IMPROVEMENT OF HOSPITAL EMERGENCY DEPARTMENT OPERATIONS USING SIMULATION-BASED APPROACH

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Scope and method of study: The study aimed at reducing the length of stay of patients in a hospital emergency department (ED) through systematic investigation using a simulation based approach. Literature review conducted during the course of study revealed a great amount of research conducted in understanding and improving the emergency department operations. Lately, ED has become the primary facility to obtain immediate healthcare services; hence, reducing patient's length of stay in ED has become a critical issue. The research developed a high fidelity simulation model, which captures the major activities that occur during the course of treatment of patients at the Stillwater Medical Center ED. Data collection and analysis was carried out to generate inputs for the simulation model. Several alternate strategies such as an additional triage station to treat less emergent patients, additional doctor during peak hours and nursing staff dedicated to treating less emergent patients were developed which aided in reducing the waiting time of patients thereby reducing the length of stay. The strategies were analyzed and their performance was compared to that of the baseline simulation model.

Findings and conclusions: A different approach of treating less emergent patients was developed by adding a triage station which increased the availability of rooms and reduced waiting time of patients before a room was assigned. Addition of a triage station dedicated to treating less emergent patients reduced patient's length of stay by 6.3%. With an additional doctor during peak hours it was observed that length of stay decreased by 13%. There was a decrease of almost 9% when a nurse was dedicated to fast-track patients. Instead of being dedicated, if the nurse had a priority for fast-track patients, the model showed a decrease in length of stay of 14%. Although the study was focused on the Stillwater Medical Center ED operations, the strategies developed during the research could also be implemented in emergency departments that operate in a similar manner. Finally, this research has proposed a strategy that could be used to treat less emergent patients quickly and efficiently and thereby achieving overall reduction in the length of stay of patients.

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CHAPTER I

INTRODUCTION

This chapter provides a brief introduction to the role of the hospital emergency department in the healthcare sector of the country, and the rising concerns of hospitals to maintain the healthcare standards and quality of service delivered in the emergency departments. Then the need for additional investigation to improve the emergency department's operational performance is established.

1.1 Hospital Emergency Department

Hospitals today are facing constant pressure to provide high quality care, keep up with the competition and meet healthcare regulations and standards. With the increasing number of the patients visiting the emergency department (ED), it is soon becoming a key part of the primary healthcare system. Patients are less willing to wait for long periods of time especially in the emergency department, and this has increased the need for hospitals to maintain their standards by providing the best care while maintaining the efficiency and swiftness in providing treatment to patients. With the ever increasing number of patient visits to the emergency department and the diversity in their acuity levels, it has become even more important for hospitals to improve the quality of healthcare given to these patients. According to the US Department of Health and Human Services, in 2010 there were 130 million visits to the ED and the number is increasing at the rate of 2.5% to 4% annually (Sanchez et al. 1999).

With such statistics, hospitals are focused on giving the best healthcare to the patients while making sure that the ED resources are utilized in an efficient manner.

In the 1960's hospitals across the US had adapted to the policy of scheduling patient admits, and hence, there was only a small percentage of patients categorized as being emergent or unscheduled. During this period hospitals often had enough capacity to cope with the inefficiencies in the system. Hospitals typically operated from 9 am to 5 pm, Monday to Friday and some of the staff was scheduled during evenings, nights and weekends. In the past decade or so, significant changes have occurred in the healthcare sector of the country with a steady increase in number of emergency visits and a greater portion of the population needing more accessible healthcare services. Consequently, the point of entry to the hospital has been shifted with a major part of patients entering through ED. It has also been observed that most of the visits have been coming during the afternoons and evenings. With such a significant shift, hospitals have not been able to adapt to these changes and continue to function in the traditional way. This has caused a mismatch between the available resources and needs which has led to capacity issues. Perhaps this explains the reason for higher death rates among patients admitted on weekends as compared to weekdays (American College of Emergency Physicians, 2008). With recent technological advancements, the number of admissions per day could now be predicted more accurately as compared to the conventional thought that emergency patient volume is highly unpredictable (American College of Emergency Physicians, 2008).

According to Schneider et al. (2003), overcrowding in the ED is stated as a systemic problem which involves those patients waiting for admission or transferring into the inpatient unit, and those awaiting a physician or a nurse in the waiting rooms (non-treatment areas). Many emergency departments in the United States are critically overcrowded and unable to respond to day-to-day emergencies, let alone natural or man-made disasters.

Crowding is a crisis that results from the practice of “boarding,” or holding emergency patients who have been admitted to the hospital in the emergency department. Crowding occurs when no inpatient beds are available in the hospital, not because of too many patients with non-urgent medical conditions seeking emergency care, but due to the on-going treatment process that is being carried out for admitted patients. The practice of boarding endangers patients and results in delays in providing care as well as ambulance diversion.

According to Olshaker and Rathlev (2006) almost every state in the United States is facing the problem of overcrowding in the ED. ED overcrowding happens because of one or more of the following reasons - longer times for treatments, unavailability of beds and lack of resources such as nurses, doctors and ancillary services (Bernstein, 2009). Overcrowding in an ED has undesirable effects on patients such as prolonged suffering, reduced satisfaction of patients, unattended patients exiting the ED and death in some cases. In 2006, the National Institutes of Health reported that overcrowding leads to a compromise in the patient’s hospital experience and also adds to the stressful working environment, thereby resulting in potential errors, delays in treatment and reduced quality of health care.

The ED performance metrics include the wait times of the patients and length of stay (LOS) for a single visit. As the wait times and LOS increase there are severe effects on critical patients as mentioned in the subsequent part of the chapter. Three factors have been identified to have effects on patients admitted in the ED: external factors, process factors and internal factors. Some aspects of the randomness that exists in the system are classified as external factors and we have very little or no control over their occurrence. Examples are patient arrival times during the day and a severe pandemic attack leading to an abrupt increase in the number of arrivals for a period of time.

Process factors are those which are inevitable and take a certain amount of time such as triage, registration of patient, laboratory work and diagnostic tests (X-Ray, MRI, and CT scan). Internal factors include availability of resources (physicians, nurses, rooms or any other ancillary resources). "Length of stay (LOS) is a term to describe the duration of a single episode of hospitalization of a patient" (Faddy et al., 2009). Length of stay of a patient is calculated by taking the difference of the admit time and the discharge time. The medical fraternity has identified that wait time reduction should be given a higher priority in order to improve the healthcare system. In recent years, LOS has reduced or remained constant; however, Canadian Institute of Health Information states that LOS is still a matter of concern that needs scientific research and investigation to find techniques to reduce the time spent by patients in the ED and increase patient satisfaction (Davidson et al., 2007). Length of stay is commonly used as a quality metric. The payment system in U.S. Medicare for reimbursing hospital care promotes shorter length of stay by paying the same amount for procedures, regardless of days spent in the hospital. According to Yoon et al. (2003) "Length of stay (LOS) is a key measure of emergency department (ED) throughput and a marker of overcrowding."

Finding ways to reduce the length of stay is a complex problem due to the characteristics of the above mentioned external, process and internal factors. First, we have the intrinsic randomness present in the patient arrival times, the care they would need and the activity times. Furthermore, availability of resources is highly dependent on the patient arrival time and the acuity levels of the patients. There are cases where a physician is preferred for specific patients making it difficult for the physician to attend to other patients waiting.

1.2 Simulation Modeling of ED Operations

Simulation is a popular analysis tool that has been used to model and study complex operations such as those in an emergency department. Simulation modeling allows exploration of the effect of alternative designs for improving operations by mimicking flows and activities within a system. It allows experimentation to understand the impact of different scenarios or proposed changes to the system. Simulation models have been extensively used to study manufacturing, transportation, telecommunication and other service operations. Developing simulation models in a hospital environment is a challenge because of the presence of human elements and difficulty in obtaining the necessary data. “One of the most critical parts of any simulation model development is validating the model—comparing the model’s output with the data observed” (Maria, 1997). In order to rely on such comparisons one has to make sure that the input data for the model, as well as the data observed for comparison with the model output, are accurate.

Discrete Event Simulation (DES) is a form of computer-based modeling which provides an in-built and flexible approach to model complex systems such as an ED. The approach provides greater flexibility when the model is customized with routine variables and parameters. DES modeling has the potential to assist the staff in training and improving the quality of service delivered. Using a simulation model, employees would be able to train new recruits by creating possible situations that could likely arise in the ED. The power of simulation would allow the user to generate “what-if” scenarios and change the outcomes of situations with various approaches to solve the problem. According to Duguay and Chetouane (2007) DES has been a popular approach to improve the healthcare processes due to its flexibility and relative ease of operation. SIMIO®, simulation software developed by Dennis C. Pegden owned by Simio LLC, has been selected to develop the experimental test-bed in this research.

1.3 Problem Statement

This research study focused on the ED operations at the Stillwater Medical Center located in Stillwater, OK. The ED at the Stillwater Medical Center is experiencing problems with increased LOS of patients which is caused by long delays within the patient treatment process.

According to Wiler et al. (2010) providing timely care is strongly correlated with the satisfaction of patients, and also staff satisfaction is reduced due to the delayed attention to the newly admitted patients in the ED. Morris et al., (2010) in their study indicated unsafe consequences with increased waiting times of patients and unsatisfied staff at the ED.

The research envisioned is intervention-oriented, as it is focused on identifying potential solutions to reduce the LOS of patients by reducing the waiting times at subsequent stages of treatment process. In order to accomplish the objective of reducing the LOS of patients it is important to understand the issues within the ED. Computable insights are needed in the current operating situation of the ED leading to the identification of delays. Once the potential causes for the delays are identified and their impact is measured with the aid of the simulation model developed, the model can then be used to design strategies that could possibly reduce the waiting times and LOS of the patients. The research objectives could be stated as follows:

1) To provide meaningful insights into patient treatment process of the ED by incorporating patient flows, activities carried out by the ED staff on these patients and contention for ED resources in a simulation model constructed in SIMIO ®.
2) To identify and evaluate possible modifications to the ED processes to reduce the LOS.

1.4 Outline of the Document

The thesis document is organized in the following manner. Chapter 2 provides a literature review of previous studies on improving ED operations. Chapter 3 presents the research statement, research objectives and research tasks identified and assumptions made. Chapter 4 describes the Stillwater Medical Center ED operations. Chapter 5 describes the data collection methods and analysis conducted during the research. Chapter 6 focuses on the baseline simulation model development and validation. Chapter 7 discusses the strategies developed to reduce length of stay of patients and Chapter 8 summarizes the research study and provides future work

CHAPTER II

LITERATURE REVIEW

This chapter provides a brief literature review pertaining to the research conducted in modeling and analyzing ED operations. Section 2.1 explains the different aspects of overcrowding in an ED. Section 2.2 summarizes the role of simulation in modeling an ED and Section 2.3 explains the preferred technique of simulation in employed in this research.

2.1 Overcrowding in an ED

Overcrowding in an ED is defined as a condition where patients experience long wait times during their course of treatment. A series of research work has been conducted in measuring overcrowding and determining the impact of overcrowding on healthcare standards and investigating possibilities to reduce those (Schull et al., 2006). Their work mentions that ED overcrowding is a system-wide issue with variety of causes and no immediate solutions. For the past 25 years, the United States has observed a great deal of increase in ED visits with diverse conditions of the patients with different diseases. ED overcrowding is posing to be an everyday issue faced by most of the hospitals throughout the United States. In a study conducted by McCaig and Burt (2001), it is shown that 60% of the hospitals across the country operate above their capacity. McCaig and Burt (2001) also showed that this phenomenon is not only restricted to urban hospitals but it is spreading to all the hospitals regardless of their size and location in the country.

The ED sector of the country faces a constant challenge of delivering excellent healthcare with the available resources as indicated by Hall (2006). This issue is being faced by the country for numerous reasons such as uninsured section of the population, expensive healthcare and so on.

According to Derlet et al. (2001), ED overcrowding also occurs due to the lack of availability of inpatient beds. Certain patients in this case are treated in hallways and corridors until a bed is assigned. This type of treatment puts a strain on the hospital staff to ensure that proper resources are available to carry out the procedures. Overcrowding may also lead to inappropriate triage of patients unless a bed is assigned to them. Overcrowding in an ED tends the staff to reprioritize the needs of the patients. Ideally, staff would consider the needs of the patient of higher acuity level as there is no time, space or equipment to address the patients of lower acuity (Derlet and Richards, 2000). For instance, if the ED is not operating at its full capacity, a nurse would have time to explain the illness of the patient in detail and also answer any questions that the patient might have. This is to ensure that the patient is completely aware about his/her illness and is aware of the necessary precautions that need to be taken upon discharge. However, in an overcrowded ED the nurse will just provide specific written instructions and not explain the condition in detail which compromises the patients' understanding of the illness (Derlet and Richards, 2000).

Han et al. (2007) studied the effects of expanding the ED by adding more resources and studied the effects of congestion. Their study showed that increasing beds in the ED had very little impact in reducing the overcrowding and there was no improvement in the wait times of the patients; the wait times were greatly influenced by other factors such as availability of physicians and ancillary services. The investigation by Olshaker and Rathlev (2006) identifies the reasons for congestion and also the necessary changes that could be incorporated by the hospitals to address the same issue. Derlet et al. (2000) published a paper that assesses the effects of overcrowding on the patients risk, prolonged pain, increased length of stay, patient satisfaction, and reduced efficiency among the staff of the hospital. The paper also provides a more in-depth analysis of overcrowding and compromised quality of health care delivered. The influence of the emergency department overcrowding was studied by Khare et al. (2009) by using a technique of addition of beds with an aim to reduce the boarding time of patients. Their study tried to show that faster rate of bed assignment to the patients could likely reduce the length of stay in the ED. The study went on to show that it was not the addition of beds that made the difference; however, the discharge rate of patients proved to be one of the major reasons for reducing the length of stay of patients.

The most challenged components of healthcare sector are the ED's. A recent study conducted by ACEP showed that various factors are responsible for delays in an ED such as advanced medical needs, prolonged ED treatments and non-availability of beds. (Anderson et al., 2005). A survey study was conducted in 2008 by ACEP for reducing the congestion in the ED which addressed various methods like vertical patient flow, a method of treating non-critical patients without being admitted into a Full-care ER (Hoot and Aronsky 2008). These effects were then observed in a way that could improve patient satisfaction, reduce the length of stay and so on.

2.2 Role of Simulation in Modeling an Emergency Department

In recent years the simulation technique has received a lot more attention to model an Emergency Department. Simulation as defined by experts is basically replicating a functional system by creating a mathematical model using a computer (Chung 2003). The goal of simulation is to build a realistic model mimicking the processes that take place in a system using real data and then analyze the process to gain meaningful understandings. The biggest advantage of using the simulation technique resides in the fact that the system can be customized virtually without actually altering any day-to-day activities. Simulation is found to be one of the most sought after tools in healthcare industry to study process efficiencies (Katsaliaki and Mustafee, 2011). Simulation models are built to study patient flow and identify bottlenecks in order to reduce wait times at every stage of the process and the length of stay and thus improve patient satisfaction. In the research conducted by Eilers (2004) wait times are considered to be non - value added and indicated a lower quality of service delivered. Appropriate data collection is one of the most critical inputs to a simulation model which ensures that the model is built in accordance to the actual operating system. It also helps in accurate determination of various performance measures such as utilization of resources, LOS and waiting times at various stages of the process.

Simulation also has a role in training the new staff and thus improving the quality of the service delivered. This can be achieved by visualizing the simulated model of the particular ED. The staff are shown different situations simulated under different circumstances and also their resulting impacts on various aspects related to the treatment of patients. Today's simulation software allows for flexibility in developing "what-if" scenarios and changing the situations to get the best desired outcome. Simulation techniques also pay a role in scheduling the work force, risk assessment, cost reduction etc. (Sundaramoorthi et al., 2007). According to Barjis and Joseph (2011) it is anticipated that by the end of 2015 the health care industry is expected to face a 20% shortage of nurses which will be the top priority for a period of time. A detailed simulation model can provide the facility operator with meaningful data to analyze the utilization of resources and also help in identifying the need for more resources. Simulation also has its drawbacks such as lack of data which in some cases gives approximate results and hence, verification and validation will be an issue for certain applications. The data needed for developing a simulation model is not readily available and also in some cases data collection may be a time consuming activity. A variety of reasons exist for lack of data due to the diverse ailments of patients and purpose of their visits. Some of the widely used simulation techniques are System Dynamics, Discrete-Event Simulation and Agent-based Simulation. The following sections provide brief explanations these techniques.

2.2.1 System Dynamics

Yen-Hao (2011) in his paper discusses System Dynamics as an analytical modeling technique which gives us a macro-level view of the problem complexity. The advantage of using this approach of simulation lies in the fact of blending both quantitative as well as qualitative aspects of the problem which helps better understand the problem (Wong et al., 2012). Wong et al. (2012) discuss the application of system dynamics approach in a Canadian hospital to model the effects of changing the patient arrival rates in the ED, changing the allocation of resources and making policy changes. An extensive study conducted by Lane et al. (2000) analyzed the effects of decreasing the bed capacity on the wait times of patients in the ED across UK's national health system and showed the adverse effects on wait times in the ED. A system level research was carried out in a healthcare facility in Singapore which studied the effects of policy changes on healthcare affordability (Liu et al., 2011).

2.2.2 Discrete Event Simulation

A typical discrete event simulation (DES) study begins with identifying the problem and formulating the problem by considering a number of factors in the system. A conceptual model is built which is focused on the flow of entities, the processes they undergo, resources required and the target that needs to be achieved (Brailsford and Hilton, 2001). The model is constructed with a source that creates discrete entities, servers to process entities and sink to destroy entities once they exit the system. The server carries out a number of processes on the entities as programmed. The role of simulation is also extended to create resources that actually perform the processes on entities at the servers (Schriber et al., 2012). The scope of simulation also extends to process multiple entities simultaneously at different processing servers. During the simulation the entities queue at the processing servers if no resources are available. An event occurs at each instance of interaction between the entity and the resource or any other part of the system. The flexibility of the software gives modeler the freedom to code entities regarding their future course of action.

While modeling using DES technique, the entities undergo specific processes based on the probabilities of occurrence of a specific type. Discrete Event Simulation is the most commonly used approach to model an Emergency Department. Jurishica (2005) discusses the standard procedure for developing a simulation model and the research work developed different scenarios for the simulation model and the model was tested in two categories- variable changes and process changes. The process change scenarios dealt with replacing the processes with alternate processes and observing the effects on the newly developed processes on the operational performance of the ED.

2.2.3 Agent-based Simulation

According to Escudero-Marin and Pidd (2011) an agent is described as an entity that is capable of making decisions subject to a set of rules. The agent has the capability to interact with other agents and can change its state dynamically based on the effects of those interactions. According to Cabrera et al. (2012) a pure agent based simulation model always generates outcomes based on the output of those interactions. An agent based simulation model has three features

- Characteristics and behavior of agents
- Setting of the agent depends on whether an agent is managing some other agents in the model to achieve a specific target
- Interactions, relations, methods of interactions between the agents and the output of those interactions.

Agent-based simulation is widely used in analyzing the human factors that influence the system in many ways.

2.3 Discrete Event Simulation: The Preferred Approach

Discrete Event Simulation takes into account the quantitative aspects of the system and ignores the qualitative part of the system. The simulation methodology is intended to be compared in quantitative terms with any other methodology applied on the model. Individual entities take part in the processes modeled in the system. The entities pass through different activities and processes and wait at the processing servers to complete their assigned activities. According to Brailsford and Hilton (2001) the system changes occurs only at discrete points of time. Studies conducted by various researchers show that System Dynamics is used to model the system in a broader sense and Discrete Event Simulation for modeling the detailed operations of the system and understanding the inherent complexities involved with those operations (Brailsford and Hilton. 2001; Chahal and Eldabi, 2008). It has been concluded that DES is more suitable when randomness exists in the system and the randomness occurs significantly. (Brailsford and Hilton, 2001; Lane et al., 2000).

This research modeled the Stillwater Medical Center's Emergency Department, henceforth known as SMC-ED using the DES approach. The simulation model was built in the SIMIO ® software and it captured the patient flow process from arrival until the patient exited the ED. The entities undergo different activities at every stage and the test-bed model was used to identify and investigate the bottlenecks for wait times between successive stages. The simulation was built based on the understanding derived from previous studies. However, from the literature survey it was observed that most of the research was focused only on increasing the resources or changing the process flow; this research has explored both modifications and made an attempt to develop operational guidelines for the ED.

CHAPTER III

RESEARCH STATEMENT

In recent years simulation has become one of the most widely used tools to model complex systems, especially, the hospital emergency department (Chung, 2003). Simulation techniques are used to gain a better understanding of the system performance under various parameter settings, and thereby identify system changes which could improve the performance of the system under consideration. With rising visits to ED it is becoming increasingly necessary for the hospitals to maintain the standards and quality of healthcare delivered. With patients of diverse acuity levels visiting the ED, streamlining the operations is becoming more complex. As discussed in the literature review chapter, ED is forming the most crucial part of the healthcare system. The hospital personnel are constantly in the process of improving the quality of healthcare delivered to the patient.

This research investigated the operational performance of the Emergency Department at the Stillwater Medical Center (abbreviated as SMC-ED) and developed strategies to reduce the waiting time and LOS. A high fidelity simulation model of the ED was built and used to conduct this detailed investigation. The results of this real-life case study have led to developing strategies /approaches that could be applied to ED's at other similar hospitals.

The LOS in ED is measured as the elapsed time between the time the patient arrives until the patient is discharged from the ED. This means that either the patient is admitted into the hospital for further care or the patient is declared to be stable. In a broader sense this research identified potential modifications in the existing patient flow process and resource allocation/scheduling strategies that would aid in the reduction of waiting time and hence, decrease the LOS.

3.1 Research Objectives

After understanding the operations of the ED at the Stillwater Medical Center and the system to be simulated, the following objectives were identified.

1. To conduct detailed analysis of the data obtained to gain insights into the operation of the ED and derive inputs for simulation model.
2. To develop a high fidelity simulation model that captured the operations of the ED as accurately as possible.
3. To propose modifications to the existing system by developing strategies which could aid in reducing the waiting times and length of stay of patients.

3.2 Research Tasks

To achieve the objectives stated previously the following research tasks were identified and executed.

1. <u>Literature Review</u>: The literature review helped in understanding the theories and insights from related studies and this was helpful in developing potential strategies to reduce waiting times and LOS of patients. This research combined the insights obtained from the literature discussed and the understanding of ED operations at SMC, to develop alternatives to improve the operational performance of the ED.
2. <u>Data Collection and Analysis</u>: This task played a crucial role in building a simulation model to represent the existing system as accurately as possible. Data collection was

carried out using two methods, historical data obtained from the ED authorities and physical collection of data that was not recorded by the system. Historical data included data related to patient arrivals, acuity level, length of stay, duration of ancillary tests performed and the wait times at subsequent stages. The SMC-ED does not record the patient treatment times; this data was collected for patients visiting the SMC-ED during the peak hours. The next stage of this task was to conduct data analysis which provided better insights into the existing system. The data collected was analyzed in MS Excel ® and StatFit ® to obtain a variety of descriptive statistics and a part of the data was used to build the simulation model such as inter-arrival time and treatment time distributions.

3. Investigation via Simulation Experiments: Using the simulation model, this research explored modifications to the existing patient treatment process which could possibly aid in improving the operational performance of the ED. Three strategies were developed which included adding an additional triage station dedicated to less emergent patients, an additional doctor during the peak hours of operation and a "dedicated" nurse to treat the low acuity patients, when present.
4. Develop Operational Guidelines: Based on the insights obtained and lessons learned through the SMC-ED case study, this research has made an attempt to generalize the findings and develop operational guidelines for the ED.

3.3 Model Assumptions and Scope

The assumptions made in constructing the simulation model are as follows

1. The model does not capture the travel (walking) time of doctors, nurses or patients inside the ED.
2. The simulation model assumes that there is no difference in patient admits during the weekends which were observed from the historical data. Hence, the same arrival process is used for everyday of the week.

3. The model does not account for processes that are not directly involved in the treatment of the patient such as administrative work or maintenance of the ED area.

CHAPTER IV

SYSTEM DESCRIPTION

4.1 Background of SMC-ED

The simulation model was built based on the operations carried out at the Emergency Department of the Stillwater Medical Center. The Stillwater Medical Center is a 119-bed facility with approximately 30,000 annual ED visits, resulting in an average of 80 to 90 visits per day. The patients are categorized into five acuity levels based on the conditions of severity. Patients with high criticality are categorized into levels 1 and 2, level 3 is the mid acuity level and levels 4 and 5 are low acuity patients. The ED is housed with 15 beds, 13 beds dedicated to levels 1, 2 and 3 and 2 beds dedicated to levels 4 and 5 termed as the "Fast-track ER".

4.2 ED Patient Flow

The patient flow is initiated with the patient arrival and is completed when the patient is discharged or admitted in the hospital.

4.2.1 Pre-Treatment Phase

The patient flow is initiated with the arrival of the patient. The SMC-ED has two modes of arrivals for patients; patients arriving by ambulance and walk-in arrivals. With every walk in arrival a set of procedures is initiated such as registration and triage.

The first step in the patient flow is “Registration” where the patient provides details such as name, age, purpose of visit and insurance policy details. Once the patient is registered in the ED, the patient waits for the triage nurse to initiate the process of “Triage”. The triage nurse accompanies the patient to a triage room where the patient describes the reason for visiting the ED in detail. The triage nurse then records all the information given by the patient and checks the patient for vital signs. In the process of triage, as the nurse records the description given by the patient, acuity level of the patient is assigned, depending on which the patient would be assigned a room (Full-care Emergency Room or Fast-track Emergency Room). The patient flow in the pre-treatment phase is shown in figure 4.1.

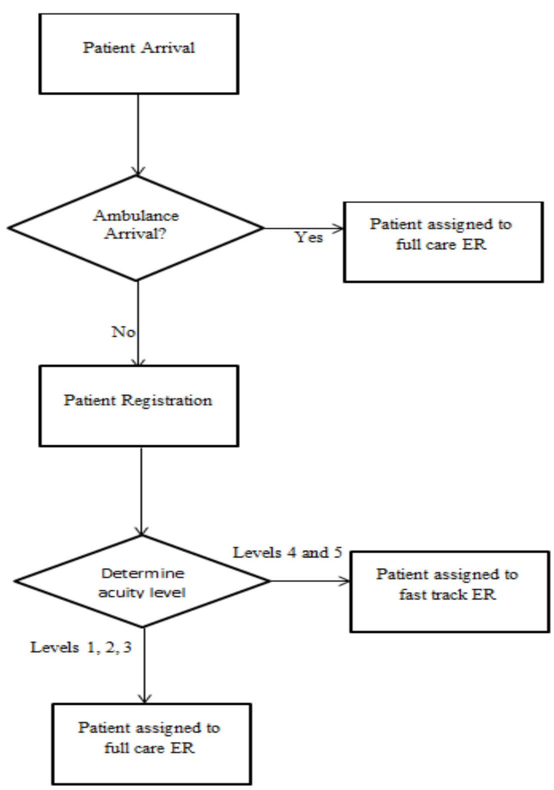


Fig 4.1 Patient Pre-Treatment Process

4.2.2 Patient Treatment Phase

The treatment phase is initiated when the patient is assigned a room based on the acuity level assigned by the triage nurse. This phase ends when the patient has completed all the treatment that is being advised by the doctor and is either discharged from the ED or is admitted to the hospital for further treatment.

During this phase the resources of the ED such as beds, doctors, nurses and ancillary services would be utilized by the patient. The treatment is initiated with a detailed nurse assessment based on the observations made by the triage nurse. The patient is checked for all vital signs such as body temperature, blood pressure and pulse rate. The patient record is created by the nurse and is then handed over to the doctor. The doctor then initiates a detailed assessment based on the record created by the nurse and determines the procedures that need to be followed for treatment. The doctor makes a judgment based on the severity of the condition, and this may include ordering lab tests, having an image test such as X-Ray, MRI or CT Scan to be done or consulting a specialist for further procedures. Treatment at ED requires supervision by doctors and nurses at regular intervals. The nurse monitors the patient and reports the conditions of the patient regularly to the doctor. The doctor revisits the patient during any of the following three situations:

1. The ordered lab-tests or imaging tests have been processed and the results are ready for review.
2. The patient is observed to be stable and there is no need for further treatment.
3. The patient is not recovering from the disease and is unstable after performing the necessary treatments; the doctor then makes a call on whether to admit the patient in the ward or to perform additional tests in the ED.

Once the treatment phase is completed the patient is advised to either get discharged from the ED or get admitted in the hospital. The process terminates once the patient completes the necessary paperwork and payment related procedures.

4.3 Mapping Patient Flow Processes

Patient flow process in the ED was mapped by constructing activity diagrams using which are part of the Unified Modeling Language (UML), a general purpose modeling language widely used to understand the functioning of a system. UML activity diagrams shows sequential and parallel activities in a process which are used for modeling complex business processes, work flows, data flows etc. (Larman, 2004). UML activity diagrams are constructed by capturing “actors” (patients and resources such as doctor, nurse, mid-level provider and ancillary services in our case) involved in completion of a process. Figures 4.2, 4.3 and 4.4 are divided into columns representing actors and every column provides the sequence of activities performed by actors. UML activity diagrams are constructed from various shapes connected with arrows showing the sequence of process flow. Shapes used in constructing activity diagrams are explained as follows

- Rounded rectangles represent actions performed by actors
- Rectangle represents an object resulting from an action. For example, registration form is obtained once the registration process is completed.
- Diamonds are the decision points in the process flow.
- Black Circle represents the start or initiation of the process.
- Enclosed black circle represents the end of the process.

The activity diagrams were constructed based on the observations made in the ED and interviews with ED staff. The diagrams were verified and validated by the SMC-ED personnel. The simulation model was developed based on the three UML activity diagrams constructed for walk-in (non fast- track) patients, walk-in fast-track patients and ambulance arrival patients.

Walk-In Arrival Patients: Figure 4.2 shows the UML activity diagram constructed for the walk-in arrival patients for acuity levels 1,2 and 3. From Figure 4.2 it can be observed that the diagram is divided into four columns each representing an actor. The first activity performed by the patient is the registration. Once the registration is completed the registration form is obtained by the registration clerk. The nurse then accompanies the patient to triage, checks vital signs and assigns priority. The patient is admitted to the Full-care ER by the nurse and the doctor begins the treatment process. The doctor determines whether additional tests are required which is shown as a decision point. If the patient does not need any additional tests the doctor prepares a prescription which is shown as an object in Figure 4.2 and then the patient completes the necessary paper work and exits the system. If the patient needs further tests the doctor then decides whether he/she needs an image test (X-Ray, CT Scan or MRI) or the patient needs non-image tests such as blood test. The nurse then draws the blood sample and sends it to lab for further procedures or if the patient needs an image test, the patient is taken to the respective room and the tests are carried out. The doctor obtains the test results and visits the patient to brief about the precautions that need to be taken. The patient then completes the paperwork and exits the system.

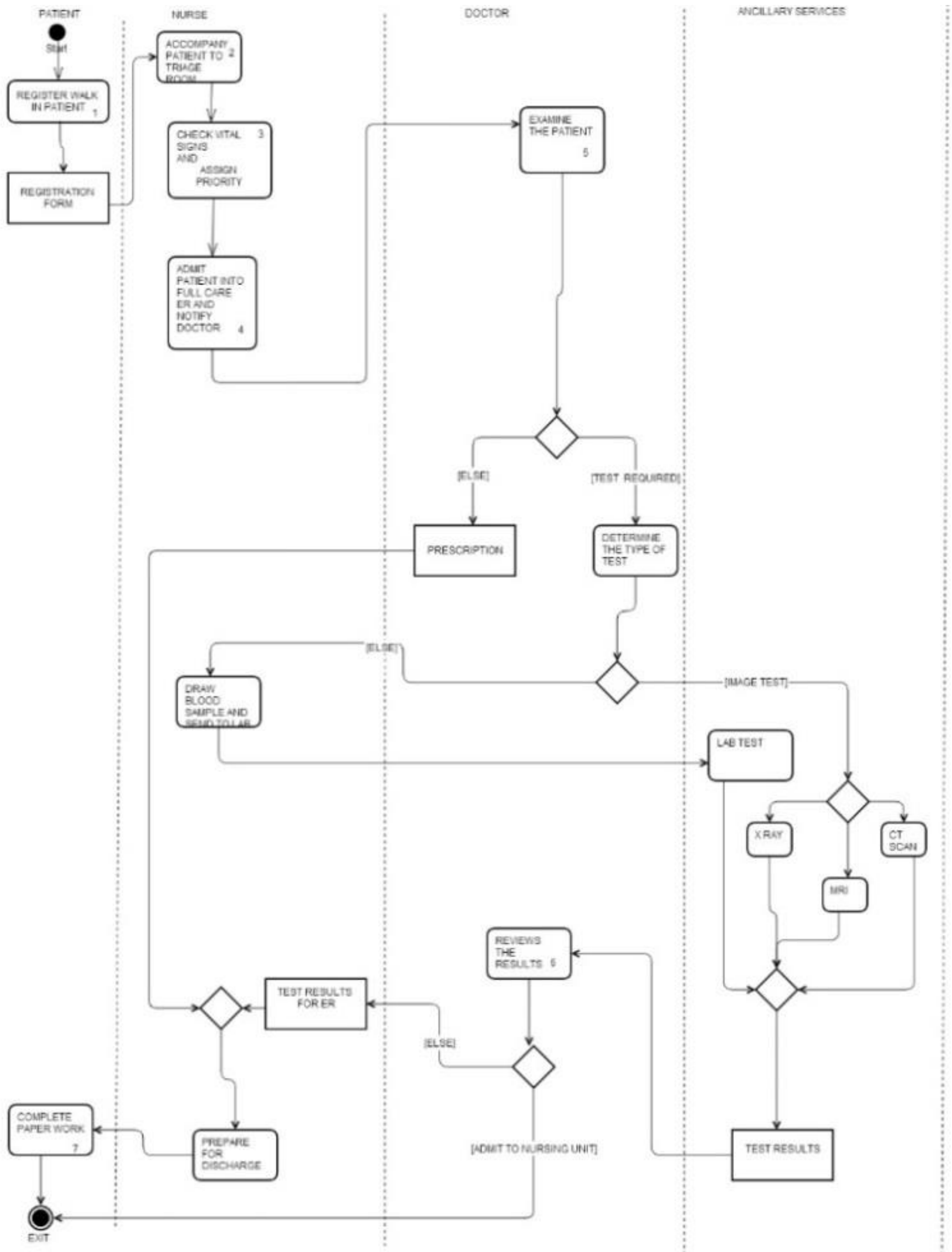


Fig 4.2 UML activity diagram for walk-in (non fast-track) ED patients

Fast-track Patients: Figure 4.3 shows the UML Activity diagram constructed for fast-track patients. The process of constructing the UML activity diagram is same as discussed for the Walk-In patients. The difference with the Fast-Track patients are that they do not need any ancillary services and their treatment is usually carried out by a Mid-Level Provider.

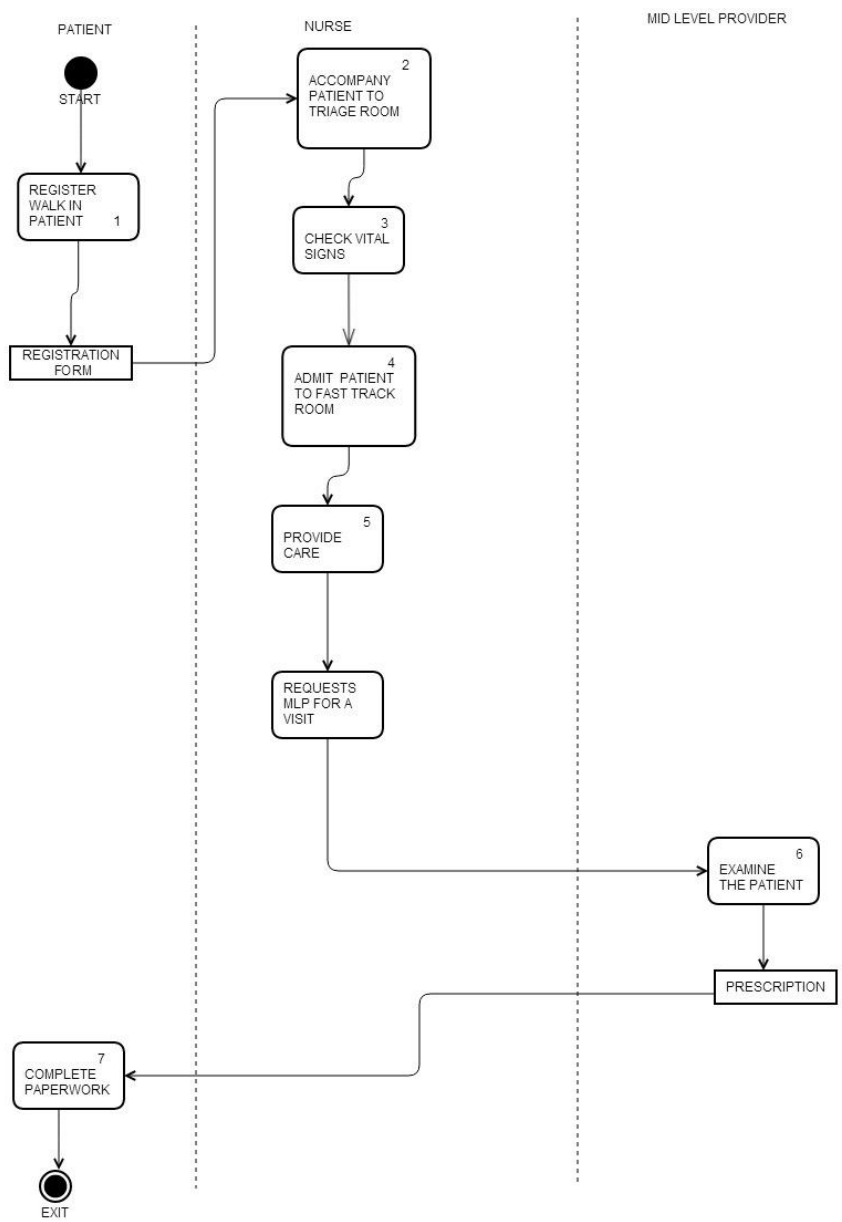


Fig 4.3 UML activity diagram of fast-track ED patients

Ambulance Arrival Patients: Figure 4.4 shows the UML Activity diagram constructed for ambulance arrival patients. In this case the patient is directly admitted to the Full-care ER room after which the nurse completes the registration process. The remaining process remains the same as that for 'Walk-In' arrival patients.

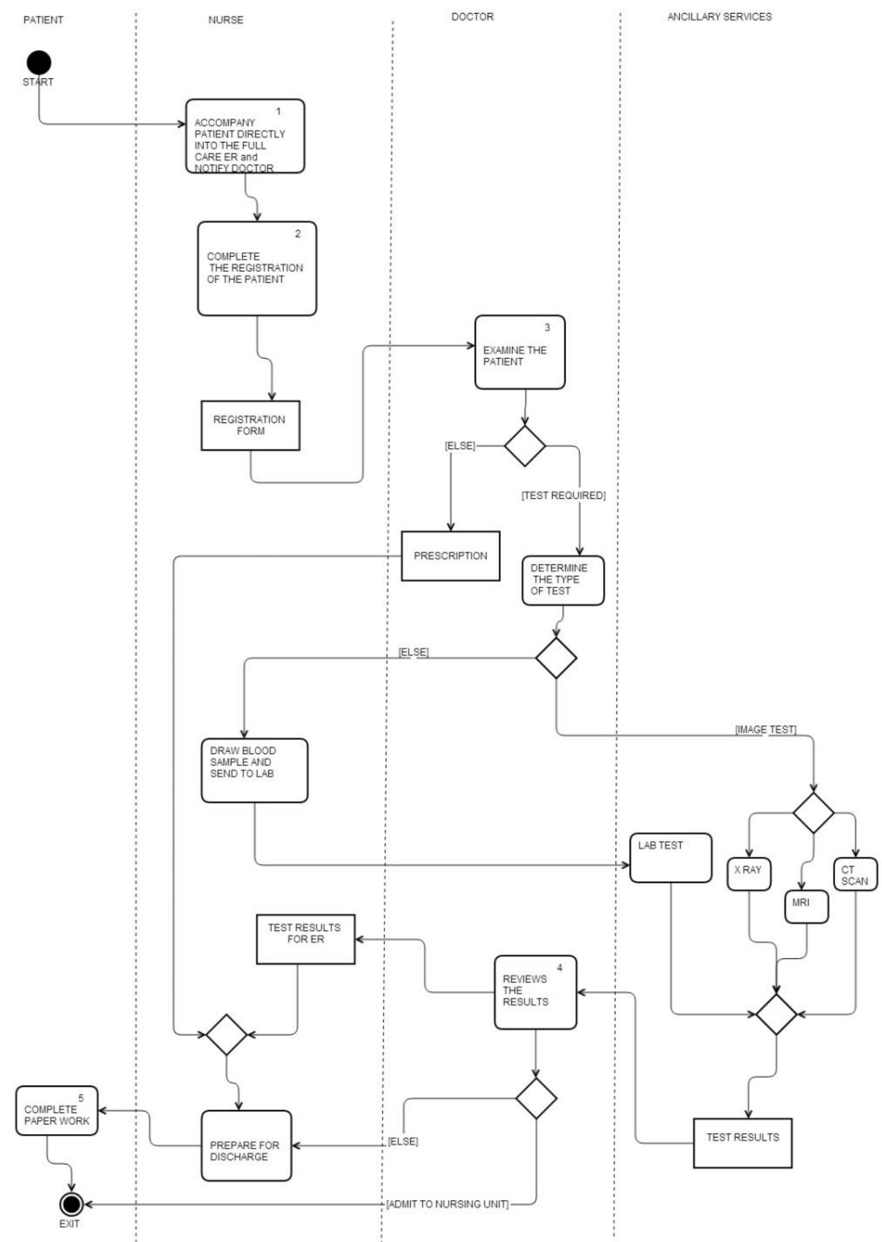


Fig 4.4 UML activity diagram for ambulance arrival patients

CHAPTER V

DATA COLLECTION AND ANALYSIS

Data collection is a critical part of any real-life case study. This chapter describes what data was collected and the mechanisms used in obtaining that data. Data obtained is usually raw data and often it has to be processed to produce useful information. This chapter also explains the data analysis that was conducted not only to obtain some insights into the SMC-ED operation, but also generate the input data needed for the simulation model. The data was collected using two methods; the historical data that was available from the ED authorities and the data collected by physical observation. The patient identity was not given by the authorities to ensure patient confidentiality. The SMC-ED authorities provided a year's worth of historical data of the Emergency Department for 28,569 patients in the form of an Excel® sheet. This data included timestamps of arrivals and exits of patients, acuity levels of patients, length of stay etc. Using this data the inter-arrival times of patients was calculated for every acuity level. The ED authorities also provided data which contained wait times of the patients before the beginning of every successive stage of the treatment process.

5.1 ED Resource Data

The ED at SMC houses a number of resources which are used by the patients and the ED staff during their visit. The resources that are utilized in the ED are as follows.

- Beds: The ED consists of 13 full-care emergency beds which are used by critical patients, i.e. patients with acuity levels from 1 to 3. The ED facility also has 2 fast-track beds which are reserved for non-critical patients needing immediate care.
- Nurses: For the smooth functioning of the ED, nurses are scheduled throughout the day to ensure timely treatment of patients. A registration clerk is present for 24 hours to admit the incoming patients. The nurses are responsible for carrying out the triage process and assigning acuity levels to patients. Nurses also perform various other activities such as checking vital signs and drawing blood. Table 5.1 provides the schedule for nurses which are used as an input to the simulation model.

Time of the day	**Number of Nurses**
3 am to 9 am	2
9 am to 11 pm	4
11 pm to 3 am	3

Table 5.1 Nurse Schedule

- Doctors: The ED facility at SMC ensures that there is at least one doctor scheduled throughout the day to provide care for admitted patients. The doctors ensure that the patients are given appropriate care and also order the necessary tests. One mid-level provider (MLP) is present who primarily sees fast-track patients. Table 5.2 provides the doctor schedule used as an input to the simulation model.

Time of the day	Number of Doctors
6 am to 10am	1
10 am to 11pm	2
1pm to 1am	1 MLP
11 pm to 6am	1

Table 5.2 Doctor Schedule

5.2 Patient Arrival

The ED has 2 modes for patient arrivals; walk-in and ambulance arrivals. Historical data was used to determine the patient inter-arrival distributions and arrival pattern by the hour.

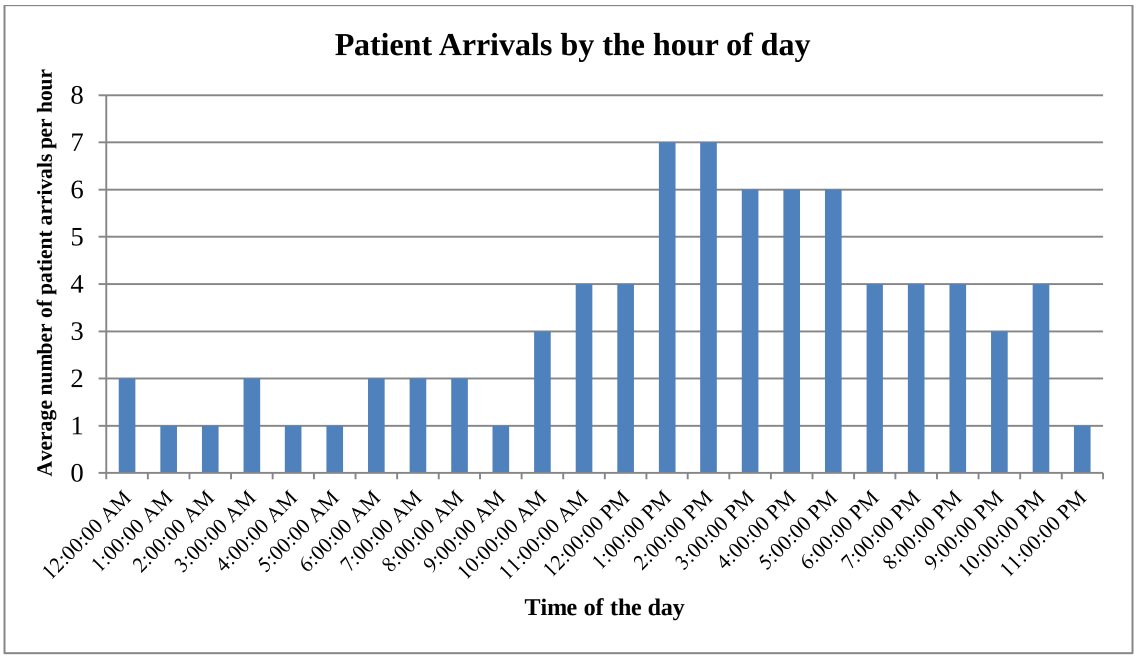


Fig 5.1 Average time varying arrival rates

The given data showed the varying arrival rates of the patients throughout the day and it was observed that the ED experienced higher arrival rates from 10 AM to 10 PM after which the arrivals gradually decreased as seen in Figure 5.1.

Every day the ED faces patients of diverse acuity levels which makes the streamlining a challenge due to higher priority assignments for patients of lower acuity levels. It has been observed that maximum arrivals to the ED are of patients with acuity levels 3 and 4; they constitute about 70% of total arrivals to the ED. Figure 5.3 shows the patient counts for different acuity levels. It was also observed that SMC-ED faced about 1,647 arrivals by ambulance annually.

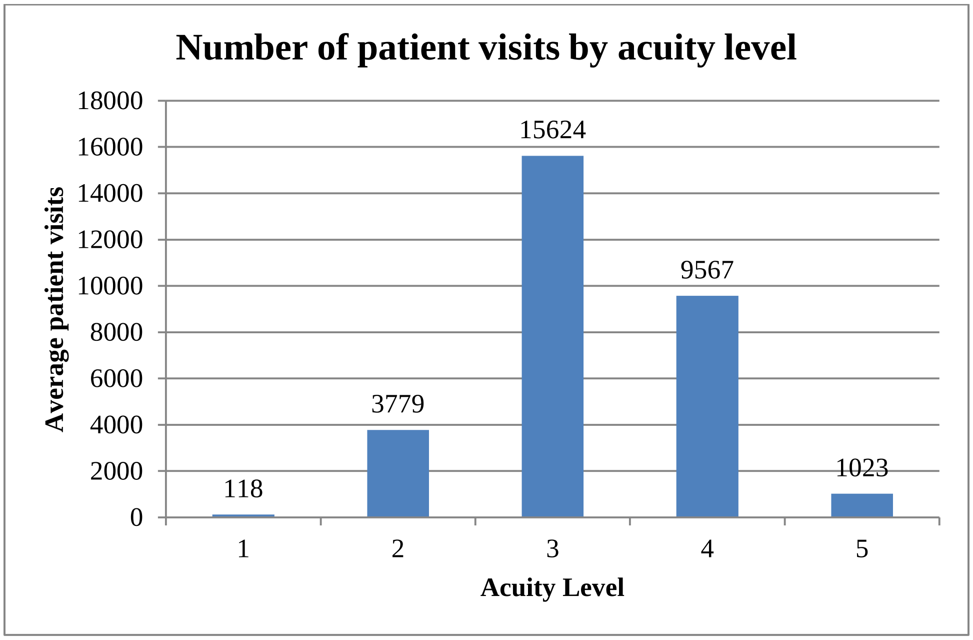


Fig 5.2 Patient visits for different acuity levels

Table 5.3 shows the distribution fitted for the inter-arrival times of patients for each acuity level. The distribution was fitted using StatFit ® software and the distribution was chosen based on the Anderson-Darling (A.D.) statistic and p value.

Acuity Level	AD statistic and P-value	Distribution
Acuity Level 1	0.219 and 0.985	Exponential
Acuity Level 2	0.501 and 0.746	Exponential
Acuity Level 3	0.308 and 0.932	Exponential
Acuity Level 4	0.333 and 0.863	Exponential
Acuity Level 5	0.324 and 0.919	Lognormal

Table 5.3 Patient arrival distributions for every acuity level

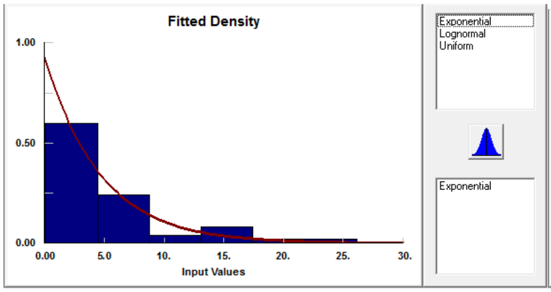


Fig 5.3a Acuity Level 1

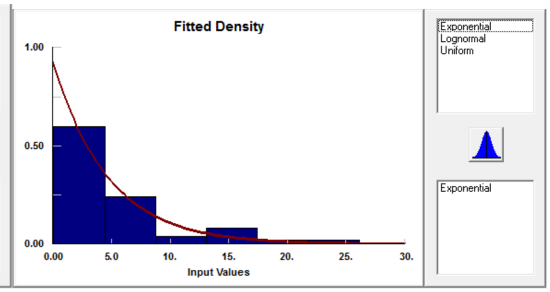


Fig 5.3b Acuity Level 2

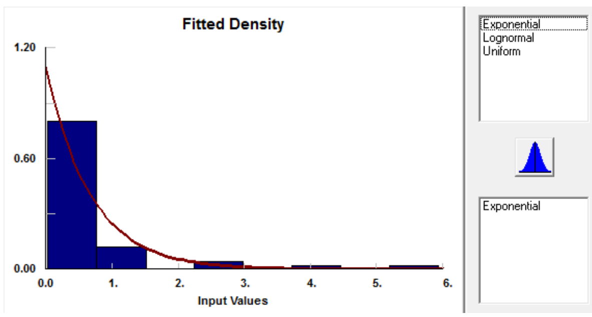


Fig 5.3c Acuity Level 3

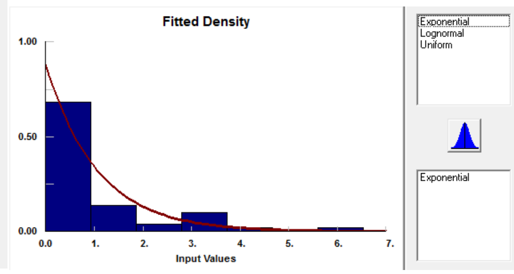


Fig 5.3d Acuity Level 4

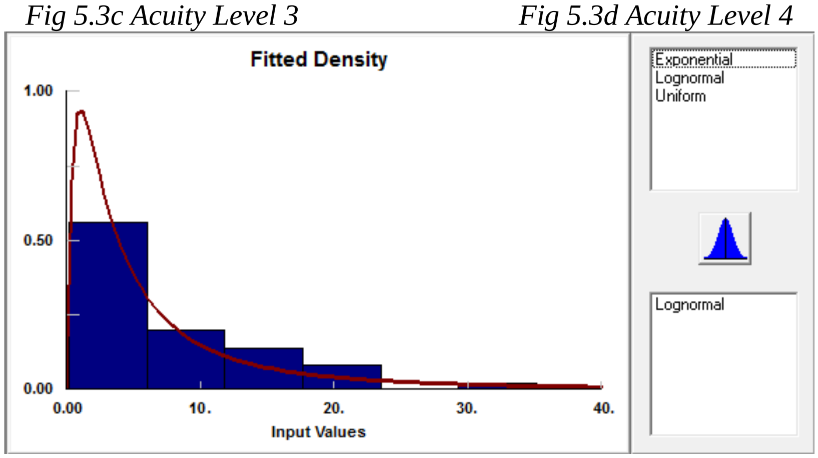
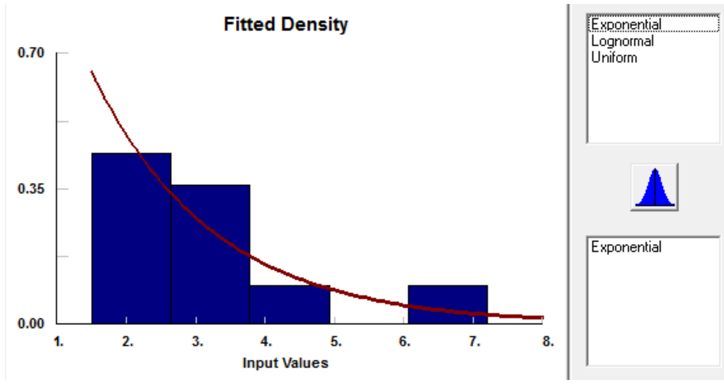


Fig 5.3e Acuity Level 5

Figure 5.3 Inter-arrival time distributions

5.3 Registration and Triage

The entry of the patient in the ED initiates the registration process where the patient fills out a form providing personal information and a brief note about his/her illness. The registration process is carried out by a registration clerk who is present for 24 hours. . Registration data was collected by physical observation for 200 patients Figure 5.4 shows the distribution fitted for the data collected for 200 patients using StatFit® software. It was observed that the patient takes a mean of 1.5 minutes to complete the registration process, Exponential distribution was chosen by the software since the rank of exponential distribution is greater than lognormal distribution.

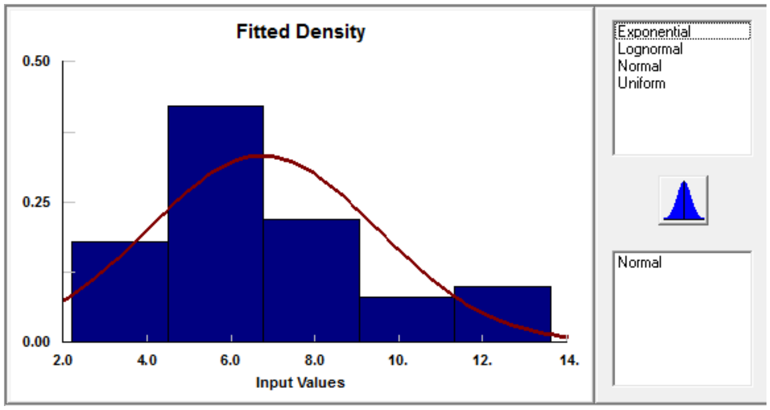


Auto::Fit of Distributions

distribution	rank	acceptance
Lognormal(0.985, 0.656, 0.569)	100	do not reject
Exponential(1.5, 1.75)	0.485	do not reject
Uniform(1.5, 7.2)	0.	reject

Fig 5.4 Registration time distribution

Once the patient has completed the registration step, the patient is then triaged by a triage nurse. The patient waits for the triage nurse to accompany him/her to the triage room where the patient is assigned the acuity level depending on the severity of illness. Observations were made for 100 patients and the time for each patient triaged was collected. Figure 5.5 shows the distribution chosen for the simulation model. The mean triage time was observed to be 11.45 minutes and comparing the ranks of the distributions normal distribution was chosen by StatFit ®.



distribution	rank	acceptance
Lognormal [-0.383,1.88,0.385]	100	do not reject
Normal [11.45, 3.65]	21.2	do not reject
Exponential [8.23, 2.42]	1.33E-02	reject
Uniform [1.25, 7.2]	0.0158	reject

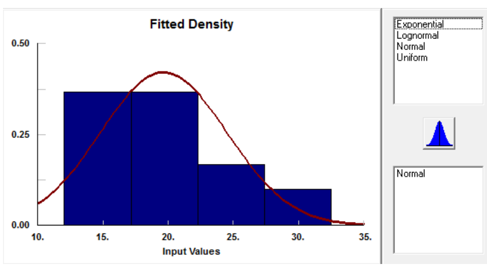
Fig 5.5 Triage time distribution

5.4 Patient Treatment

After the triage nurse completes the procedure of checking the patient for vital signs, performing preliminary tests and recording the observations made for doctors reference, the patient is assigned an ER and waits for the doctor to begin the treatment. The ED database does not record the time doctor takes for treating the patients, this data was collected over a week after observing the patients of different acuity levels. A total of 150 observations were made to determine the treatment time for patient of each acuity level. Table 5.4 summarizes the details of the times taken by the doctor for each acuity level. Fig 5.7 depicts the distributions for patient acuity levels 1 to 5 and Figures 5.7 a, 5.7 b, 5.7 c, 5.7 d, 5.7 e show the distributions chosen for the treatment of acuity levels 1, 2, 3, 4 and 5 respectively.

Acuity Level	Treatment Time (min, avg, max)	Chosen Distribution
1	(19.65, 32.35,43.22)	Normal
2	(17.72, 22.74, 31.52)	Normal
3	(10.52, 18.67, 23.34)	Lognormal
4	(7.46, 12.78, 19.35)	Normal
5	(6.27, 10.54, 16.22)	Uniform

Table 5.4 Treatment time distributions



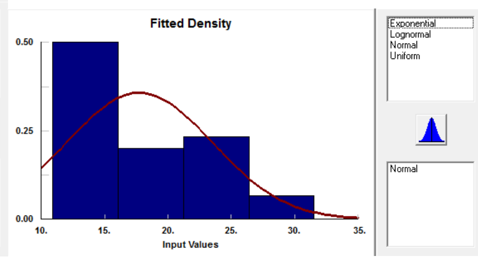
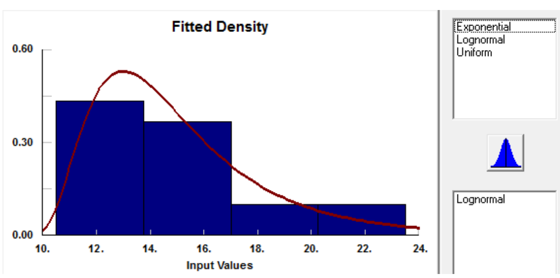


Fig 5.6a Acuity Level 1

Fig 5.6b Acuity Level 2



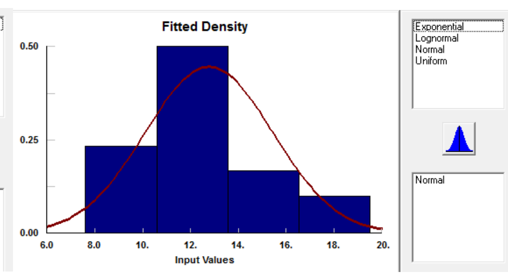


Fig 5.6c Acuity Level 3

Fig 5.6d Acuity Level 4

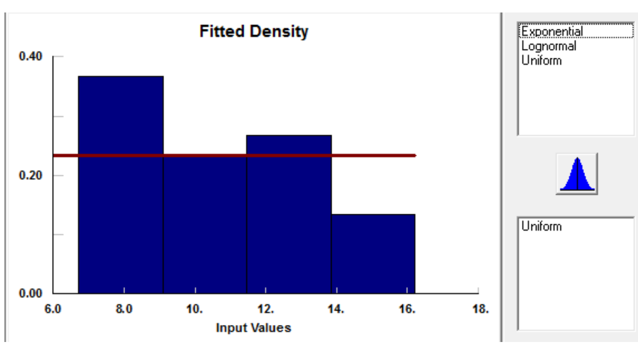


Fig 5.6e Acuity Level 5

Figure 5.6 Treatment time distributions

5.5 Waiting Times for patients between the successive stages

The LOS of patients is directly related to the patient treatment process followed at the SMC-ED. As discussed in the literature review section, there are various opportunities where contribution has been made to simplify the patient treatment process in the ED by modifying the existing procedures and sequences followed. After keen observation at various operations carried out at SMC-ED, some of the reasons that were responsible for holding patients at subsequent stages are identified. Some of the major causes of delays were observed to be unavailability of rooms especially the full-care ER rooms, and also the unavailability of the doctor or MLP to examine the patient for the first time. It was also identified that a lot of patients waited for considerably larger amount of time for the triage during the peak hours and it also included people having some critical conditions which needed immediate attention. Furthermore, as the ED approached its full capacity the time to see the doctor increased greatly. The reason for such long waiting times of the patients was probably the hierarchy of the acuity level that doctor followed for treating the patients. The ED recorded the waiting times for the patients at successive stages of their treatment process which are summarized in Table 5.5 as follows.

Description	Historical Average
Waiting time before registration (min)	Not captured in the system
Waiting time before triage (min)	24.23
Waiting time before assigning a room (min)	31.23
Waiting time for MLP/Nurse (min)	44.34

Table 5.5 Average waiting times at SMC-ED

After analyzing the data and observing the operations at SMC-ED it can be seen that patients face longer waiting times before a room is being assigned and before the doctor or an MLP visits for the first time. This research has modified the patient flow which has resulted in the reduction of waiting time of patients and thereby reduced the patient LOS. The model development and results obtained from modifications are discussed in the next chapters of the document. The SMC-ED recorded the disposition status of the patients who entered the ED. It was observed in the system that some patients left the ED after being triaged due to longer waiting times before a room was assigned. The patients who left the ED under such conditions were categorized as “Left Without Being Seen” (LWBS). From the literature reviewed lower LWBS ratio indicates better performance of the ED. Table5.6 captures the count of LWBS patients by acuity level that was recorded and it was observed that 2.42% of patients were categorized as LWBS.

Acuity Level	Historical Data
1	1
2	7
3	294
4	279
5	111
Total LWBS	692
% of LWBS	2.42%

Table 5.6 LWBS patients for different acuity levels

CHAPTER VI

MODEL DEVELOPMENT AND VALIDATION

This chapter describes the simulation model which replicates the processes that occur in ED to the desired accuracy level. The simulation model developed represents the current ED operations in practice at the Stillwater Medical Center. The model developed captures the processes starting from the patient arrival until the patient exits the ED. The baseline model developed in SIMIO captures the processes which are common to most of the ED's throughout the country (Wang et al, 2013). To understand the system that is to be modeled, it is necessary to get a clear idea of processes that take place in the ED. Understanding of the processes facilitated the development of UML Activity diagrams which captured each activity that a patient undergoes.

6.1 Baseline Simulation Model Development

The activity diagrams for the different patient types were discussed in Chapter IV of the document. To model the patient flow process Simio ® software was used. The arrival of the patient occurs through the "Source" object which allows the creation of entities in Simio (Simio Reference Guide version 6, 2013). The model triggers one entity per arrival. The patient arrival occurs with reference to the "Rate Table" specified in the source object. The rate table captures the average arrival rates of patients per hour of the day for a 24 hour period. Figure 6.1 shows the Registration and Triage layout developed in Simio.

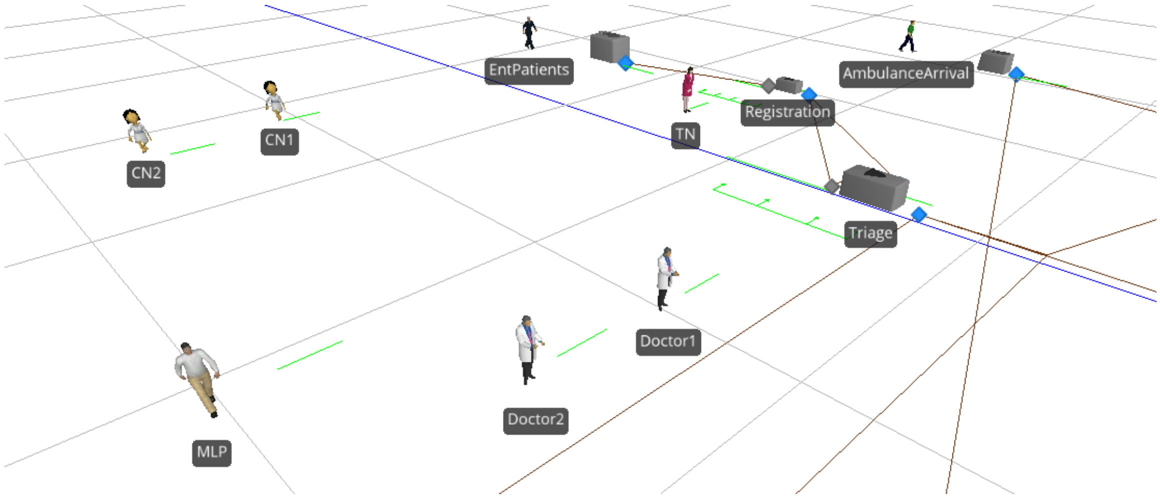


Fig 6.1 Registration and Triage layout

The patient is then directed to the Registration desk where a registration nurse is present for 24 hours. After completing the registration process, the patient waits in the waiting area for a triage nurse to accompany him/her to the triage room for initial assessment. The registration desk is a “Server” object which is a capacitated resource with input and output buffers (Simio Reference Guide version 6, 2013). The capacity of the server is specified to be one and the time for registering is specified in the processing time field. Resources such as nurses, doctors and mid-level provider (MLP) are modeled using the “Worker” object which is a dynamic resource which can be seized and released during the simulation in Simio (Simio Reference Guide version 6, 2013). The triage nurse accompanies the patient to the triage area which is represented as a server and begins the triage process for the specified time. Triage nurse remains with the patient until the process is completed and this is achieved by using the “Seize” step. Once the patient completes the triage process, depending on the acuity level of the patient they are directed to a specific set of rooms created using a “Node List”. The triage nurse then returns to the specified home node and waits until there is a patient waiting to be accompanied to the triage room. The output at the registration desk is specified as the “Home” node for triage nurse. The patients are then categorized into emergency patients and fast-track patients; emergency patients are directed to one of the rooms specified using the node list created and the same logic applies for fast-track patients. Figure 6.2 shows the treatment area layout developed in Simio.

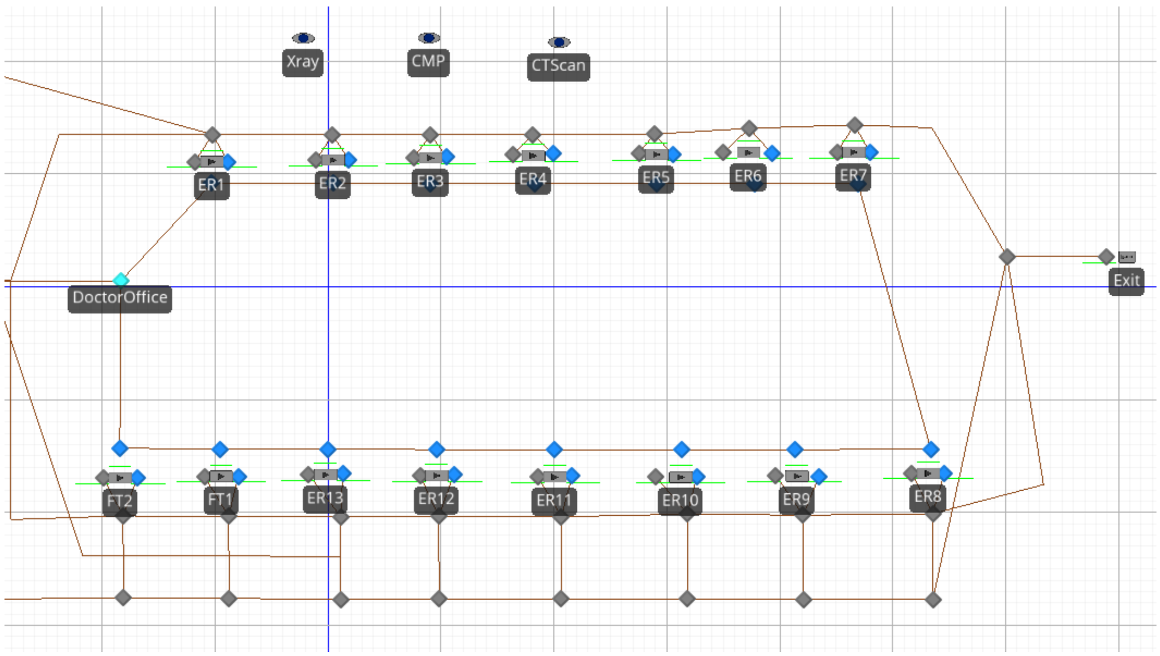


Fig 6.2 Treatment area layout in Simio

Once the patient enters one of the rooms a “Charge Nurse” is seized at the specific server. The logic of seizing the worker has been extended to first serve the patient with a lower acuity level by assigning a “State Variable” indicating the acuity level of the patient. The nurse then conducts a detailed examination of the patient by referring to the triage report, which is followed by a doctor visiting the specific ER. A separate node has been created as a “Doctor office” in the model where the doctor stays if he/she is not treating a patient. The model also includes a mid-level provider who is designated to treat fast-track patients upon their visit to fast-track rooms. Specific “Node Lists” for Full-care and Fast-track emergency patients are created to seize the respective resources in the preferred order and depending on their availability. Once the patient is in the room the resources are seized with reference to the lists created for specific patient types. The model also captures the ambulance arrivals using a different source object.

Because of insufficient data on the interarrival times of patients arriving by ambulance it is specified that 4 patients in a day enter the ED through this mode of arrival. The patients arriving through the ambulance are directly sent to full-care ED rooms and given a higher priority. The treatment procedure is initiated once when the doctor is seized at a particular server. The processing times have been mentioned for the different acuity levels by using the distribution selected by StatFit ® software. A data table is created which includes the percentage of patients of different acuity levels arriving to the ED, the node lists specifying the respective rooms for every acuity level of patients and the percentage of patients requiring ancillary services. During the treatment procedure the doctor decides if the patient requires ancillary services such as X-Ray, Comprehensive Metabolic Panel (CMP) or CT scan, all these ancillary resources have been modeled as "Fixed Resource" objects which cannot move in the simulation model and each of these resources is seized based on the historical data contained in the data table. The fixed resources are seized using the "Decide" step modeled in the "Processes" tab of the software. The logic used is such that the model will decide whether the patient is a "Walk-In" or an "Ambulance-arrival" patient. The percentages of the patients needing ancillary services are obtained using the data tables created for Walk-In and Ambulance arrivals. A nurse is seized at the particular server requesting an ancillary procedure and the resources are seized using the decide step in the process to check what ancillary tests are required and also based on the acuity levels of patients assigned before entering the ED rooms. If the patient does not require any additional tests both the doctor and the nurse are released and the patient goes through the billing procedure which is accounted as a "Delay" step in the model. If the patient requires an additional test then the nurse waits until the test procedures are completed the doctor then visits the particular server. There is a delay of a specified time indicating review of results after which both the doctor and the nurse are released from the server and patient completes the billing procedure and exits the system using the "Sink" object which destroys the entities after carrying out the processes modeled (Simio Reference Guide version 6, 2013). All the doctors, nurses and MLP's follow a work schedule which is currently in operation at the SMC-ED.

6.2 Model Validation and Results

The goal of validating a simulation model is to ensure that the model built behaves in the same way as the actual ED in operation. The model results were discussed with subject matter experts to assess its accuracy. The model was validated by the staff of SMC-ED based on live demonstration and follow-up discussions. As mentioned in Chapter V, a year's worth of historical data was available. Hence, it was also possible to validate the simulation model by comparing its output to those derived from historical data. As discussed in Chapter V the patient arrivals were used as an input to developing the model and hence it is possible to compare the actual visit counts with that observed in the simulation model (often referred to as the baseline simulation model). The key performance indicators (KPI's) considered in this research is the patient LOS and the waiting times at subsequent stages during their visit to the ED. The hospital database also records the patient disposition status after the treatment which includes LWBS. Historical values for LOS and waiting times at subsequent stages could be compared for validating the model with simulation estimates. The model was simulated for one year with a warm up period time of 3 months. Table 6.1 summarizes and compares the number of patient arrivals obtained from the simulation model with the historical visit counts.

Acuity Level	Actual Data	Baseline Simulation
1	118	120.65
2	2452	2459.57
3	15409	15451.84
4	9567	9599.72
5	1023	1034.61

Table 6.1 Number of arrivals of patients throughout a year

From Table 6.1 it could be observed that the total number of patients visiting the ED in a year is close to the historical visit counts in each acuity level. From the existing data it was possible to calculate average number of patients at any time in the system. Table 6.2 shows the average number of patients in the system calculated from the historical data and the simulation estimates

Annual visit count	Walk-In Patients		Ambulance Patients	
	Historical Data	Baseline Simulation Model	Historical Data	Baseline Simulation Model
Visits throughout the year	28569	29465	1542	1550
Average Number in System (any given time in the day)	13.324	13.309	1.056	1.061

Table 6.2 Visit counts and average number in ED

The results obtained from the model captured the average LOS of the patients which is considered to be one of the key performance indicators (KPI's). Table 6.3 shows the average LOS of the patient and compares with the historical data obtained from the system.

Patient Type	Historical Average LOS (hrs)	Average LOS observed (hrs)	% Difference
Full-care ER Patient	4.35	4.37	1.63%
Fast-track Patient	0.92	0.90	2.17%

Table 6.3 Average LOS of patients

It can be observed that the average LOS for the patients obtained by simulation model is very close providing additional evidence that the model is performing as per the system in operation. The hospital database also recorded the waiting times of the patients before every subsequent stage. Table 6.4 shows the waiting times observed at every stage of the treatment process.

Description	Historical Average Wait Times	Baseline Simulation Model
Average Waiting time before registration (mins)	Not captured in the actual system	3.87
Average Waiting time before triage (mins)	24.23	17.57
Average Waiting time before assigning a room (mins)	31.23	30.65
Average Waiting time for Doctor/MLP/Nurse (mins)	44.34	44.24

Table 6.4 Wait times of patients at subsequent stages

From the waiting times in Table 6.4, it can be observed that the patient waits for a considerably longer time before being assigned a room and also before he/she is seen by the doctor. This indicates two potential points/stages in the process to focus for waiting time reduction strategies. The next chapter explains the strategies identified that could possibly reduce these waiting times and hence, reduce the LOS.

From the historical data it was observed that patients left the ED after being triaged due to longer waiting times before a particular room was assigned to the patient based on the acuity level. By creating a state variable in Simio ® which tracked the waiting time of the patients, it was determined through a trial and error technique, that if a patient left upon waiting for 1.5 times the average waiting time before assigning a room, then the LWBS percentage from the simulation was close to historical values. Table 6.7 summarizes the number of patients who were categorized under LWBS section and compares with the results observed in baseline simulation model. From the table it can be understood that majority of the patients constituted in acuity levels 3 and 4. From the literature reviewed it was understood that LWBS depends on various other factors than just the waiting time of patients, this research did not consider any other factor other than the waiting time of patients before assigning a room.

Acuity Level	Historical Data	Baseline Model
1	1	0
2	7	6
3	294	291
4	279	281
5	111	106
All levels LWBS	692	684
All levels LWBS (%)	2.42%	2.38%

Table 6.5 LWBS comparison

CHAPTER VII

LENGTH OF STAY REDUCTION STRATEGIES

This chapter presents the strategies identified with reference to the current SMC-ED operations represented by the baseline simulation model that would aid in the reduction of waiting times, thereby decreasing the LOS of patients. These strategies were developed based on the observations made from the historical data and insights obtained from the baseline simulation model. In doing so, we analyzed the components of the length of stay that were estimated using the baseline simulation model and identified the areas of improvement that could potentially reduce the waiting time of the patients. Figure 7.1 shows the components of the length of stay of patients observed in the baseline simulation model.

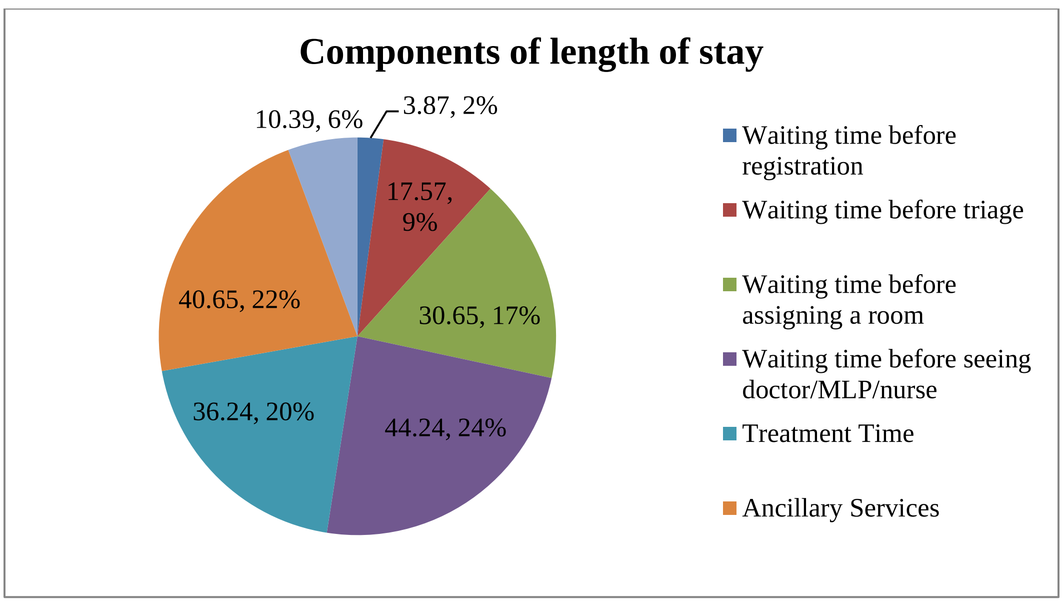


Figure 7.1 Components of length of stay

7.1 Additional Triage Station to Treat Less Emergent Patients

From the historical data it was observed that about 24% of the fast track patients were categorized as less emergent. The patients considered in this category were those identified with a minor illness such as a sprain in the leg, headache, general checkup, dental caries, mild fever and toothache. In the existing system at the SMC-ED, each patient goes through the same triage station irrespective of their stated condition. Under the assumption that the patient's stated reason for visiting the ED is fairly reliable, the following modification is proposed. This modification includes an additional triage station exclusively dedicated for less emergent patients who are seen by an MLP or a triage nurse. The patient is treated at the triage station and then the patient is discharged from the ED. Figure 7.2 shows the flowchart for the proposed additional triage station.

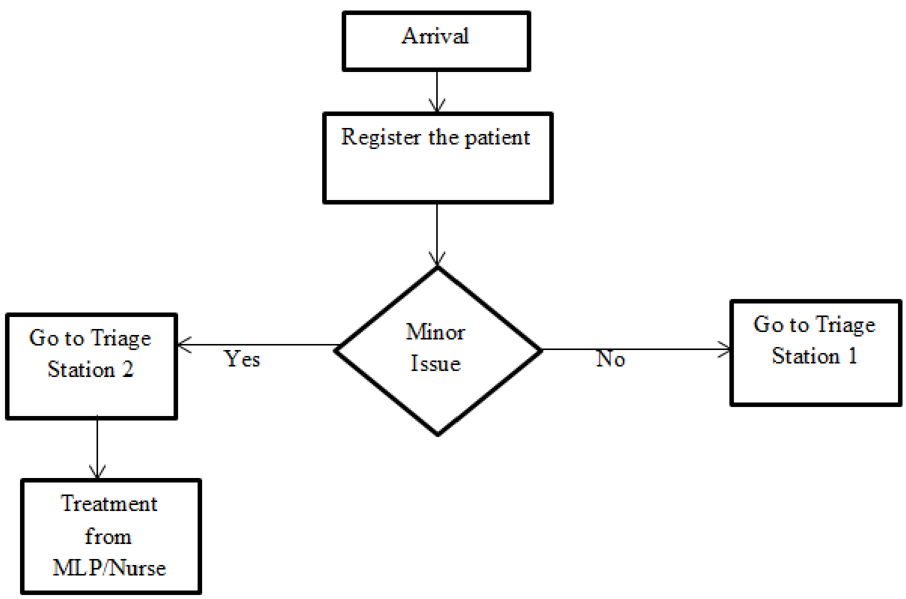


Fig 7.2 Modified treatment process with additional triage station

The average waiting time for the patients before triage was observed to be 17.57 minutes and the average waiting time before assigning the room was observed to be 30.65 minutes. The motivation for adding an additional triage station was to not only reduce the waiting time before triage and but also the waiting time before a room is assigned by potentially reducing the number of patients who need a room assigned.

It was observed that the average waiting time before triage was reduced by approximately 7 minutes and average waiting time before a patient was assigned a room was also reduced by approximately 6 minutes. The LWBS ratio reduced from 2.38% to 1.68%. The threshold waiting time was set to 1.5 times the average waiting time before assigning the room observed in the baseline simulation model. Table 7.1 summarizes the results obtained for the additional triage model.

Description	**Baseline**	**Additional Triage**
Average waiting time before registration (min)	3.87	3.89
Average waiting time before triage (min)	17.57	10.62
Average waiting time before assigning a room (min)	30.65	24.62
Average waiting time for Doctor/MLP/Nurse (min)	44.24	32.23
LWBS	2.38%	1.38%

Table 7.1 Comparison of waiting times after adding a triage station

The simulation was carried out for 1 year and the LOS for the patients of every acuity level was observed. Table 7.2 summarizes the LOS observed for every acuity level of patient and compares it with baseline simulation model. Table 7.3 summarizes the LOS observed for full-care ER patients and the fast-track patients and Table 7.4 summarizes the overall LOS.

Acuity Level	Baseline	Additional Triage
1	4.39	3.67
2	4.21	3.36
3	4.52	4.21
4	1.01	0.82
5	0.79	0.64

Table 7.2 LOS (hrs) by acuity level with an additional triage station

The average waiting time for doctor/ MLP/ nurse in the room was reduced because of the reduction of the number of patients who were admitted in the room. The less emergent patients are discharged after treatment in the additional triage station, which would reduce the number of patients the doctor or MLP had to see in rooms.

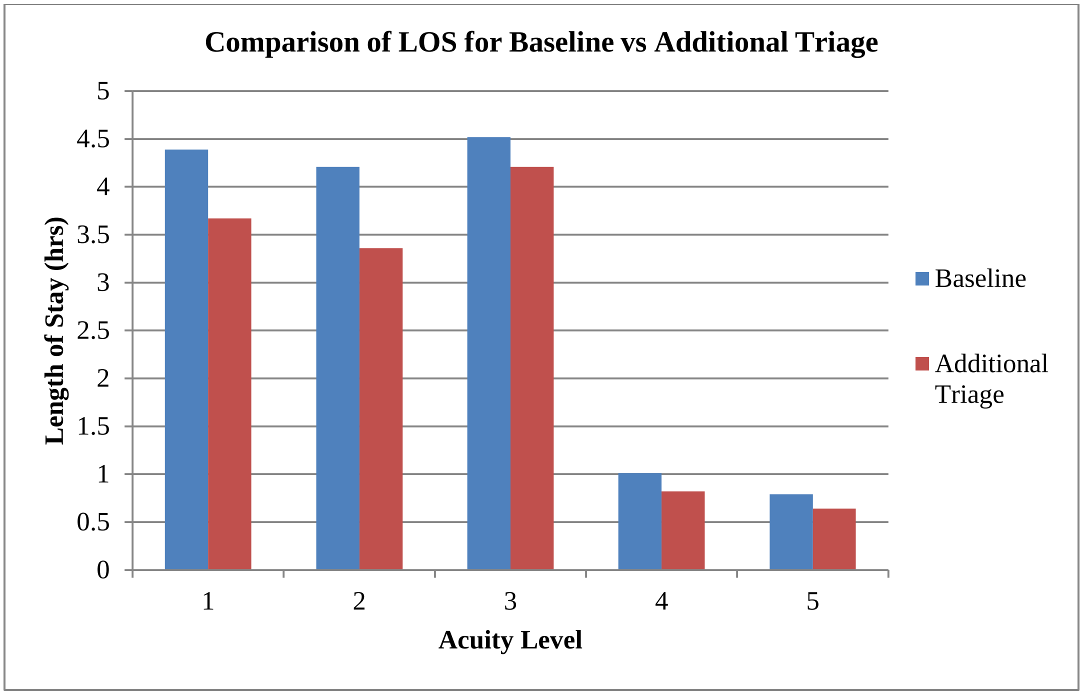


Figure 7.3 Comparison of LOS by acuity level with an additional triage station

Category	Baseline	Additional Triage
Full-care ER Patients	4.37	3.76
Fast-track Patients	0.9	0.75

Table 7.3 Comparison of LOS for full-care and fast-track patients with an additional triage station

	Baseline	Additional Triage
Length of Stay (hrs)	3.01	2.62

Table 7.4 Overall LOS of patients with an additional triage station

From the results obtained above it can be observed that there is significant drop in LOS of patients of acuity levels 1 and 2 this is observed due to the fact that the addition of triage station has increased the availability of rooms to the patients and the doctor will prioritize higher acuity level patients over lower acuity patients and hence, this explains the drop of LOS for patients of acuity levels 1 and 2. It is also observed that the overall LOS reduced from 3.01 hours to 2.62 hours indicating a 13% decrease in LOS of patients.

7.2 Additional Doctor During Peak Hours

To further the scope of this research and identify alternate strategies that could aid in the reduction of waiting time of patients, we explored the common strategy of adding resources, but we did so when it was needed the most; we analyzed the impact of adding an extra doctor during the peak hours. The data collected showed that the ED faced a greater number of arrivals during the day until 10 pm. The patients waited a longer time to see the doctor for the first time, which was caused due to provider unavailability. Previous research has been done to address this issue which was discussed in literature review. Figure 7.4 shows the observed average daily arrivals in the baseline simulation model by the hour of the day.

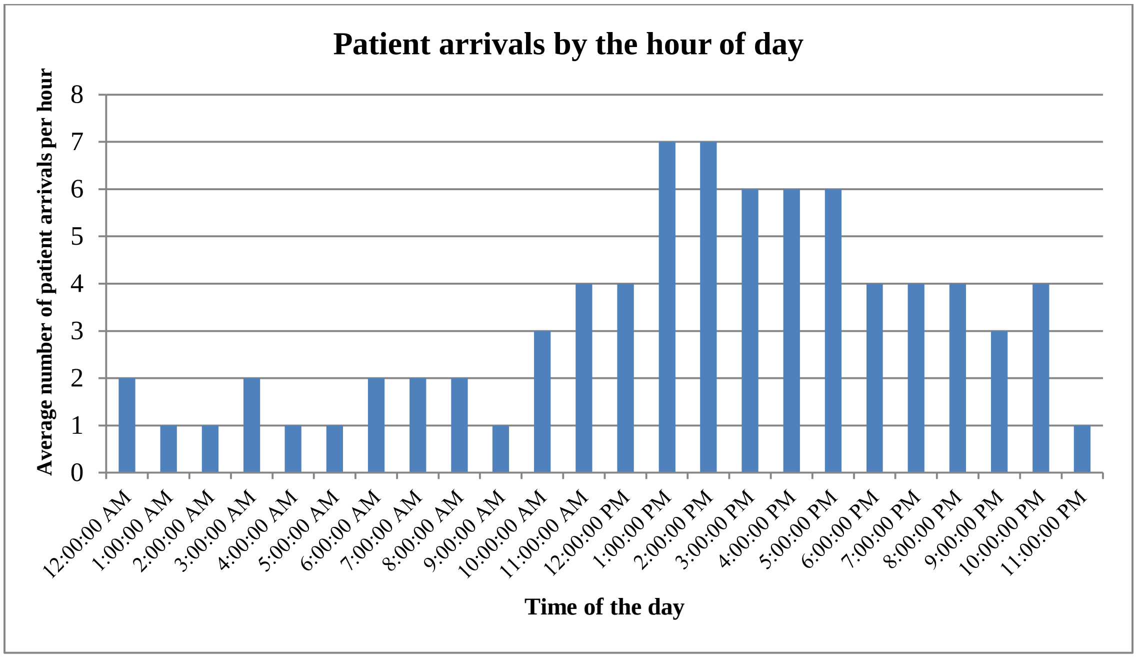


Fig 7.4 Average patient arrivals by the hour of day

From Figure 7.4 it can be observed that the ED faces larger number of arrivals from 10:00 am until 10:00 pm. Hence, we add an extra doctor for an 8-hour period from 1 pm until 9 pm. The simulation was carried out for 1 year and the results were tabulated. Table 7.5 shows the average waiting times observed in this additional doctor model and compares it with baseline simulation.

Description	Baseline	Additional Doctor
Average waiting time before registration (min)	3.87	3.89
Average waiting time before triage (min)	17.57	16.62
Average waiting time before assigning a room (min)	30.65	21.43
Average waiting time for Doctor/MLP/Nurse (min)	44.24	27.63
LWBS	2.38%	1.42%

Table 7.5 Waiting times with an additional doctor

From Table 7.5 we can see that there is an average decrease of almost 9 minutes in waiting time before assigning a room and a decrease of almost 17 minutes before seeing a doctor. This is due to the fact that the addition of the resource has increased the availability of the doctor. As there is no role of the doctor until the patient is triaged and enters the room there is no significant change in the waiting time before triage. The LWBS ratio dropped from 2.38% to 1.42% mainly because of the reduction in waiting time before getting a room assignment. Table 7.6 summarizes the LOS by acuity level of the patient and compares it with the baseline model. It should be noted that due to the addition of an extra doctor during the peak hours, the LOS of patients of acuity levels 1, 2 and 3 has been reduced significantly, but there is a slight increase in the LOS of the fast-track patients. The additional doctor in this model prioritizes the more urgent cases and hence, there is no significant change in LOS of fast-track patients.

Acuity Level	Baseline	Additional Doctor
1	4.39	3.06
2	4.21	3.34
3	4.52	3.87
4	1.01	0.92
5	0.79	0.80

Table 7.6 LOS (hrs) by acuity level with an additional doctor

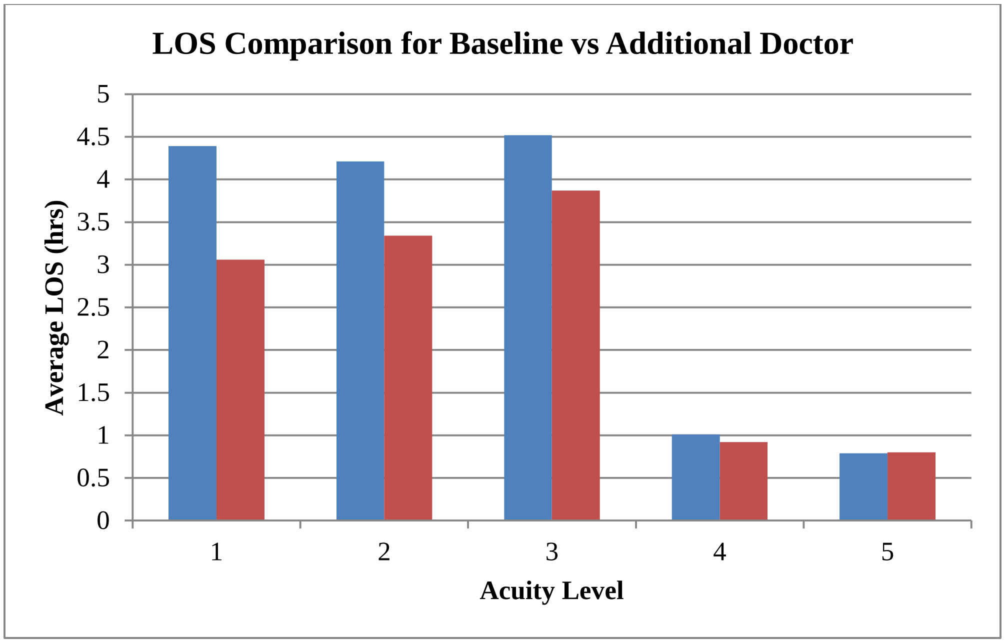


Fig 7.5 Comparison of LOS (hrs) by acuity level for baseline and additional doctor models

The simulation model also captured the LOS of full-care ER and fast-track patients which are summarized in Table 7.7 the addition of a doctor during peak hours has made the doctor more accessible to the full-care ER patients. However, there is not much of a change observed in LOS of fast-track patients. The overall LOS decreased by approximately 15% as shown in Table 7.8

Category	Baseline	Additional Doctor
Full-care ER Patients	4.37	3.61
Fast-track Patients	0.9	0.87

Table 7.7 Comparison of LOS (hrs.) for fast-track and full-care patients in baseline and additional doctor models

	Baseline	Additional Doctor
Length of Stay (hrs)	3.01	2.55

Table 7.8 Overall LOS comparison for baseline and additional doctor models

7.3 Nurses Dedicated to Fast-Track Patients

From the baseline model it was observed that patients waited for an average of nearly 18 minutes before the triage process was carried out by a nurse. The current staffing of the SMC-ED has nurses treating all types of patients and during the peak hours nurse availability becomes an issue. As this research is focused on reducing LOS by reducing waiting times of patients, this explored the modification of the existing staffing pattern of the nurses without adding any additional nurse. From the nurse schedule obtained from the SMC-ED there are 4 nurses staffed during the peak hours, 2 nurses from 3am to 9 am and 3 nurses from 11pm to 3 am. It was observed that most of the fast-track patients entered the ED from 10 am till 7 pm and hence because of the conventional way of attending the patients it was observed that the fast-track patients faced an issue of nurses unavailability due to the prioritization of full-care patients over fast-track patients. Figure 7.6 shows the average arrival rate of fast-track patients throughout the day. This data was obtained from the baseline simulation model.

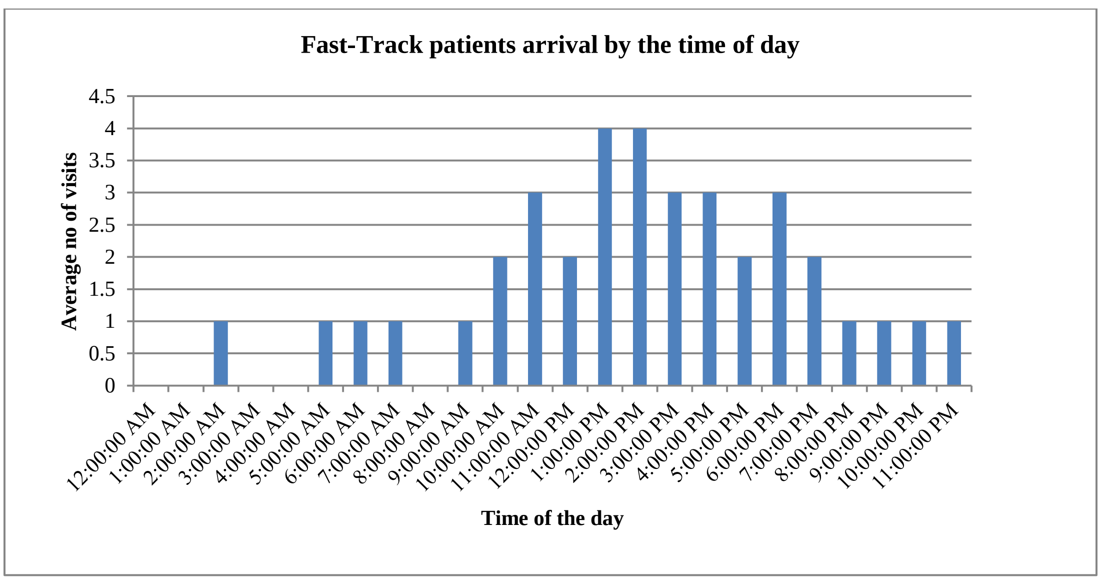


Figure 7.6 Average arrival rates of fast-track patients observed in baseline model

Our proposed strategy does not add any additional nurse, but modifies the existing practice in order to reduce the waiting time of the patients. As it is observed that there is a significant portion of the patients who are entering the ED due to minor issues, by dedicating nurses just for the Fast -Track patients this model attempts to reduce the overall LOS of the patient.

Time of the day	Number of Nurses
3 am to 9 am	1 Full-care ER Nurse, 1 Fast-track Nurse
9 am to 11 pm	3 Full-care ER Nurses, 1 Fast-track Nurse
11 pm to 3 am	2 Full-care ER Nurses, 1 Fast-track Nurse

Table 7.9 Revised Nurse Schedule

Description	Baseline	Dedicated Nurses
Average waiting time before registration (mins)	3.87	3.88
Average waiting time before triage (mins)	17.57	12.62
Average waiting time before assigning a room (mins)	30.65	27.28
Average waiting time for Doctor/MLP/Nurse (mins)	44.24	39.61
LWBS	2.38%	1.26%

Table 7.10 Waiting time with a nurse dedicated to fast track patients

Table 7.11 summarizes the length of stay of patients for patients of all acuity levels and also establishes a comparison between the baseline and dedicated nurse models. Table 7.12 shows the results for full-care and fast-track patients. While the LOS of fast-track patients has reduced, there is a slight increase in the LOS of full-care patients due to the reduced flexibility of the nurses to attend the full-care patients. From Table 7.10 It can be seen that there is a decrease in the LWBS ratio which is one of the positive indicators for patient satisfaction.

Acuity Level	Baseline	Dedicated Nurse
1	4.39	4.34
2	4.21	4.12
3	4.52	4.71
4	1.01	0.87
5	0.79	0.61

Table 7.11 LOS (hrs) comparisons for baseline and dedicated nurse

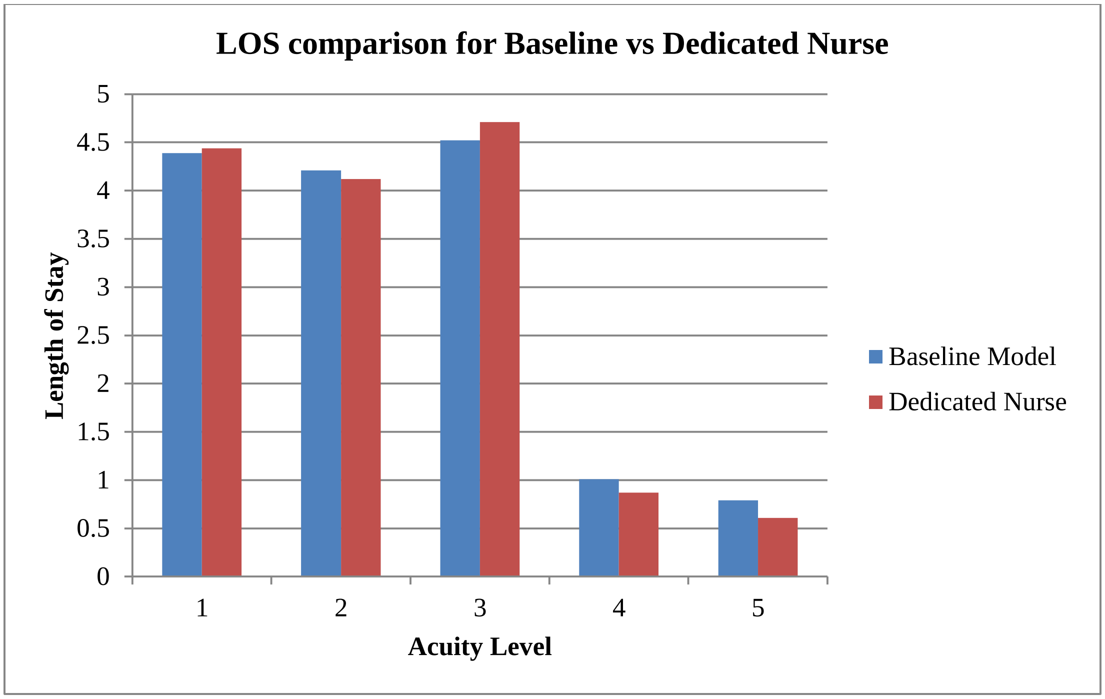


Figure 7.7 Comparing LOS (hrs.) with a dedicated nurse

Description	Baseline	Dedicated Nurse
Full-care ER Patients	4.37	4.41
Fast-track Patients	0.9	0.75

Table 7.12 LOS for full-care and fast-track patients' with a dedicated nurse

Table 7.13 presents the overall LOS of the patients nurses for fast-track patients the baseline and dedicated nurse models.

	Baseline	Dedicated Nurse
Length of Stay (hrs)	3.01	2.79

Table 7.13 Overall LOS for baseline and dedicated nurse

The slight decrease in the overall LOS is mainly due to the reduction in the LOS of fast-track patients.

7.4 Nurse with priority for Fast-track Patients

The dedicated nurse strategy reduces the flexibility by assigning one nurse to only attend to fast track patients. This variation allows the designated nurse to prioritize fast-track patients over full-care patients. However, when there are no fast-track patients and if there is full-care patient waiting then the nurse attends to full-care patient. The nurse schedule follows the same pattern as indicated in the dedicated nurse model with the modification as discussed above. In order to achieve overall reduction in the LOS of patients this model was simulated for one year and the results were tabulated. This model showed an increased availability of nurses to the patients and hence the waiting time of the patients reduced, thereby achieving reduction in the overall LOS. Table 7.14 summarizes and compares the waiting time observed in the case of prioritized nurse model with the baseline model.

Description	Baseline	Nurse with fast-track priority
Average waiting time before registration (mins)	3.87	3.88
Average waiting time before triage (mins)	17.57	12.49
Average waiting time before assigning a room (mins)	30.65	23.24
Average waiting time for Doctor/MLP/Nurse (mins)	44.24	36.54
LWBS	2.38%	1.18%

Table 7.14 Waiting times for a nurse with priority for fast-track patients

It can be observed that there is a reduction of 5 minutes before the patient is triaged and almost 7 minutes reduction in waiting time before assigning a room. It can be noted that waiting time for doctor has been reduced nearly by 8 minutes due to increased availability of nurses. The LWBS has dropped to 1.18% indicating better patient satisfaction.

Acuity Level	Baseline	Prioritized Nurse
1	4.39	3.65
2	4.21	3.73
3	4.52	3.87
4	1.01	0.92
5	0.79	0.68

Table 7.15 LOS comparison by acuity level with a nurse with priority for fast track patients

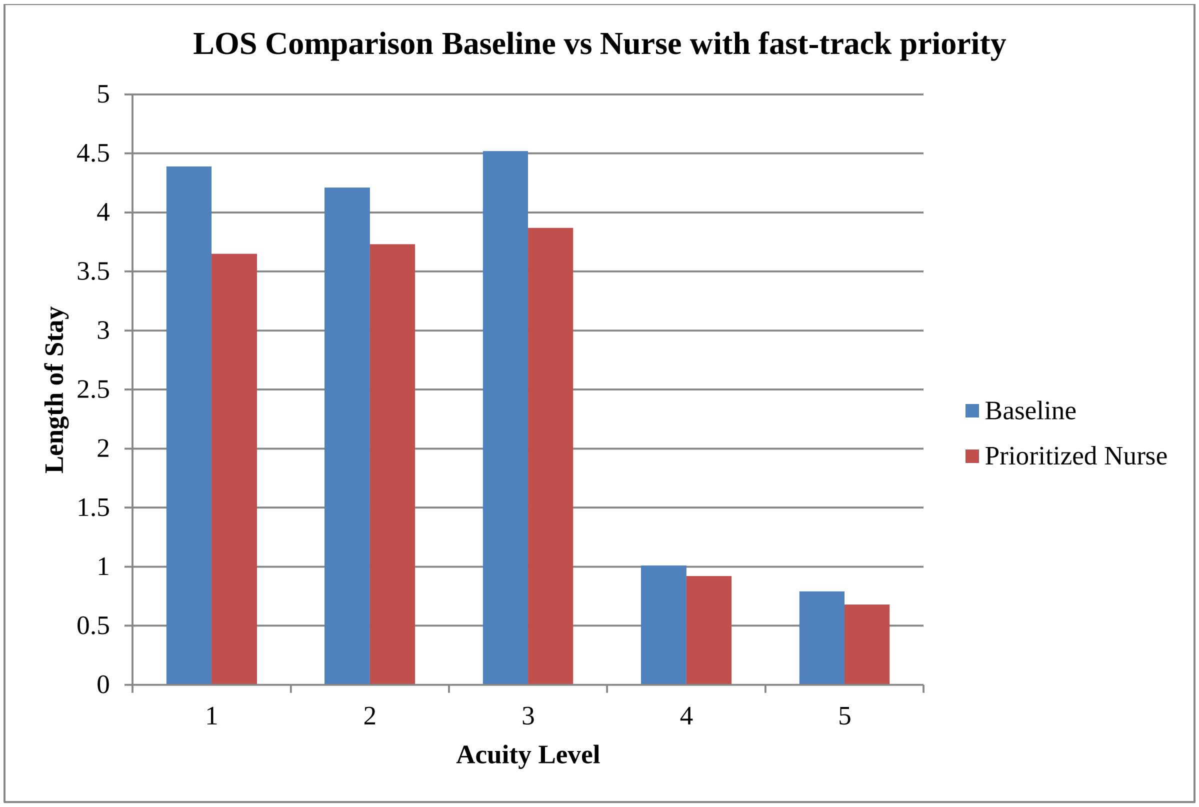


Figure 7.8 LOS (hrs.) by acuity level with a nurse with priority for fast track patients

Table 7.16 summarizes the LOS for the full-care and fast-track patients and it can be clearly observed that there has been a reduction in the LOS for both the categories. The overall LOS has been reduced from 3.01 hours to 2.61 hours as indicated in table 7.17. It is observed that the LOS of the fast-track patients has been slightly increased in comparison with the dedicated nurse strategy, there is a reduction in the overall LOS mainly because the nurse also treats a full-care patient when there is no fast-track patient waiting in the ED.

Description	Baseline	Nurse with fast track priority
Full-care ER Patients	4.37	3.72
Fast-track Patients	0.9	0.81

Table 7.16 LOS (hrs.) for Full-care and Fast-track patients' with a nurse with priority for fast track patients

	Baseline	Nurse with fast track priority
Length of Stay (hrs)	3.01	2.65

Table 7.17 Overall LOS for baseline and nurse with priority for fast track patients

7.5 Combination of Additional Triage and Prioritized Nurse for Fast-track

With various alternative strategies for LOS reduction developed and evaluated, we now evaluate the impact of combining two strategies developed; additional triage station and the nurse with fast track priority. The logic for the proposed strategy still remains the same as those discussed in the individual strategies; combined additional triage and nurse with fast track priority. The strategy assumes the same modification in the nurse schedule as discussed in the section 7.3. The main advantage of this combination is the increased availability of resources such as nurses, rooms and doctors. The patients waited less time and hence there was a notable reduction in the LOS. Table 7.18 summarizes wait times at subsequent stages and compares it with baseline model.

Description	Baseline	Additional Triage + Nurse with a priority for fast track
Average waiting time before registration (mins)	3.87	3.86
Average waiting time before triage (mins)	17.57	11.23
Average waiting time before assigning a room (mins)	30.65	19.32
Average waiting time for Doctor/MLP/Nurse (mins)	44.24	28.82
LWBS	2.38%	1.02%

Table 7.18 Waiting time for Additional Triage + Nurse with a priority for fast track

It can be clearly seen from Table 7.18 that there has been significant reduction in waiting time before assigning a room and waiting time before seeing a doctor/MLP/nurse. The LOS comparison for patient of each acuity level has been summarized in Table 7.19.

Acuity Level	Baseline	Additional Triage + Nurse with a priority for fast track
1	4.39	3.62
2	4.21	3.76
3	4.52	3.89
4	1.01	0.72
5	0.79	0.67

Table 7.19 LOS comparison by acuity level additional triage+ Nurse with a priority for fast track

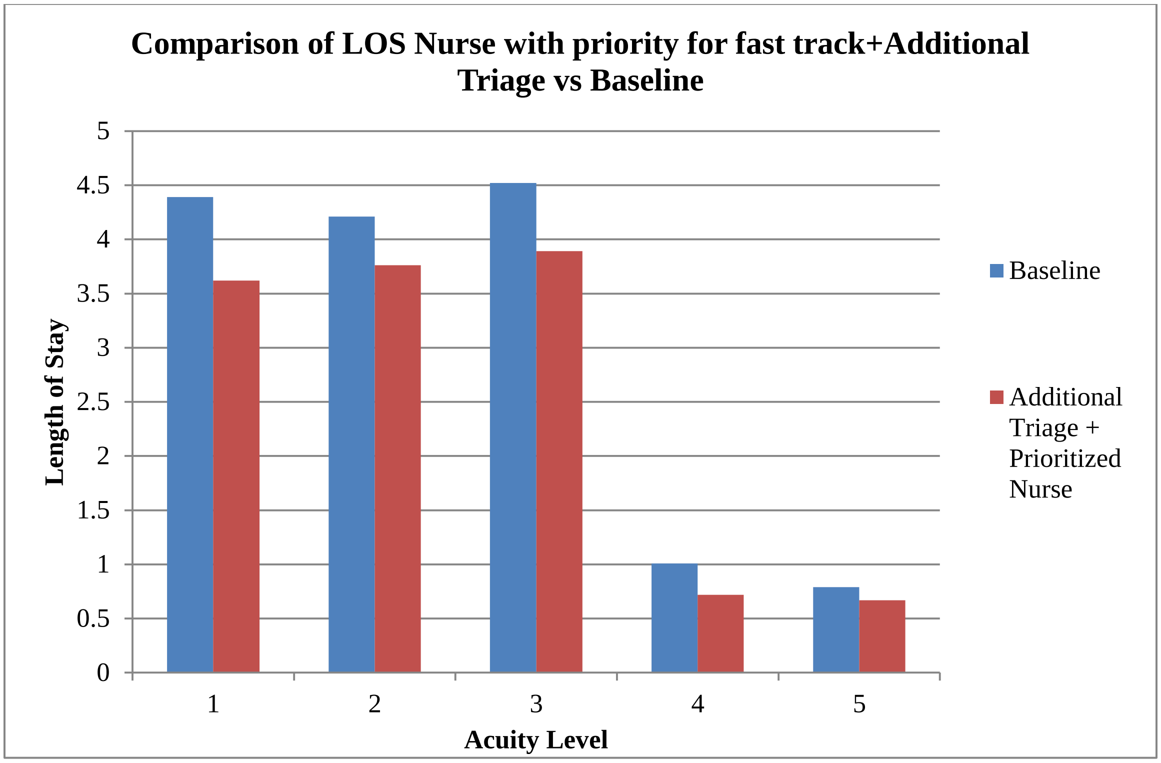


Figure 7.8 Comparing LOS (hrs.) by acuity level patients for baseline and additional triage + Nurse with a priority for fast track

As observed the LOS of the patients has been decreased significantly for patients of every acuity level. It can be observed that the LWBS ratio has dropped from 2.38% to 1.02% although; the drop in the ratio is not significant reduction as compared to prioritized nurse model because the waiting time before room does not observe a significant reduction. Table 7.20 compares the LOS for the full-care and fast-track patients and table 7.21summarizes and establishes the comparison of overall LOS with the baseline model. It is clearly observed that the overall LOS has reduced from 3.01 hours to 2.48 hours.

Description	Baseline	Additional Triage+ Nurse with a priority for fast track
Full-care ER Patients	4.37	3.78
Fast-track Patients	0.9	0.70

Table 7.20 LOS (hrs.) for full-care and fast-track patients' baseline and additional triage+ Nurse with a priority for fast track

	Baseline	Additional Triage+ Nurse with a priority for fast track
Length of Stay (hrs)	3.01	2.48

Table 7.21 Overall LOS for baseline and additional triage + Nurse with a priority for fast track

CHAPTER VIII

SUMMARY AND FUTURE WORK

The main objective of this study was to develop strategies that would aid in reducing the LOS of patients in the hospital emergency room. The research study started by documenting the patient flow and the different activities that occur in the SMC-ED. Historical data was used to gain operational insights and fit inter-arrival time distribution for walk-in patients. UML activity diagrams were constructed to describe the patient flow processes for both walk-in and ambulance arrival patients and all the diagrams were validated by the SMC-ED staff. The baseline simulation model was built based on the activity diagrams and was validated by comparing the ED performance estimates obtained from simulation with performance metrics derived from the historical data. Using the simulation model the patient treatment processes were studied in greater detail and various “bottleneck” points were identified in the patient flow. The SMC-ED operates in a fairly traditional manner like most of the EDs discussed in the literature review, and hence the LOS reduction strategies developed for the SMC-ED could be implemented in other similar EDs to achieve operational improvements.

The results from the baseline model and the historical data indicated three places where patients waited a significant amount of time before proceeding to the next stage in the treatment process. These were waiting before triage, waiting for a room assignment and waiting to see a doctor/MLP/nurse in the room. An underlying theme of the strategies explored was to treat and discharge fast-track patients quickly to improve the availability of resources – rooms, doctors and nurses for the full-care ER patients that accounted for more than 60% of the arrival to the SMC-ED. The first strategy explored was the addition of a triage station to treat less emergent patients (nearly a quarter of the fast-track patients). These patients would be discharged after treatment at the triage and with this strategy the overall LOS reduced from 3.01 hours to 2.62 hours. .To reduce the waiting time to see a doctor for the first time, an additional doctor was added during the peak hours of operation. With this modification there was a reduction in the overall LOS from 3.01 hours to 2.55 hours. However, there was no noticeable reduction in LOS of fast-track patients as the doctors gave priority to full-care patients.

In order to reduce the LOS of fast-track patients, the study went on to explore the modification of existing nurse schedule. In the dedicated nurse strategy, a nurse was dedicated at all times to treat the fast-track patients while the rest of the nurses were dedicated to the full-care patients. With this modification the LOS for fast-track patients decreased from 0.9 hours to 0.75 hours. However, due to decreased flexibility of nurses to attend to all the patients, the LOS of the full-care patients increased slightly to 4.41 hours; but the overall LOS of patients reduced from 3.01 hours to 2.79 hours. The shortcoming of the dedicated nurse strategy led us to explore a modification in which the fast-track nurse gives priority for fast-track patients and is available to treat full-care patients when there are no fast-track patients. With this variation the overall LOS reduced from 3.01 hours to 2.65 hours. The research also explored combining strategies to further improve the performance of the ED. The additional triage station and fast-track priority nurse strategies were combined. This combination reduced the overall LOS from 3.01 hours to 2.48 hours with significant reduction in average waiting time before a room was assigned and before seeing the doctor, MLP or a nurse for the first time.

The simulation model could also be used to see how the SMC-ED would perform if there were an increase in the demand for its services. The average arrival rates were gradually increased to observe the effect on the LOS of patients. As the arrivals of the patients increased there was a gradual increase in the overall LOS of patients till about a 15% increase in arrival rates. However, beyond a 15% increase, there was a much steeper increase in the overall LOS of the patients. The reason for this steeper increase could be the much higher utilization of resources leading to increased waiting time of the patients and hence, a higher rate of increase in the overall LOS. Table 8.1 and Figure 8.1 show the LOS increase with increasing demand.

Increase in Arrival Rates	Overall LOS (hrs)
No change	3.01
10%	3.32
15%	3.65
20%	4.29
25%	4.92

Table 8.1 Impact on LOS with increase in demand for ED services

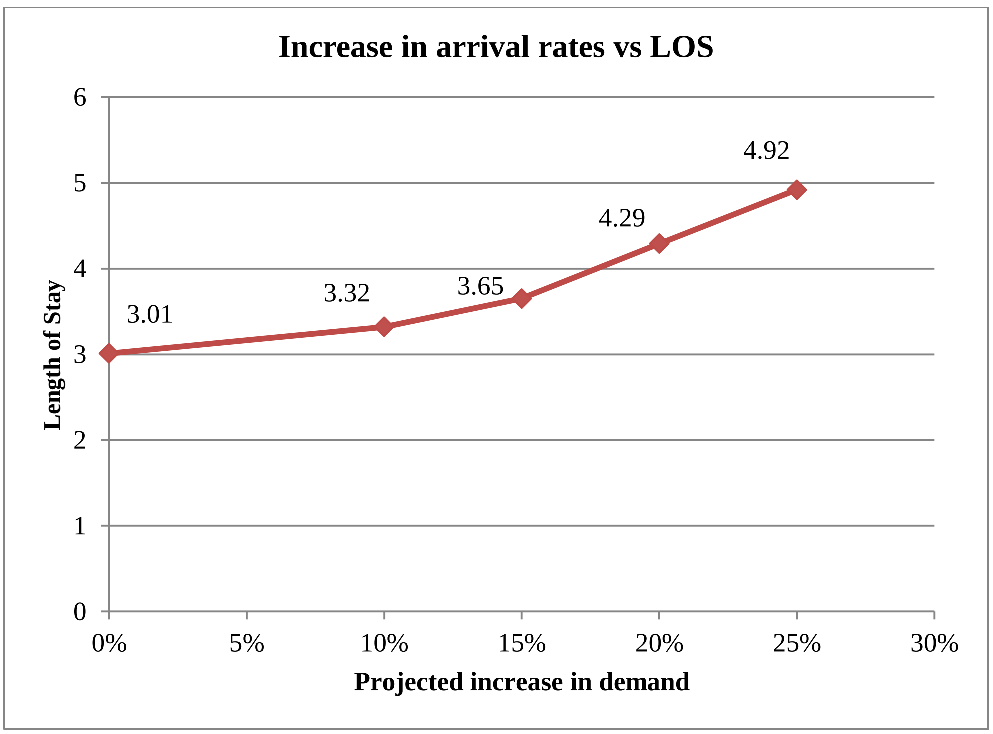


Fig 8.1 Impact on LOS with increase in demand for ED services

From the literature studied during the research it was observed that a greater number of hospitals have conventional EDs that are not very well suited for treating fast-track patients. With the modifications proposed in this research it would be possible for these EDs to treat less emergent cases more quickly. The additional triage station allows patients with minor complaints to be treated in the triage area without having the patient to occupy a room thereby allowing other more severely ill patients to occupy the rooms. This would reduce the waiting time thereby increasing patient satisfaction. The combination of additional triage station and fast-track priority nurse would be a potential strategy that could be implemented in the EDs for operational improvements.

There are multiple extensions to the research reported that could be explored in the future as listed below.

- This research did not consider the financial aspects. The potential economic benefits of the strategies and the costs of implementing them could be the subject of a follow-up study.
- From the literature review it is known that there are multiple departments that work in coordination with the ED. The influence of other departments on the patient flow has not been considered in this study and should be explored.
- To improve the efficient use of ED rooms, some studies have explored adding a separate area for those patients who are waiting on ancillary services or results. The SMC-ED holds the patient in the room until the results are obtained from the ancillary services. Adding an extra room to hold these patients could be studied.

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