5] min for all triage stations. Because as mentioned in the earlier section, the introduction of a physician to the triage team may enable inexperienced staff to extend their knowledge and practice to a senior level with mentorship and guidance from the physician; thus advance on efficiency in triage can be expected due to experienced staff. In the model, the triage time are defined by using uniform distribution (Ruohonen et al. 2006). Since the statistical parameters of the triage time by using PIT strategy are not collectable beforehand, it is assumed that every value in the range of [1, 5] min is possible.

During this first step of the experimentation by using PIT strategy, we do not consider the option of building more capacity in either triage stations or triage nurses than the current state. Because as demonstrated in the previous experimental testing, purely adding more triage stations or triage nurses without changes to the current patient flow does not shown any great improvement in patient average waiting time and throughput time in the ED. But in order to determine the isolated impact of PIT strategy on the patient flow, the intervention of PIT-2 is tested where only one PIT enforced triage station is open to function for 24 hours a day.

As turns out in the PIT testing results, opening only one individual PIT enforced triage station to patients may have an increased risk of stacking patients in the waiting room resulting in even higher numbers in both LOS and WTBS. It is more effective and efficient in the intervention of PIT-1 if we create one PIT enforced triage station and meantime retain one station with nurse triage. *Figure 5-6* visually displays the difference in LOS and WTBS by using *PIT-1* in comparison with the existing measures. In reality, *PIT-1* may even exhibit greater power of reducing patient average waiting time and throughput time because in the model we do not consider an immediate discharge of patients after triage but in reality it may happen quite often if the patient condition is not urgent at all.

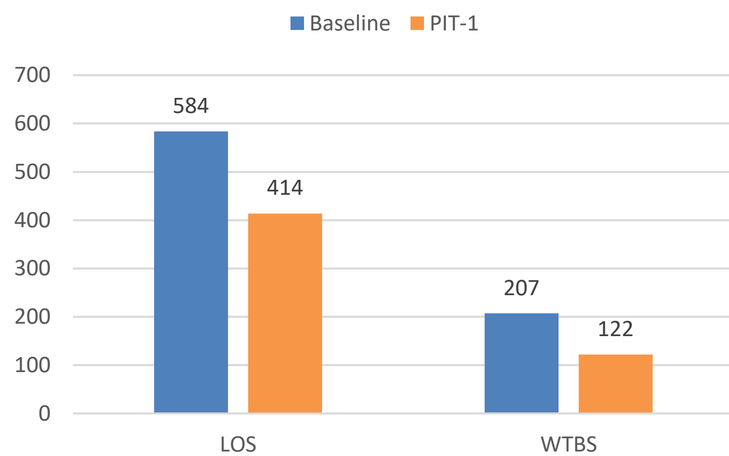



*Figure 5-6: The results of patient average waiting time and throughput time by using PIT-1 in comparison with the baseline measures (24hrs)*

*b) Step 2 of the PIT experimentation – Exploring PIT allocation options in busy hours*

According to the first step of the PIT experimentation, in the case of adding no more nurse resources in triage, the PIT-1 intervention of initiating one triage station with PIT strategy for 24 hours a day and meantime retaining one current nurse triage station for day and evening shifts shows great positive impact on patient average LOS and WTBS. The next step is to break down into details in PIT working schedule rather than 24 hours a day to consider how to best allocate a physician in triage within an 8-hour working shift.

It is necessary to revisit patient arrival pattern in *Figure 4-4* in order to meet patient care demands for the ED service. As the figure shows, average patient arrivals to the ED become intensive during the hours of 8:00am – 23:00pm. The remaining of this section is going to test eight allocation options for a physician in triage with a working shift of 8 hours, and the results for each option are shown in *Table 5-7*.

*Table 5-7: The effect of different PIT allocation options on patient average waiting time and throughput time (8hrs in busy time)*

| | | **Op1** | **Op2** | **Op3** | **Op4** | **Op5** | **Op6** | **Op7** | **Op8** |
|---|---|---|---|---|---|---|---|---|---|
| **8-hour Shift** | **Start time** | *8:00* | *9:00* | *10:00* | *11:00* | *12:00* | *13:00* | *14:00* | *15:00* |
| | **End time** | *16:00* | *17:00* | *18:00* | *19:00* | *20:00* | *21:00* | *22:00* | *23:00* |
| **LOS** | **Mean (min)** | 380 | 385 | 383 | 416 | 358 | 387 | 375 | 392 |
| | **Effect (%)** | -34.93 | -34.08 | -34.42 | -28.77 | -38.70 | -33.73 | -35.79 | -32.88 |
| **WTBS** | **Mean (min)** | 158 | 225 | 47 | 65 | 91 | 85 | 57 | 112 |
| | **Effect (%)** | -23.67 | 8.70 | -77.29 | -68.60 | -56.04 | -58.94 | -72.46 | -45.89 |

Here we use *Op1* as an example to illustrate how the human resources (i.e. physician and nurse in particular) are assigned in triage during the busy hours of 8:00am – 16:00pm (*Table 5-8*). One physician is assigned to triage patients during 8:00am – 16:00pm; within this time period, testing (i.e. lab, x-ray, radiology test or any combination of the three) may happen beforehand in triage as prescribed by the physician based on patient medical needs. Nurse A in this case works as a "facilitator" to help conduct or arrange testing as required by the physician. For Nurse A's remaining working hours when the physician is off shift (i.e. 16:00pm – 8:00am [+1 day]), Nurse A switches back as a triage nurse. Nurse B is assigned same as the current rule, conducting triage from 7:30am – 11:30pm (i.e. hours of current day and evening shifts for nurses). Nurse A or Nurse B indicates a job function rather than a specific person. By counting the total number of shifts within Nurse A and B we can easily identify the quantity of nurses (i.e. 5) that need to be assigned in the triage model of *Op1*.

*Table 5-8: The allocation of human resource in physician and nurse in the triage model of Op1*

| | **PIT Enforced Triage *Op1*** | **Traditional Nurse Triage** |
|---|---|---|
| **Physician** | 8:00am – 16:00pm (1 Shift) | N/A |
| | Triage patients | |
| **Nurse A** | 8:00am – 16:00pm (1 Shift) | 16:00pm – 8:00am [+1 day] (2 Shifts) |
| | Conduct/arrange testing as required by the physician in triage | Triage patients |
| **Nurse B** | N/A | 7:30am – 3:30pm & 3:30pm – 11:30pm (i.e. current day & evening shifts) |
| | | Triage patients (2 Shifts) |

*Note: "Nurse A" or "Nurse B" indicates a job function rather than a specific person.*

To visually observe the changes by using different PIT allocation options, *Figures 5-7 and 5-8* are plot to compare the measures of LOS and WTBS with the baseline model performance. The findings are as follows:

1) *Figures 5-7* shows great reduction in average LOS by using all eight PIT allocation options, and generally a 34% reduction in average LOS can be expected by allocating a physician for 8 hours during the busy period of 8:00am – 23:00pm to conduct triage for ED patients.
2) *Figures 5-8* shows a general great reduction in average WTBS by using PIT allocation options; however, a slight increase in WTBS may be observed.
3) Compared the reduction in LOS with WTBS, the reduction in LOS fluctuates less strongly than the reduction in WTBS.

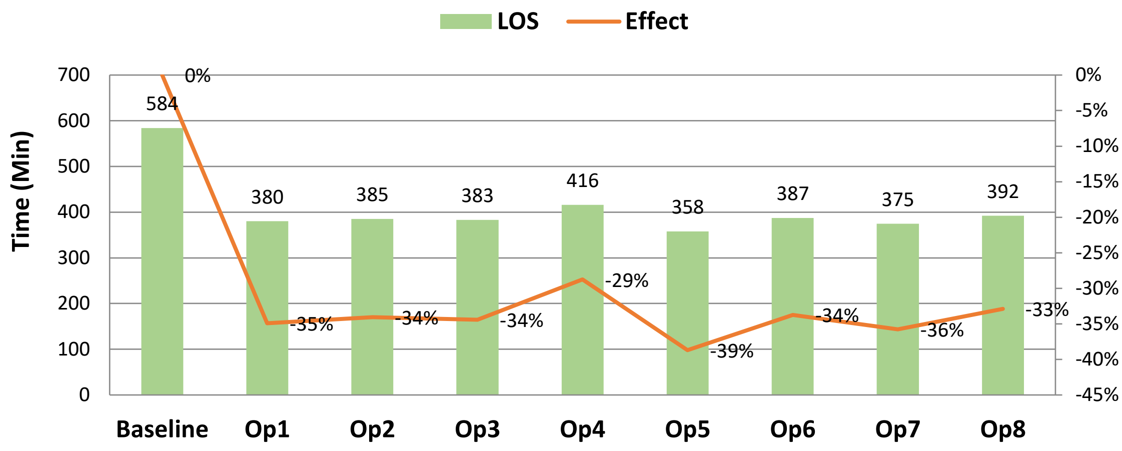



*Figure 5-7: The results of patient average throughput time by using different PIT allocation options in comparison with the baseline measure (8hrs in busy time)*

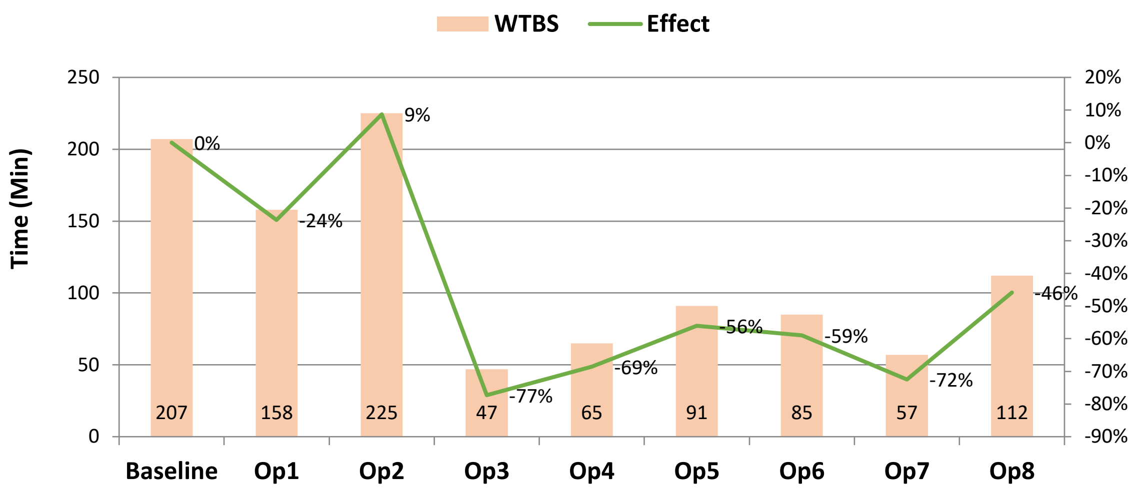



*Figure 5-8: The results of patient average waiting time by using different PIT allocation options in comparison with the baseline measure (8hrs in busy time)*

*c) Step 3 of the PIT experimentation – Discovering the connection between PIT allocation and patient care demand*

The third step of the PIT experimentation is to look at the influence level on patient average waiting time and throughput time when one physician is allocated in triage during a non-busy period of a day (i.e. 23:00pm-8:00am). Here we name this triage model as *PIT-3*. The allocation of physician and nurses shares the same rule as we explained in the triage model of *Op1* except that the physician in *PIT-3* is on shift during 23:00pm-8:00am instead of 8:00am – 16:00pm.

*Figures 5-9* and *5-10* are the results of LOS and WTBS by allocating a physician in triage during different hours of a day (i.e. full day [*PIT-1*] vs. 8 hrs during a busy period of a day [*Op1 - Op8*] vs. a non-busy period of a day [*PIT-3*]). By comparison with these two figures, it can be found that:

1) Applying PIT strategy causes general reduction in average LOS, but its reduction level in LOS does not show great change in the case of whether a PIT is allocated in busy hours or non-busy hours;
2) In contrast, the allocation of a PIT in non-busy hours greatly increases WTBS in comparison with the baseline measure; its allocation in busy hours tends to fluctuate wild in correspondence to patient care demand for ED service;
3) Recognizing the patient arrival pattern (i.e. care demand) plays an important role in order to determine the best working hours for a PIT so that a greatest reduction in WTBS can be expected; assigning more working hours for a PIT does not necessarily cause greater reduction in patient average waiting time and throughput time.

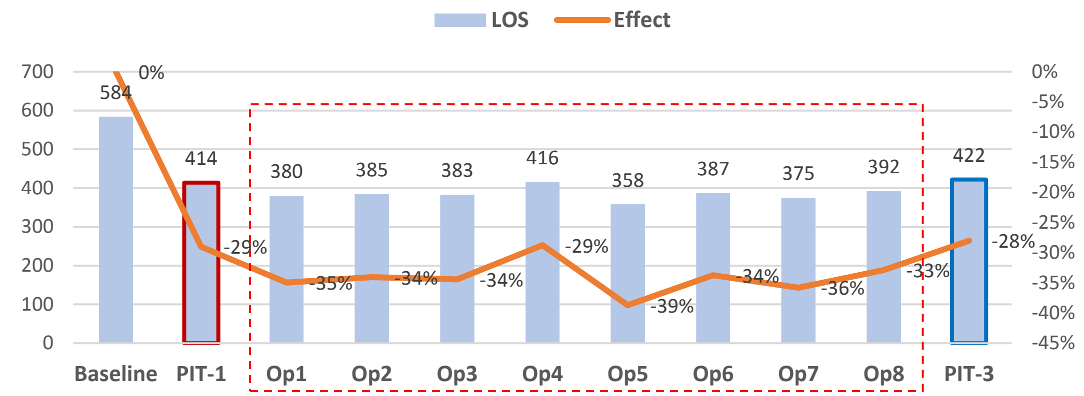


*Figure 5-9: The effects of allocating a PIT during different hours of a day on patient average throughput time in comparison with the baseline measure (24hrs vs 8hrs in busy time vs non-busy time)*

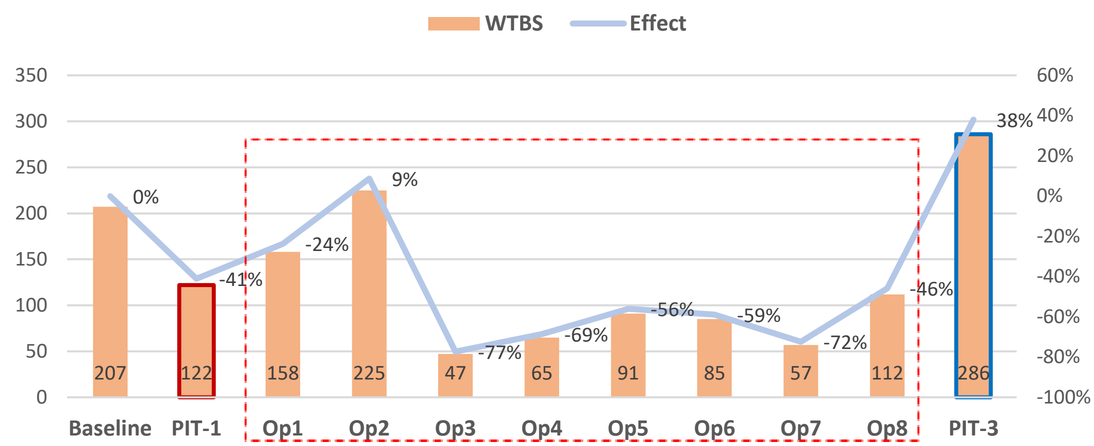


*Figure 5-10: The effects of allocating a PIT during different hours of a day on patient average waiting time in comparison with the baseline measure (24hrs vs 8hrs in busy time vs non-busy time)*

*3) Suggestions for the implementation of PIT strategy*

Based on the above findings from the PIT experimentation, it is advised that under the current situation of the ED visits assigning a physician during the hours of 10:00am – 18:00pm (i.e. *Op3*) to conduct triage for patients will make greatest improvement to relieve the overcrowding.

The reason of choosing the PIT intervention *Op3* is because in *Op3* patient average waiting time to see a doctor is reduced most amongst all the other seven options (referring back to *Figure 5-8*); and meantime whether to allocate a PIT in busy hours or non-busy hours does not apparently show great difference in its reduction level of patient average throughput time (referring back to *Figure 5-9*).

In future if there are changes to the patient arrival pattern (i.e. care demands or ED visits), the allocation hours of the physician in triage need to be adjusted correspondingly. The choice of when to best allocate a physician in triage is pertinent to the patient care demands for the ED service. A smart decision is to always allocate the physician during the busiest time of the ED to conduct triage for patients.

In reality the LOS and WTBS by using PIT strategy may not exhibit as much reduction as what we present in *Figures 5-7* and *5-8*. Because in the model we do not consider the case of when the PIT is off shift patients will have to do testing during their treatment cycle in a designated treatment area. Hence, its positive effects on ED performance by using PIT strategy will have to be partially discouraged by this fact. Through experimentation, we also find out that PIT strategy may cause a risk of stacking patients in the waiting room, prolonging patients waiting time to see a doctor and their length of stay in the ED.

# Chapter 6

# Conclusion

## 6.1 Research Summary

In this research, a validated discrete-event simulation (DES) model has been successfully introduced to emulate the existing ED patient flow in St. Boniface General Hospital. By using the validated model, various operating alternatives have been tested in order to relieve bottlenecks in the current ED system and to reduce patients waiting times to see a doctor and their length of stay in the ED. Such alternatives are generally categorized into two groups: one without changes to the current ED patient flow, and another with changes to the current patient flow specifically using PIT strategy. The validated DES model provides a quantitative tool for the analyst to evaluate the influence level on LOS and WTBS among various operating alternatives in comparison with the baseline measures.

To summarize, some major findings from this research are:

1) Reducing triage time has a great positive impact on both LOS and WTBS;

2) Building capacity in MTA causes reduction in both LOS and WTBS, and generally leads to a greater reduction in WTBS compared to LOS;
3) Observation time reduction in RU does reduce the average LOS; however, reduction in WTBS is rarely observed;
4) Without making changes to the current patient flow, LOS and WTBS can be reduced if the ED allocates another physician to look after the patients in ERms and MTA;
5) Great reduction in both LOS and WTBS can be expected if we allocate one physician in ED busy hours to conduct triage for patients.

## 6.2 Research Contributions

Three major contributions have been made in this research:

*1) Exploring various ED operating alternatives for the hospital management team*

This research explores various operating alternatives in order to achieve a more efficient ED system. As healthcare continues to become more competitive, the ability to reduce cost, improve efficiency and provide quality service grows in importance. This research has engaged a quantitative approach for hospital decision makers to explore numerous trade-offs between efficiency, workload and capacity.

*2) Extending simulation applications in healthcare, specifically in EDs*

This research demonstrates the usefulness of simulation modeling for predicting the impact of various solutions to the ED overcrowding. Meantime, simulation has shown its great power of examining preliminary findings of a novel solution to determine its application and limitation. A small contribution has also been made to extend the scientific evidence of the PIT impact on EDs.

*3) Advancing promotion in healthcare*

This research has made contributions to the healthcare promotion by discovering various potential possibilities to improve the overall service delivery in emergency care system. Improving the patient flow within EDs is a major priority in Winnipeg as stated in the WRHA strategic plan (2016-2021). This research hence may facilitate WRHA to drive essential changes to the current emergency care process.

## 6.3 Future Research

This research is solely focused on improving patient flows inside the ED. However, as discussed in the previous section, factors causing ED overcrowding may penetrate all levels of the entire healthcare system. Besides improving patient flows in the ED, optimization strategies can also be associated with improving patient flows into the ED and out of the ED. Finding ways to reduce the number of ED visits or to release ED patients fast are effective as well to help alleviating ED overcrowding.

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