A COMPUTER SIMULATION MODEL OF A LEVEL II EMERGENCY DEPARTMENT

THESIS

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CHAPTER I

INTRODUCTION

A trauma center is a special hospital designated to provide care to severely injured patients. There are four levels of trauma centers in the United States differing in their capabilities to provide trauma care. In a trauma facility, most admissions originate in the emergency department, so high patient satisfaction is important, especially in the presence of a competing facility. Yet, due to inadequate reimbursement and cost containment, the emergency department manager must also be concerned with minimizing costs. This concern must be balanced against providing adequate staffing and resources, which depend on the random nature of both patient arrivals and acuity levels.

Health care planners and managers, recognizing the need to continuously improve the quality and efficiency of their emergency department operations, are often required to make changes, sometimes costly ones, to the system without knowing if improvements will result. Indeed, making such difficult decisions on a trial-and-error basis in such a complex environment can be not only difficult, but also very costly, and may result in unacceptable quality of care. With the increasing capability and availability of computers, a growing number of hospitals are using simulation technology to help identify ways to improve the system, especially when there are several alternatives to consider (McGuire, 1997).

Simulation is a powerful modeling tool that enables researchers to study and experiment with complex probabilistic systems. A simulation model allows a researcher to experiment with alternative designs and operations to determine how the changes effect overall system performance (Harrell & Tumay, 1995). Researchers can examine the impact of a change or innovation using simulation modeling. They then can determine if the new operational procedure should be implemented within the present system. An analysis of the proposed system can be conducted, evaluated and modified, if necessary, before spending funds to implement a system, which may prove to be ineffective or inefficient.

Computer simulation modeling is an effective tool that can assist emergency department managers in many areas such as: lowering costs, reducing patient wait times, improving facility design, scheduling staff, training and educating staff, and testing new equipment. For instance, patient flow can be tracked and hypothetical scenarios tested to evaluate staffing levels required to maintain (or reduce) waiting and throughput times. Emergency departments want to achieve and maintain high levels of patient satisfaction. Patients are no longer willing to accept long waits in an emergency department. Patient waiting times can increase as a result of high patient volumes and high acuity levels, but all too often increased waiting times are the result of non-urgent patients seeking access to the health care system through the emergency department. Using simulation modeling, emergency department managers can examine more effective ways of addressing this issue.

There are 22 Trauma Service Areas (TSAs) in Texas, divided geographically by county. Brackenridge Hospital located in Austin is designated in Area O, serving the 13-

county Central Texas area. This hospital is part of the Seton Healthcare Network serving as the leading trauma facility in Area O, and offering the highest level of trauma care where the majority of critically injured patients receive care. The facility is capable of providing comprehensive trauma care for all types of injuries and illnesses, except for seriously burned patients who are stabilized and transported to burn centers. The administrators at Brackenridge would like to identify ways to make the emergency department more efficient, as well as examine the present system. Simulation modeling is an extremely effective analytical tool for this task

Statement of the Problem

The goals of this research project are to capture data, to model the delivery of emergency care within the adult emergency department at Brackenridge, and to provide estimates of system performance. The simulation software selected for this project is MedModel, a Microsoft Windows based simulation software manufactured by ProModel Corporation developed for modeling health care systems. Proposed analysis issues are: determination of the average patient waiting times by patient type, the average throughput times by patient type, resource utilization rates, and how these times and rates are affected by changing process flows or resource levels.

Research Questions

This study addresses the following questions:

- What is the average patient length of stay for each patient type?
- What is the average patient waiting time for each patient type?
- What are the utilization rates for physicians, technicians and nurses?
- How do changing scheduling practices impact patient length of stay, patient waiting times and resource utilization rates?

Significance of the Study

The administrators at Brackenridge can use this simulation model as a baseline to evaluate the existing system and identify specific areas for further evaluation and improvement. The model serves as a tool for continuous quality improvement because it documents patient flow and resource utilization and also can be used to evaluate the consequences of potential changes that are intended to improve quality and performance. Managers can develop the "should be" model based on the results of analysis of the "as is" model and the examination analysis done on possible alternatives to the existing system.

Limitations of the Study

The simulation study was limited by environmental factors, available technology and resources, and time constraints. Some of the specific limitations are discussed as follows:

- The simulation study was limited to the adult emergency department at Brackenridge Hospital.
- The hospital had never collected the type of data needed for this study, so a historical comparison was not possible.
- The primary source of data came from patient medical records. Due to time restrictions, the sample of data collected was limited to the months of May, June, and July of 1999. Over 50,000 patients were treated in the year preceding this study, but only 1776 records were reviewed.
- The researcher used direct observation to understand processes, as well as to supplement data collected from medical records, emergency department logs, interviews, and surveys.
- The model was built using MedModel, version 3.5, so simulations were limited by the capabilities of this software. Some of the aspects of the system could not be incorporated into the simulation model due to the complexity of the system.

Glossary of Terms

The following is a brief glossary of terms relevant to this study.

Activities: tasks or operations initiated at an event that causes changes in a system, such as transporting lab samples (Harell & Tumay, 1995).

Controls: rules that govern how, when, and where activities are conducted (Harrell & Tumay).

Entities: elements being processed through the system, such as customers, paperwork, or machines (Harrell & Tumay).

Events: a moment in time at which a significant change in a system's state occurs (Pidd, 1992).

Discrete-event simulation: the modeling of a system as it evolves over time by a representation in which the state variables change only at discrete points in simulation time (Law & Kelton, 1982).

Injury: damage to the body caused by an exchange with environmental energy that is beyond the body's resilience (Jacobs, Jacobs, 1996).

Immediate patients: patients whose condition is manifested by acute symptoms of sufficient severity that the absence of immediate medical attention could reasonably be expected to result in placing the patient's life, or limb, in serious jeopardy (Brackenridge Hospital Emergency Department procedural standard).

Level II trauma center: a definitive trauma care facility within a regional system capable of providing emergency services to the most severely injured patients. A Level I center may not be able to provide the same comprehensive care as a Level I trauma center, so patients with complex injures are initially treated and stabilized and then transferred to a level I facility (American College of Surgeons Committee on Trauma, 1993).

MedModel: a Microsoft Windows based simulation software produced by ProModel Corporation, developed for modeling health care systems.

Minor-care patients: patients whose symptoms indicate a condition that generally needs medical evaluation and treatment for minor needs but in which time is not a critical factor (Brackenridge Hospital Emergency Department procedural standard).

Non-urgent patients: patients whose symptoms indicate a condition that generally needs medical evaluation and treatment but in which time is not a critical factor (Brackenridge Hospital Emergency Department procedural standard).

Regional Trauma System: a multidisciplinary approach to coordinate and facilitate the care of severely injured patients in a timely manner. A regionalized trauma care system serves a geographically defined region made up of several counties, providing personnel, facilities, and equipment in response to the injured patient on an emergency basis (Jacobs, Jacobs, 1996).

Resources: the means by which services to entities are performed.

Service System: systems that provide assistance to their customers (McGuire, 1998).

Simulation: a model-building approach for forecasting how systems, as yet unbuilt, will behave (Flagle, 1970).

Simulation model: puts system elements into a form that researchers are able to comprehend based on known behavior and allows researchers to experiment with alternative designs and operation strategies to determine how the changes effect overall system performance (Harrell & Tumay, 1995).

State variables: the collection of all information needed to describe the state of a system at a given point in time (Banks, 1998).

System: a collection of interacting components working together toward accomplishing some goal (Law & Kelton, 1982).

System analysis: the approach to define the most practical, appropriate, and acceptable means for evaluating a system in its entirety and for testing new innovations (Chorafas, 1965)

System performance measures: used to measure the efficiency of a system and to determine how a system is performing after changes have been made (Harrell & Tumay).

System state: the set of relevant properties which a system displays at a given instant in time (Shannon, 1975).

Trauma: "the term used to describe bodily damage in clinical, emergency medical services, surgical, and combat environments" (Jacobs & Jacobs, 1996).

Urgent patients: patients whose symptoms indicate a condition that requires prompt medical attention but who will not generally suffer loss of life, or limb, if such attention is delayed for a short period of time in a controlled medical environment (Brackenridge Hospital Emergency Department procedural standard).

CHAPTER II

REVIEW OF THE RELATED LITERATURE

Trauma

William Haddon, Jr., the first director of the now National Highway Traffic Safety Administration (NHTSA) defines injury as "damage to the body caused by an exchange with environmental energy that is beyond the body's resilience" (Jacobs & Jacobs, 1996, p.16). Injuries are caused by the absence of such essentials as heat or oxygen, or by acute exposure to physical agents such as mechanical, electrical, chemical, or thermal energy interacting with the body in amounts that surpass the threshold of human tolerance (Baker, O'neil, & Karpf, 1984). "Trauma is the term used to describe bodily damage in clinical, emergency medical services, surgical, and combat environments" (Jacobs & Jacobs, p.16). The terms "injury" and "trauma" can be used interchangeably. For the purposes of this study, the term trauma will be used to describe these types of ailments.

Scope of the Problem

Trauma is one of the most serious public health issues facing developed countries. The magnitude of the problem in the United States is sobering. Trauma is the greatest killer for those younger than 45 years old and ranks as the fourth leading cause of death in all age groups, following heart disease, cancer and cerebrovascular accidents. Almost half of all deaths for those between age 1 and 4 are caused by trauma. Each year in this country, trauma kills over 100,000 people, and causes over 300,000 permanent disabilities (American Trauma Society, 1998). Trauma is also a major source of medical expenses and losses to the economy. The United States spends over 100 billion dollars on trauma annually (Stern *et al.*, 1997). These disturbing figures make trauma an extremely significant health issue.

Trauma affects so many young, productive citizens, causing deaths long before they reach the end of their projected life span. In fact, of the 34,548 deaths of persons between 15 years and 24 years of age in 1992, exactly 26,715 (77%) were caused by trauma (Jacobs, Jacobs, 1996). The burden of premature mortality is measured in the years of potential life lost (YPLL) by each death occurring before an arbitrary age, typically 65 or 70. Trauma disproportionately strikes the young, which accounts for more years of potential life lost than cancer, cardiovascular disease, and other chronic diseases. In fact, trauma accounted for approximately one-third of the 11.8 million years of potential life lost in 1985 (The National Committee for Injury Prevention and Control, 1989).

The major causes of trauma deaths are homicide, suicide, and unintentional (or accidental) factors. Unintentional trauma is usually the result of automobile crashes, drowning, fires, falls, suffocation, firearms, or poisoning. Intentional injuries may result from some of the same mechanisms, but the injuries are deliberately inflicted by an assailant or self-inflicted by the victim. Intentional deaths are usually caused by homicide or suicide.

Among all fatalities resulting from trauma in the United States, motor vehicle accidents are undeniably the most common cause of death. Over 40,000 people die annually as a result of traffic injuries. Barss, Smith, Baker, and Mohan (1998) reported that the death rate in 1994 for motor vehicle crashes per 100,000 population was 21.9 for males and 10.2 for females. Traffic injuries alone have caused more deaths than all the combined wars the United States has fought in (The National Committee for Injury Prevention and Control, 1989). The number of trauma-related deaths and disabilities is truly a national tragedy. The most disturbing statistic is that at least half of trauma deaths are preventable if injured patients are treated in specialized trauma centers within a regionalized system (Trunkey, 1981).

Regional Trauma Care Systems

Regionalized trauma systems have been developed in the United States to address the issue of cost as well as to reduce the mortality and morbidity resulting from trauma. A regional trauma systems may be defined as a multidisciplinary approach to coordinate and facilitate the care of severely injured patients in a timely manner. A regionalized trauma care system serves a geographically defined region made up of several counties, providing personnel, facilities, and equipment in response to the injured patient on an emergency basis (Jacobs, Jacobs, 1996). The results of research continually indicate that regionalized trauma systems improve the immediate outcome of life-threatening injuries and disabilities (Arroyo, Crosby, 1995).

The concept of a trauma system evolved during wartime, advanced during the Vietnam conflict, and has been adapted to the civilian environment. Over 20 years ago, establishing trauma systems was proposed as a strategy to advance trauma care throughout the nation, to help improve the treatment and outcome of seriously injured patients, and to decrease the costs of treating these patients. In the early 1970's, trauma systems began to evolve with the passage of the Emergency Medical Services System Act of 1973, which provided federal funds to states to support these efforts. Great attempts were made in developing guidelines for optimal trauma care delivery. In 1976, the American College of Surgeons (ACS) established the first document of guidelines for care of the injured patient. This document has been revised several times since, and is now widely recognized as the national standard for hospitals planning to become trauma centers.

These early efforts to develop statewide trauma systems were affected in the 1980's by reductions in federal support. Many trauma centers began to close in the late 1980s, largely due to uncompensated trauma care. In 1987, West and colleagues cited that only Maryland and Virginia had complete statewide trauma systems in place. They identified eight essential elements based on recommendations of the ACS that are used to define a complete statewide system. Theses are:

- Legal designating authority resides with the state
- Formal designating process is in place
- ACS standards are used
- Out-of-state survey teams are used
- Number of centers is based on assessment of population need

- Triage criteria allows for bypassing closest hospital
- Monitoring process for trauma centers is in place
- Trauma centers are available statewide (Maull, Rhodes, 1996)

More recently, interest among state agencies to develop trauma systems has been renewed due to the availability of federal grant support. The Trauma Care Systems Planning and Development Act was passed in 1990 (Public Law 101-590), calling for a model trauma care system plan and federal grant support to state health agencies. This legislation was passed to promote the development of a national trauma system. "Under the provisions of the act, small communities could link with major trauma centers and work together to develop trauma care delivery systems that prevent unnecessary deaths from trauma injuries and reduce trauma care costs" (Lewis, Richards, 1996, p.1). For the first time, the federal government allocated funds specifically for the development and implementation of statewide trauma systems (Moore, 1995). Nineteen states were awarded development grants for trauma systems and 16 additional states received grants to refine existing systems.

In 1995, Moore reported that regional trauma systems had not been developed in half the states and there were still problems with existing systems. Furthermore, many of these trauma systems did not meet the criteria established by West *et al.* In 1993, the number of complete trauma systems having met the essential standards of West *et al.* had increased to merely five.

Many states are compliant with most of the criteria of a complete trauma system, except for the criterion to limit the number of designated trauma centers based on community need. Research indicates that the number of trauma deaths can be reduced if patients are concentrated in a few facilities and professional skill is increased. "During the development of the trauma systems approach, trauma surgeons emphasized that limiting the number of designated trauma centers was important to maintaining quality patient care and reducing costs" (Trunkey, 1995, p. 421). Overdesignation of trauma centers leads to "duplication of services and dilution of experience" (Moore, 1995, p. 1). For states to develop complete trauma systems will require support from physicians to limit the number of designated trauma centers.

The 1990 Trauma Care Systems and Development Act called for a Model Trauma Care System Plan. The plan was developed in 1992 with recommendations from the American College of Surgeons Committee on Trauma (COT). The plan encouraged the development of an inclusive trauma system. However, a vast majority of regional trauma systems are presently based on an exclusive design. The distinction between these two types of systems will now be discussed.

Exclusive Versus Inclusive Trauma Systems

An exclusive trauma system is driven by critically injured patients only. Non-trauma centers are excluded from the statewide system. Yet, these non-trauma centers may treat a majority of patients with minor injuries. An inclusive trauma system maintains the trauma center as the key clinical facility in the system where severely injured patients should be treated, but stresses the need of other health-care centers within the system to care for the less critically injured (American College of Surgeons Committee on Trauma, 1993). Trauma patients are oftentimes managed in undesignated trauma centers, and less severely injured patients are frequently treated at designated trauma centers. In fact, 85%

of hospitalized trauma patients do not need trauma center management (Moore, 1995). Regional trauma centers need to become inclusive to be cost effective and potentially improve care for all injured patients.

Within an inclusive system, all injured patients are matched to appropriate hospital facilities in a timely manner. The inclusive model establishes a system that depends on the emergency medical system (EMS) to rapidly transport the injured patient to an appropriate care facility. The importance of the relationship between health care facilities is emphasized with pre-established patient transfer agreements among the trauma and non-trauma facilities.

> The preplanned response to care for the injured patient requires the use of coordinated communication mechanisms, accurate identification of the level of care needed by an injured patient, rapid transport to an appropriate care facility, and the integration of support and rehabilitation services designed to return the patient as a productive citizen back to the community (American College of Surgeons Committee on Trauma, 1993, p. 8).

Components of Trauma Systems

A trauma system consists of facilities, personnel, equipment, and public service agencies that have preplanned responses to caring for the injured patient on an emergency basis. The National Highway Traffic Safety Administration defines a trauma care system as "a system of health care delivery that combines the pre-hospital EMS resources and hospital resources to optimize the care and, therefore, the outcome of traumatically injured patients" (The National Committee for Injury Prevention and Control, 1989, p.

271). There are a number of components that make up a fully operational trauma system. They are:

- Facilities (including the trauma centers)
- Personnel
- Transportation
- Communications
- Education and training of physicians, nurses, paramedics, and dispatch personnel
- Evaluation process for quality improvement

The trauma center is made up of several components:

- Pre-hospital care
- Emergency department
- Operating room
- Intensive care units
- Rehabilitation Care (Maull, Rhodes, 1996)

Levels of Trauma Centers

The purpose of a trauma system is to get the injured patient to definitive care in the shortest amount of time. Initially, the goal is to match the injured patient's needs with the most appropriate trauma care available. Effective trauma care requires the collaboration and cooperation of hospitals providing all levels of care. The regionalized trauma care system is made up of definitive trauma care facilities that provide a wide range of care for all injured patients. Pre-hospital field care provides rapid identification of critically injured patients who require immediate transport to trauma facilities. Prearranged patient transfer agreements among trauma facilities of different levels provide appropriate care to the injured patient in a timely manner.

Trauma centers are special hospitals designed to treat the most critically injured patients.

Trauma centers are special hospitals designed to treat the most critically injured patients. They have to meet rigid standards for staffing and equipment (as outlined by the ACS) to regulate high quality of care. Trauma centers must undergo rigorous evaluations of their performance and report their outcomes of patient care to regulatory agencies to retain their designation. There are four levels of trauma centers in the United States, each differing in levels of capabilities based on standards developed by the American College of Surgeons. They are: Level I or comprehensive trauma facility, Level II or major trauma facility, Level III or general trauma facility and Level IV or basic trauma facility.

The level I and level II facilities provide emergency services to the most severely injured patients. There are only minimal differences between the two types of facilities. Level I centers offer the most advanced trauma care, and typically are university-based teaching hospitals involved in education and research. In contrast, level II facilities are not required to train physicians in trauma care or to engage in trauma research. However, Level II facilities are encouraged to lead in education, research, and systems planning if Level I facilities are absent from the region.

Both Level I and level II facilities must have at least one physician specifically trained in trauma care available at all times. Level I facilities must have a trauma surgeon and sub-specialty surgeons in-house 24 hours a day, while trauma surgeons in level II facilities are required to be at the hospital when the patient arrives. Level II centers may not have surgical and/or medical sub-specialties (e.g., burn care units) available, so patients needing specialized care are initially treated and stabilized and then transferred to a level I facility. The American College of Surgeons (1993) distinguish between Level I and Level II facilities as follows:

- Clinical Capabilities
  - Cardiac surgery
  - Hand surgery
  - Microvascular surgery
  - Infectious disease
  - Pediatric surgeons
  - In-house general surgeon
- Facilities/resources
  - Cardiopulmonary bypass
  - Operating microscope
  - Acute hemodialysis
  - Nuclear scanning
  - Neuroradiology

Level III centers are usually located in rural areas. These facilities are generally not located in urban or suburban areas that have immediate access to Level I and Level II facilities. Level III centers have a trauma team capable of providing rapid resuscitation, emergency surgery, and stabilization of the trauma patient. They are primarily responsible for prompt transportation of critically injured patients to level I or level II facilities with which they have prearranged transfer agreements. General surgeons are available when the patient arrives at the hospital in Level III facilities.

In contrast, Level IV facilities usually do not have surgeons available. These centers are usually located in remote rural areas where no other level of care is available. Level IV centers are responsible for providing advanced trauma life support and immediate transfer of severely injured patients to a facility that can provide the level of trauma care needed.

Factors Affecting Trauma Center Financial Viability

Research has shown that patients treated in specialized centers within a regionalized trauma system have improved chances of survival. Trauma systems also reduce mortality and morbidity. Despite the effectiveness of trauma systems, the impetus to establish and maintain them has been affected by start-up costs, high operating costs, and inadequate reimbursement. The latter two factors are largely responsible for more than 90 trauma center closures between 1985 and 1993 (Kellerman, 1993).

Start-up costs for developing a trauma center vary with respect to the level of care provided by the facility, and its geographical location. Start-up costs to develop a trauma center can exceed $3 million, with similar costs to maintain services annually (Matson, 1992). In 1988, the average start-up cost in Florida for a level I facility was $420,000 (Laskowski-Jones, 1993). Level I facilities typically develop from universities so they have initial start-up resources. The cost to initiate a Level II center is in fact higher because these facilities are usually community-based hospitals with no existing resources. In 1989, the average start-up cost in Florida for a Level II facility was $800,000 (Laskowski-Jones, 1993).

The expenses to maintain a trauma center also involve a substantial financial commitment. The annual costs to operate Level I and Level II facilities average $1.9 million and $550,000, respectively (Laskowski-Jones, 1993). The costs to maintain a trauma center are categorized as follows:

- Administration
- Communication equipment upgrades
- Personnel training
- Transport equipment
- Staff, facilities, and equipment upgrades
- Patient care (Laskowski-Jones, 1993)

Twenty years ago, hospital administrators rarely paid attention to operational costs. Furthermore, they did not have to worry about reimbursement issues because they were always fully reimbursed. Hospitals generated enough profit from commercial insurance, and even Medicare insurance, to pay for treating indigent patients (Trunkey, 1999). Today, trauma centers are faced with increased operational costs and declining levels of reimbursements, so attention to financial matters is important to their viability. Hospitals are now pressured to reduce costs and charges. By controlling costs, administrators can improve the financial viability of trauma centers.

The magnitude of losses from inadequate reimbursement and uncompensated care has predominately contributed to trauma center closures in recent years. Trauma centers have a hard time surviving financially. Medicare and Medicaid are not even close to paying the costs to treat their recipients (Kellerman, 1993). Also, many trauma patients are underinsured or uninsured. Millions of poor Americans are without any health insurance because they are not eligible for Medicaid. There are approximately 45 million Americans who are uninsured (Trunkey, 1999). In 1996, 27% of Texans had no health coverage (American Hospital Association, 1996). Texas ranks first among states on the percentage of uninsured population. In all states, a majority of those between the ages of 15 and 24 are uninsured and injury rates are the highest for this group.

Many Medicaid and uninsured patients do not have access to primary care facilities, so they frequently utilize emergency departments for health care. Emergency departments are required to treat all patients, regardless of their ability to pay. The general belief in the United States is that every individual has the right to access health care services. As a result, emergency departments are overloaded with patients who could receive proper care in more appropriate and lower-cost facilities. Extreme measures need to be taken to move low-acuity patients to less costly sites of service, since emergency departments contribute significantly to the high cost of operating a trauma center. Otherwise, major trauma centers will continue to collapse (Vikhanski, 1992). When a trauma center closes, injured patients may no longer have immediate access to care.

Managed care organizations (MCOs) have recently focused on costly patient visits to emergency departments. Hospital administrators welcome the goal of MCOs to move non-urgent patients to more appropriate and less costly sites of service. However, these health plans restrict patient access to "preferred providers". Preauthorization to treat patients in an emergency department is usually required by most MCOs and there are strict rules for reimbursement in terms of charges from the majority of these third party payers.

Trauma centers that treat patients under MCOs with which they have not contracted with may not be fully reimbursed.

Emergency Departments

Emergency departments are a significant part of the trauma system. Emergency departments offer emergency care 24 hours a day, providing critically injured patients with physicians, nurses, and other personnel trained in emergency care who can immediately evaluate and treat them. "They are called on in crucial moments where time is measured in seconds, those seconds that make up the first "golden" hour in which trauma patients have significant chances of survival if they undergo the best care" (Hylton, 1992, p. 38). Emergency departments were intended for treating severely injured patients, but are now also called upon to offer primary care services to the poor and uninsured who have no other access to medical care. Emergency departments are increasingly treating patients with minor injuries and illnesses such as bronchitis, fractures and minor lacerations, in addition to the major trauma patients they are designed to care for. Emergency departments also serve as the main portal of entry into the hospital. A majority of adult and pediatric hospital admissions are generated in the emergency department. In fact, 40 percent of hospital admissions originated in emergency departments in 1990 (Lynn, 1997). Nearly two thirds of intensive care unit admissions originate in the emergency department (Mayer, 1997).

Emergency Department Utilization

There has been a substantial increase in emergency department utilization in recent years. As the population of the United States has increased, so has emergency department utilization. In 1995, exactly 99,911,108 visits were made to emergency departments in the United States and 6,544,457 in Texas (American Hospital Association, 1996). From 1980 to 1995 emergency department visits in the United States increased 22 percent -from 82.0 million in 1980 to 99,911,108 in 1995. Matson (1992) identified several factors contributing to the growth of utilization in emergency departments:

- Population growth
- Increased number of elderly using emergency department services
- Greater number of poor, uninsured, or underinsured patients
- More patients utilizing emergency departments for primary care
- Increased patient acuity levels

The expansion in the elderly population has contributed to the growth in emergency department utilization. There were roughly 26 million Americans 65 years old or older in 1980; this figure is predicted to exceed 36 million by the year 2000 (Matson, 1992). The elderly need three times more medical resources than younger patients, and often require more specialized care. As the numbers and needs of the elderly continue to increase so will the utilization of emergency departments.

The rise in the number of uninsured and underinsured has also contributed to increased emergency department utilization. Emergency departments are mandated by the Consolidated Omnibus Budget Reconciliation Act (COBRA) to provide care to all patients regardless of their injury or their ability to pay. So, emergency departments are frequently utilized by uninsured or underinsured patients who have nowhere else to go. For many indigent patients, the emergency department is the only source of health care available because these facilities provide care to patients who have no other options or who lack the ability to pay. Oftentimes, patients who lack health coverage arrive at emergency departments with nonurgent injuries. In 1993, the United States General Accounting Office (GAO) reported that 43 percent of emergency department visits in 1990 were considered nonurgent (Lynn, 1997).

Some patients with nonurgent conditions seek care in emergency departments because their primary care physician is not available. Emergency departments offer convenient features that are generally not offered by primary care physicians. For instance, they are open 24 hours a day, seven days a week, with no appointment necessary. Sometimes, nonurgent patients go to an emergency department because physician offices are closed. Primary care physicians generally work during the day. It may be difficult for a patient who works those same hours to schedule an appointment.

Increased patient acuity levels have also led to greater frequency of visits in emergency departments. For instance, patients with AIDS, drug addictions, and injuries caused by violence increasingly consume emergency department resources. The number of AIDS cases increases significantly each year. AIDS patients often turn to emergency departments for treatment when their regular sources of care are unavailable (Matson, 1992). Drug-related injuries have also significantly contributed to the growth in emergency department visits. Alcohol is still believed to be the most abused drug in America. Alcohol plays a significant role in the number of motor vehicle crashes occurring nationally: 20 percent of crashes involving serious injury to a driver or passenger, approximately 50 percent of all fatal crashes, and about 60 percent of single-vehicle fatal crashes (The National Committee for Injury Prevention and Control, 1989). Alcohol and drug abuse have also been linked to violence. Violent acts usually result in physical injuries or death. Patients with injuries caused by violence have also contributed to increased visits in the emergency department setting.

<u>Overcrowded Emergency Departments</u>

The increase in the number emergency department visits has contributed to "ED gridlock", or overcrowding (McNamara, 1992). Emergency departments all over the country are overcrowded and overwhelmed with patients. Overcrowding also results when admitted patients cannot leave the emergency department because all inpatient and intensive care unit (ICU) beds are occupied. Oftentimes, there are too many patients who need acute inpatient care and there are too few beds and/or inpatient staff to care for these patients (Lynn, 1997). Patients must remain in the emergency department until inpatient beds become available. These patients awaiting admission generally require disproportionate care, which limits the ability of emergency department staff to treat other patients. When an emergency department becomes extremely overcrowded, pre-hospital care personnel must be diverted to another emergency department.

In 1989 the American College of Emergency Physicians (ACEP) conducted a survey to determine the extent of nationwide emergency department overcrowding (Lynn, 1997). Forty-one states reported overcrowding problems. ACEP's survey identified several factors contributing to overcrowding:

- Shortage of health care professionals

- Use of emergency departments as a route of hospital admissions
- High inpatient daily census
- Hospital bed reductions
- Hospital or emergency department closures
- Increased number of drug-related admissions
- Increased number of AIDS patients
- Increased number of poor or uninsured patients
- Prolonged use of acute care beds by elderly and shortage of nursing home beds (Lynn, 1997).

The ability of emergency departments to meet the needs of patients is increasingly being stretched beyond capacity. The overutilization of emergency departments by poor and uninsured patients accompanied by a shortage of inpatient beds for admitted patients have predominately led to overcrowded emergency departments. These two factors alone severely strain the capacity of emergency departments. The growing number of patients with high acuity levels utilizing emergency department resources intensifies the problem. Furthermore, emergency departments are not adequately compensated for treating the medically indigent. The federal government has not assumed financial responsibility for the care of these patients. Present reimbursement practices threaten the financial viability of emergency departments. The "system traditionally believed to be the ultimate safety net may collapse if measures are not taken soon" (Vikhanski, 1992, p. 50).

One way that emergency departments try to manage the overcrowding problem is to increase patient throughput, that is, reduce patients' overall length of stay. However, this may require unfeasible increases in staffing levels.

Patient Throughput

A major goal of emergency departments is to reduce patients' overall length of stay. Patient satisfaction is largely dependent on the amount of time patients spend in the emergency department and how well the flow through the emergency department is managed (Salluzzo, Terranova, & Verdile, 1997). Emergency departments want to achieve and maintain high levels of patient satisfaction. Emergency departments need to have an efficient way to move patients through the system. "The emergency department is a process-rich environment. Regardless of size or volume, all emergency departments have multiple, cross-functional processes at work on each patient. Success requires careful, sequential coordination of these processes" (Mayer & Salluzzo, 1997, p. 464).

The patient throughput process consists of several stages, all of which can be quite complex. Salluzzo, Terranova, and Verdile (1997) discuss several strategies to help emergency department managers make improvements in patient throughput. For instance, they discuss how developing a fast track or a minor care area in the emergency department can reduce patient throughput times. By segregating the critically injured and the nonurgent cases, nurses and doctors are not attempting to treat both simultaneously. Instead, physicians' assistants can take care of the minor care patients, while nurses and physicians can concentrate on the major trauma patients. Other strategies discussed by Salluzzo *et al.* are: ensuring that admissions leave the emergency department promptly, improving laboratory and radiology turn-around times, and ensuring adequate staffing.

Staffing Levels

Another major goal of emergency departments is to provide adequate numbers of appropriately qualified personnel who are on duty at suitable times for the number and type of patients seen. A national standard for nursing and physician staffing does not exist as of yet. However, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) has established minimum requirements for nursing and physician staffing for each of the four levels of emergency departments. Staffing requirements and patterns may vary across emergency departments. Patient volume and acuity should be trended to identify patterns as a basis for staffing a specific emergency department (Greenberg, 1997). Ensuring adequate staffing levels reduces delays in patient flow, improving the quality of service as perceived by the patient.

Continuous Quality Improvement

Continuous quality improvement (CQI) evolved from traditional management approaches of quality assurance (QA) and has been widely applied in both manufacturing and service systems across the country (Mayer & Salluzzo, 1997). The Joint Commission of Accreditation of Health care Organizations (JCAHO) has accepted CQI as the model to be used by hospitals to monitor and improve the quality of services they provide. The tools and techniques of CQI were developed by a group of remarkable thinkers, including Shewhart, Deming, Juran, and Ishidawa (Mayer & Salluzzo). The basic principles inherent to the new paradigm are:

- Customer focus

- Statistical application of knowledge of variation
- Focus of the process
- Design and redesign
- A redefinition of leadership (Mayer & Salluzzo).

Continuous quality improvement defines quality as meeting or exceeding the customer's expectations (Mayer & Salluzzo). Customers include any person who is affected by a process or product. This includes both internal customers, such as patients and their families, and external customers, such as physicians and nurses (Mayer & Salluzzo). The first component of CQI is customer focus. Customer focus refers to the obligation to place the needs and requirements of the customer first (Graves, 1998). Through surveys or focus groups, customer feedback can be measured on an ongoing basis in order to understand the changing needs of customers. Areas of dissatisfaction are identified to determine where improvements can be made. One of the goals of CQI theory is to continually evaluate all products and services as part of a constant striving towards satisfactory customer outcomes (Colton, 1997).

The second key component of CQI is to identify and reduce variation in service delivery by using statistical techniques (Mayer & Salluzzo). This component of CQI has evolved from the science of statistical process control (SPC), which is frequently used in manufacturing industries. First, data is collected evaluate the efficiency of the system and to examine areas of customer dissatisfaction. Actual events should be compared to desired levels of performance. Then, acceptable control limits of variation are calculated. Next, areas where variations exist in the data are identified. The processes causing variations that exceed acceptable thresholds are examined, and appropriate interventions are taken to reduce variation in those areas (Colton, 1997).

The third component of CQI is to focus on the process. The CQI approach emphasizes the improvement of processes and systems rather than focusing on individual performance, as was the focus of traditional approaches (Mayer & Salluzzo). The emergency department is a process-rich environment, so it is essential to continuously evaluate and monitor processes, and to identify areas that need improving.

The fourth major feature of CQI theory is the emphasis on design and redesign. The redesign process is a function of management and staff members. In the CQI model, it is essential to continuously monitor and improve systems and processes as needed. As Donald Berwick states, "every process provides information by which that process can be improved" (as cited in Mayer & Salluzzo).

The fifth component of CQI is a redefinition of leadership and empowerment of workers. Continuous quality improvement emphasizes the necessity of input from those responsible for providing services to customers or patients (Mayer & Salluzzo). For instance, doctors and nurses in an emergency should predominately be the ones responsible for redesigning the ways in which healthcare is delivered. From a CQI perspective, "the manager is more like a coach, consultant, and facilitator, who ensures that the providers have the necessary tools and techniques to redesign the processes" (Mayer & Salluzzo, p.470). Some activities and issues that should be monitored in emergency departments include:

- Patient complaints
- Patient satisfaction surveys

- The number of patients who leave before physician evaluation
- The number of patients returning to the emergency department within 24 to 48 hours
- Prolonged stay in the emergency department
- The number of hospital admissions through the emergency department
- Average patient wait times and throughput times
- The turnaround times for the laboratory (Rowland, 1998)

Today, health care providers are expected to evaluate the quality of the services they provide and to identify ways to improve system performance. With the increasing capability and availability of computers, emergency departments are increasingly using simulation technology to help identify ways to improve the system (McGuire, 1997). Evidence has shown that simulation modeling is an extremely effective analytical tool in developing solutions that improve the performance of emergency departments. A computer simulation model can serve as a tool for continuous quality improvement because it can documents patient flow and resource utilization and, can be used to evaluate the consequences of potential changes that are intended to improve quality and performance.

Simulation

Simulation is the "imitation of the operation of a real-world process or system over time" (Banks, 1998, p. 3). It serves is "an adjunct of the decision-making process, a way of designing and testing alternative systems or approaches to problem solving. It is a model-building approach for forecasting how systems will behave" (Flagle, 1970, p. 1). In all situations involving simulation, the entire system or parts of the system are represented by models that reflect the actual system. For instance, a pilot may be trained in a realistic simulated cockpit having programmed inputs to the flight instruments instead of flying real aircraft in a wide variety of conditions. By using simulation, aircraft operators have significantly reduced the costs to train pilots (Deutsch, 1969).

When building an adequate simulation model, there should be a one-to-one correspondence between elements of the actual system and the elements of the model. The simulation model must reflect all the important elements of the real system. Simulation allows analysts to make intelligent decisions about the design and operation of a system in a short amount of time and at a reasonable cost.

There are two fundamental concepts involved in simulation: system and model. The first refers to the actual process or system being studied. The second refers to the device used to mimic the system. These will now be discussed in some detail.

Systems

A system is defined to be a collection of interacting components working together toward accomplishing some goal (Law & Kelton, 1982). The term system is used in many diverse ways. There are natural systems and man-made systems (Fishman, 1973). Examples of natural systems readily come to mind. For example, biologists might use the term system to refer to a group of organs and glands working together to accomplish a certain goal, such as the digestive and circulatory systems. Geologists may speak hydrologic systems in which water is continuously recycled.

Man-made systems also easily come to mind. City planners speak of transportation systems, and water and sewage systems. Mathematicians may speak of a system of equations where there is more than one unknown variable. A service system may be a medical clinic where doctors and nurses are working together to better the health of their patients. A manufacturing system might be a steel company, which converts iron ore to steel. In general, service systems provide assistance to their customers, whereas manufacturing systems convert raw materials into finished products for their customers (McGuire, 1998).

Although specific systems might differ in their details, often they have common structural relations (Deutsch, 1969). Thus, the library of techniques and fundamental approaches used to examine one system might be applied to another system study. This thesis will focus on discussing service systems, particularly emergency rooms.

Factors Influencing System Design

Researchers are increasingly searching for ways to improve the performance and the design of actual systems. As a result of competition, rising consumer demands, and advancing technologies, businesses are forced to reevaluate the way they are performing (Harrell & Tumay, 1995). The challenge of companies to rethink the way they are operating has been brought on by three main factors, discussed as follows by Harrell and Tumay.

First, systems have shorter life spans driven by steadily changing requirements and the rapid advancement of new technologies. Successful businesses are those that can keep up with changes. Some major reasons to change or modify existing systems are:

- *Adequacy*: Equipment requires replacement when it no longer operates adequately.
- *Process changes*: New or modified products and services require changing the current system or developing a new system.
- *Volume*: An increase or decrease in production volume or service loads.
- *Competition*: Increased competition or declining profits.
- *Technology*: Improved technology makes the current practice obsolete.

Second, because of advancing technology, systems are becoming increasingly more complex and sophisticated. As systems become more complex, the challenge of system design and management becomes more difficult. There is a growing need to modernize and streamline service systems with new and improved technology. To address this challenge, system managers often turn to new and improved technology. But the technology comes at a cost. Researchers need to be able to predict whether or not this cost exceeds their projections of benefits resulting from implementing the new technology.

Third, systems have higher performance requirements as a result of rising consumer expectations and growing competition. The ability of a service provider to deliver timely and efficient services will determine its level of success in a competitive marketplace. Inefficient operating practices occur in almost every business. Businesses today continuously monitor, detect, and eliminate inefficiencies that lead to improved system performance.

Elements of the system

The system elements are the components, parts, and subsystems that perform a function or operation. The relationships among these elements and the manner in which they interact determine how the overall system behaves and how well it fulfills its overall purpose (Shannon, 1975). Designing a new system or changing an existing system requires one to understand the elements that make up the system. At the most basic level, entities and resources constitute the elements of the system.

Entities represent the elements being processed through the system, such as customers, paperwork, or machines. Entities model such things as shoppers in a supermarket, planes at an airport, phone calls in a communication center, patients in an emergency room, work in progress in a manufacturing system, and so on (Norman & Banks, 1998). Entities may be grouped into classes depending on identifiable characteristics, for example cost or priority. Characteristics of entities are called attributes. An individual entity can possess one or more attributes that distinguish that entity. For instance, an attribute of a particular entity in an emergency room might be time of arrival. Harrell and Tumay (1995) categorize entities into three types:

- *Organic*: entities that are human or animate objects such as customers, patients, etc.
- *Inorganic*: entities that are inanimate objects such as paperwork, lab specimens, machines, etc.
- *Intangible*: entities that can be observed but not touched such as calls, electronic mail, etc.

Resources provide services to the entities. They can serve one or more than one entity at the same time. Resources in a manufacturing system include machinery, machine operators, transportation vehicles and conveyors, and temporary storage space for work in process and finished goods (Norman & Banks, 1998). Among the resources in an emergency room are doctors, nurses, lab technicians, beds, and x-ray machines. Resources may have characteristics such as capacity, speed, cycle time, and reliability (Harrell & Tumay, 1995). Examples of resources listed by Harrell and Tumay are as follows:

- Equipment
- Staff
- Facilities
- Money

State Variables

Shannon (1975) defines the state of a system at a particular instant to be "the set of relevant properties which that system displays at that time." Analyzing a system involves studying the state of the system at a given point in time and understanding how the system changes over time. The collection of all information needed to describe the state of a system at a given point in time are called state variables. (Banks, 1998). Examples of state variables include:

- Current number of entities waiting in a line
- Current state of a machine (idle, busy, processing, down)
- Current number of busy resources
- Current number of entities in the system (Harrell &Tumay, 1995).

<u>Changes in a System's State</u>

Changes in a system's state occur as a result of an event, an activity, or a control. An event is a moment in time at which a significant change in a system's state occurs (Pidd, 1992). For example, suppose that a critically injured patient arrives at an emergency department in an ambulance. The arrival is an event because it changes the system's state, namely the number of entities in the emergency department. Transitions in the state of a system can occur continuously over time or at discrete moments in time. The specific distinction between the two will be discussed later. Events are often grouped together chronologically into a sequence of events. Such a sequence is called a process and is usually used to represent all or part of the life of entities (Pidd).

Activities are tasks or operations initiated at each event that cause changes in a system, such as transporting lab samples, repairing equipment, or checking out a customer. The activities are usually performed by resources or entities, thus changing their states. Activities that occur outside the system are exogenous, while those occurring inside the system are endogenous. Examples of activities include:

- Entity processes (registering, blood drawn, phone calls)
- Entity movement
- Resource movement
- Resource setups
- Resource maintenance and repairs (Harrell & Tumay, 1995).

Controls determine how, when, and where activities are conducted. They also influence what task is performed for certain situations. Controls could be in the form of plans, schedules, and policies, or written procedures and computer logic. Some typical controls include:

- Employee schedules
- Manufacturing plans
- Process plans
- Treatment protocols
- Instruction manuals
- Maintenance policies (Harrell & Tumay, 1995).

System Performance Measures

The factors influencing system changes were noted previously (see p.2). These factors challenge managers to improve system performance. System performance refers to the states that a system assumes over a specified time interval (Fishman, 1973). Performance measures are used to measure the efficiency of a system and to determine how a system is performing after changes have been made (Harrell & Tumay, 1995). Examples of common performance measures for service systems are:

- *Cycle time*: The throughput or service time for processing material or customers
- *Resource utilization rates*: The amount of time that equipment and personnel are being used.
- *Value-added time*: The percentage of time that material and customers actually spend in operation or receiving service.

- *Waiting time*: The percentage of time that material and customers spend waiting for operations and services.
- *Processing rate*: The throughput or service rate of material, customers, etc.
- *Quality*: The percentage of parts produced or customers served that meet a defined, acceptable set of standards.
- *Cost*: The operating costs of a system.
- *Flexibility*: The ability of the system to adapt to changes in volume and variety. (Harrell & Tumay)

Performance measures should be specific goals that include measurable objectives. For instance, a fire department might want to reduce their average response time by a full minute or an emergency room may want to reduce average length of stay for patients to 180 minutes. Goals should not be indistinct or vague such as "to improve quality of care" in an emergency room.

System Analysis

The approach to define the most practical, appropriate, and acceptable means for evaluating a system in its entirety and for testing new innovations is called system analysis (Chorafas, 1965). Ideally, system analysis is done with the actual system in its true setting. However, experimenting with the actual system may be impractical, costly, or disruptive to the present practices of the system (Law & Kelton, 1982). For instance, suppose an emergency department decided to reduce the number of doctors working during a particular shift, without knowing the effect it would have on patient waiting and throughput times. Indeed, making such complex decisions on a trial-and-error basis in such a complex environment may be not only difficult, but also potentially very costly and may expose patients to avoidable risks. Instead of experimenting with the actual system, system analyst often use a model to study how the corresponding system behaves.

Modeling

The first step in studying a system is to construct a model. A model is an imitation or representation of a system designed for the purpose of studying the system and its components. Its purpose is usually to aid us in explaining, understanding, predicting and ultimately improving a system's behavior (Shannon, 1975). A model is usually less complex than the system it mirrors. Although a model is only a representation of actuality, it provides insights into the real system. Harrell and Tumay (1995) characterize a good model as follow. A good model:

- Includes only those components that directly relate to the study.
- Accurately corresponds to the system.
- Provides meaningful results.
- Is easily modified and expanded.
- Is fast and inexpensive to build.
- Is credible.
- Is reusable.

The concept of a model is not new. Man has always used modeling to try to represent and understand ideas and objects. For instance, new democracies around the world attempt to model the United States constitution. Children model the behavior of parents, teachers, athletes, or musicians. Many of the major advances in science and engineering were made by studying models of natural phenomenon. For instance, the modeling with complex mathematical equations has helped send men to outer space. The functions of models are many. Fishman (1973) recognizes eight reasons for using a model:

- *Insight*: greater understanding of the system.
- *Prediction*: forecasting the effects of system modifications.
- *Facilitation*: the evaluation of change and the manipulation of the system is easier.
- *Control*: the ability to manipulate more sources of variation.
- *Time*: the speed with which an analysis can be completed is increased.
- *Organization*: enables researchers to organize their theoretical beliefs and empirical observations about a system and to deduce the logical implications of this organization.
- *Perspective*: balance detail and relevance.
- *Cost*: less expensive.

Types of Models

There are four categories of models. They include: physical (or iconic), symbolic (or schematic), analytical, and simulation models.

A physical (or iconic) model is a scaled replica of the system or object being studied. Physical models may be scaled down (such as a model of an airplane) or scaled up (such as a model of a molecule). They can be two or three dimensional (such as a map or a world globe). The distinguishing characteristic of a physical model is that it resembles in appearance and structure the phenomenon being analyzed.

A symbolic or schematic model uses graphic symbols to display the basic logical interactions between system elements. For instance, a symbolic model might be an organization diagram where boxes and lines are used to represent the formal chains of authority and communication existing among members of an organization (Shannon, 1975). Flow process charts are widely used to model systems symbolically in which various occurrences such as operations, delays, inspections, etc. are depicted by flow lines and symbols. Symbolic models are commonly used in systems studies because they can be constructed easily and quickly and are easy to interpret.

Analytical models are abstract expressions of the relationships among system variables that yield quantitative solutions. Although an analytical model is an abstraction, we can learn about the corresponding system or phenomenon by interpreting its variables and deducing a solution. These models can be simple calculations manipulated with paper and pencil or complex linear programming algorithms that determine the optimum solutions for a given set of problems (Harrell & Tumay, 1995). Other analytical models are sets of differential equations.

> An example of a system that can be described by an analytical model is an inventory control system with constant demand and fixed lead time for replenishment. The decision-maker's goal in studying such a system is to minimize the total cost of its operation. This cost, as a function of reorder quantity, can by mathematically described, and the optimum order quantity can be analytically obtained (Boxerman & Serota, p. 72)

Whenever feasible, researchers should use analytical methods to model systems or phenomenon. If the analytical model constructed is simple enough, the exact solution may be found using analytical methods such as algebra, calculus, or probability theory (Law & Kelton, 1982). However, an accurate mathematical expression representing the system is oftentimes too complex to write or solve using analytical methods. In practice, it is rarely possible to use analytical tools to solve models for systems that are extremely complex. Many systems are too sophisticated to model and/or solve using analytical means. In these instances, an appropriate approach is to turn to computer simulation as a way to model systems.

Simulation is a powerful modeling technique that enables researchers to study and experiment with complex systems. A simulation model allows a designer or researcher to experiment with alternative designs and operation strategies to determine how the changes effect overall system performance (Harrell & Tumay, 1995). Investigators can test the impact of a change or innovation using simulation modeling. They then can determine if the new operational procedure should be implemented within the present system. An analysis of the proposed system can be conducted, evaluated and modified, if necessary, before spending funds to implement a system, which may prove to be ineffective or inefficient. Simulation modeling allows investigators to anticipate the effects of changes, as well as to examine the current system.

Most computer simulation models produce a statistical summary of the important activity in the model over a specified period of time (Harrell & Tumay, 1995). Output may provide quantitative measures of system performance such as resource utilization rates, customer waiting times, or processing rates. The main objective of most simulation studies is to estimate performance measures of the current system and to identify input parameter values that will possibly improve these performance measures (Alexopoulos & Seila, 1998).

"As an experimental tool, simulation is used to test the efficiency of a particular design and does not, in itself, solve a problem or optimize a design (Harrell & Tumay, 1995)". Simulation models do not solve problems, but can identify problem areas and evaluate alternative solutions. By comparing the results of different scenarios, the optimal solution may be obtained.

Other modeling techniques often complement computer simulation. For instance, before building a simulation model of an emergency room, symbolic models of patient processes through the system may be constructed. These flowcharts can then be translated into the computer logic.

Model Classification

There are a number of ways of classifying models: We can broadly classify models by applying the following criteria to the state variables.

- *Temporality*: Do the state variables vary with time (dynamic) or are they static?
- *Topology*: Do the state variables allow infinitesimal variation (continuous) or finite variation (discrete)?
- *Precision*: Are the state variables predicted exactly (deterministic) or predicted probabilistically (stochastic)?

A dynamic model is one where the system state changes with respect to time. The events that occur within the model continually unfold, one event affecting another. As time passes, the state of a dynamic model changes. Most phenomenon occurring in our lives is dynamic in nature. An example of a dynamic model would be simulation model of a grocery store's activities in a 24-hour day. A static model is one that either omits any recognition of time or provides a snapshot of the state of a system at a moment in time (Fishman, 1973). For instance, an architectural model of a bridge is a static model.

Law and Kelton (1982) define and clarify the differences between discrete and continuous models. A discrete model is one for which the collection of dependent variables comprising the model change only at a finite number of time intervals. For instance, a simulation model of a bank is an example of a discrete model since the number of customers in the bank only changes when a customer enters the bank or when a customer finishes being helped and departs. A continuous model is one for which the variables change continually with respect to time. Such models typically are described by a system of differential equations. A model plane is an example of a continuous model since the variable, its velocity, changes continuously in time.

A model is said to be deterministic if the future behavior of the corresponding system can be predicted exactly, given complete information about the system at one instant in time or at one stage (Maki & Thompson, 1973). As noted previously, a pure mathematical model is a representation of a system in which the real phenomenon and its components are described by mathematical equations. For instance, Newton's law of universal gravitation mathematically models the attractive force between two bodies. This is a deterministic mathematical model because, for all practical purposes, there is little error in predicting the gravitational force between any two masses. There are many deterministic mathematical models that explain events that occur in nature. Mathematical textbooks are filled with deterministic models, most of them describing phenomenon about the world. In a deterministic simulation model, the result of one single simulation run provides exact measurements of the system's performance (Harrell & Tumay, 1995).

In contrast to a deterministic model, a stochastic model contains one or more random variables. These are probabilistic models. No matter how much one knows about the system under investigation, it is impossible to predict with absolute certainty how the system will behave in the future (Maki & Thompson, 1973). Lewis and Smith (1979) describe an example of a stochastic model discussed as follows. Picture a person dropping a penny repeatedly from a tall building and then recording the landing positions. The penny will not land in the same spot at each trial. The landing locations may vary as a result of some other phenomenon such as wind, so the position of the penny at each iteration is subject to some unknown error. There may be an apparent pattern in the landing spots, but the exact landing spot of the penny is, for all practical purposes, unpredictable. However, some landing spots are more likely then others which enables one to estimate the expected landing spot of the penny.

The output data for a stochastic model are themselves random and thus only give estimates of the true behavior of the system (Law & Kelton, 1982). That is, stochastic models only yield average responses. Confidence in the results is obtained by using a large enough sample size so that the estimation is a likely one. Deterministic methods are usually used to model well-understood events. Many systems, particularly man-made ones, are too complex to model using deterministic methods. For example, there is a deterministic method for modeling the penny example but it requires infinitely many variables, which makes the model impractical, if not impossible, to use. Thus, stochastic models become very useful.

Discrete-Event Simulation

Simulation models of systems can be classified as either discrete-event, continuous-event, or combined. Discrete-event simulation involves the modeling of a system as it evolves over time by a representation in which the state variables change only at discrete points in simulation time (Law & Kelton, 1982). In contrast, continuous-event simulation is used to model systems whose state is represented by variables that change continuously through time. Some systems are neither entirely discrete nor entirely continuous. Occasionally, it is necessary to construct a simulation model capable of modeling discretely changing and continuously changing state variables (Law & Kelton, 1982).

Most service systems are discrete-event systems. Examples include typical service settings such as banks and outpatient clinics. For example, a customer arrives at the bank and waits for a teller to become idle. A teller performs a variety of services for the customer who then departs the system. The arrival is a discrete event. The initiation of service by the teller also constitutes an event that reduces the number of customers waiting in the queue. Service completion and departure of the customer from the system constitute other discrete events that change the state of the system.

Throughout the remainder of this thesis, discussions will focus on discrete, dynamic and stochastic simulation models.

Advantages and Disadvantages of Simulation

Advantages and disadvantages of using discrete-event simulation as discussed by Law and Kelton (1982) include:

- Most complex, real-world systems with stochastic components cannot be accurately analyzed with an analytical model, even if such a model is available, because of the complexity of the analysis. For example, the number of parameters and variables may be in the thousands. Thus, a simulation is often the only type of analysis possible.
- Simulation allows one to test the effects of changing operating conditions, policies, and system design. New possibilities can be explored without committing funds and disrupting the actual system.
- Alternative systems can be evaluated using simulation to determine which alternative best meets the specified requirement(s). New systems can be designed, or an existing system can be redesigned or refined based on the simulation results.
- Using simulation, one can maintain much better control over experimental conditions than generally would be possible when experimenting with the actual system.
- System behavior can be studied over a long period of time within a short time frame.

Models of simulation can also be used as a tool in familiarizing personnel with a system or to demonstrate a new idea, system, or approach. (Chorafas, 1965). Simulation also provides better insights into interactions that may exist among variables in a complex system and to determine why certain phenomenon occur in a system (Banks, 1998). Simulation is not without disadvantages. Law and Kelton outline some drawbacks of using simulation.

- Simulation models take time to develop and are sometimes expensive.
- A stochastic simulation model only produces estimates of a model's true characteristics. These estimates are based on data and process designs introduced by the researcher. Confidence in the results is attained by running the simulation several times to ensure that the sample size is large enough and by validating that the output from the model is consistent with the data collected about the actual system. Simulation models are generally not as capable of optimization as they are at comparing a fixed number of specified alternative systems.
- If the simulation model does not accurately represent the corresponding system, the results will provide little beneficial information about the system's behavior. Researchers may place too much confidence in results that appear impressive.

Harrell and Tumay (1995) add other potential dangers of using simulation. The results can be misinterpreted. And sometimes it is hard to determine whether the results are valid. They agree with Law and Kelton in regards to the cost and time issues. However, Harrell and Tumay justify the these issues in stating that "the savings from the project far exceeds the cost of simulation. The cost and time to simulate a system becomes minuscule compared with the long-term savings from having efficiently operating systems"(Harrell & Tumay, p. 13).

When to Simulate

The benefits and drawbacks should be taken into account when deciding whether or not to use simulation to model a system. If an analytical model can be developed it should be used over a simulation model. Harrell and Tumay (1995) say simulation is appropriate when:

- Building a mathematical model is impractical or impossible.
- The system has one or more interdependent random variables.
- The interactions between variables of the system are extremely complex.
- The question of interest requires observing the system over a very long or very short period of time.
- The ability to illustrate the system using animation is important.

Uses of Simulation

Simulation was first used by the aerospace industry during the 1950's, primarily for military applications. The popularity of simulation progressed slowly because computers were costly, modeling required difficult and extensive programming, computer memory was constrained, and processing speeds were slow (Harrell & Tumay, 1995). Today, simulation is used in many areas. Computers are now less expensive, and have greater processing speeds and memory. Furthermore, the simulation products available are easier to use and provide more capabilities.

Simulation is now commonly used in a wide spectrum of manufacturing and service systems. There is a vast amount of software available today for modeling these systems. For instance, there are now industry-specific simulation products that are tailored to model specific domains. Simulation can be used in many different ways including the following listed by Pritsker (1998):

- As an *explanatory tool* to understand a system or problem
- As a *communication means* to describe the operations of a system
- As an *analysis tool* pinpointing critical elements affecting system performance
- As a *design assessor* to evaluate proposed solutions and construct new alternative solutions
- As a *scheduler* to develop schedules for resources, tasks, and jobs
- As a *training tool* to help personnel in learning how a system operates
- As a *control mechanism* for the distribution and routing of materials and customers
- As a *part of the system* to provide on-line information, status projections, and decision support.

As an explanatory tool, an analysis tool, and a design assessor, simulation can be used to develop a new system or modify an existing system. In constructing a new system, simulation can help planners predict how a system will operate and, if necessary, make changes before spending funds to implement a system, which may prove to be ineffective or inefficient. In an existing system, simulation is used to identify critical elements affecting system performance, to examine and test proposed solutions to problems, and to determine the best alternative solution.

When simulation is used to design a new system or modify an existing system, the following issues are addressed:

- *Methods selection*: Should several activities all be performed at a single station or broken up into several operations?
- *Optimization*: What is the optimum number of resources that best achieves performance goals?
- *Capacity Analysis*: What is the throughput capacity of the system?
- *Control system decisions*: Which tasks should be assigned to which resources (Harrell & Tumay, 1995)?

As a control mechanism and a scheduler, simulation helps in managing the operation of a system. It can be used to determine the best way to control the distribution and flow of customers and materials, in addition to developing schedules for resources, tasks, and jobs. "A manager can more accurately predict outcomes and therefore make more intelligent and informed decisions by simulating alternative production schedules, operating policies, staffing levels, job priorities, decision rules, etc." (Harrell & Tumay, 1995). Simulation can assist managers in making these decisions:

- *Production/Customer scheduling*: What is the best sequence and timing for introducing products or admitting customers into the system?
- *Resource Scheduling*: What staff and equipment are necessary during which shifts?
- *Maintenance Scheduling*: What preventive maintenance schedule is the least disruptive to the system operation?
- *Work Prioritizing*: What is the best way of prioritizing tasks to maximize results?

- *Flow Management*: What is the best way of controlling the distribution and flow of customers/materials in the system?
- *Delay/Inventory Management*: What is the best way to keep customer waiting or inventory levels to a minimum?
- *Quality Management*: How will operations be affected if inspection points are taken away and personnel assume full responsibility for the quality of their work (Harrell & Tumay, 1995) ?

As a means of communication and a training tool, simulation can help personnel to learn about the operations of a system. It enables operators, service representatives, or supervisors to understand what occurs when alternative decisions and operating procedures are implemented (Harrell & Tumay, 1995). This will greatly assist personnel in understanding system operations, thus preparing them to work with the actual system. Training personnel using simulation is also "less expensive and less disruptive than on-the-job-learning" (Banks, 1998, p. 12).

Steps in the Simulation Project

There are several necessary steps designing a simulation model. The following steps were developed by Banks (1998), Musselman (1998), McGuire (1998), and Shannon (1975).

- *Problem formulation*: The researcher defines the problem to be studied and identifies the process to be simulated. The statement of the problem must be well understood by the researcher and the client. Also, the researcher must be certain that he or she clearly understands what aspects of the process are to be included in the simulation.

- *Define the objectives and goals of the study*: The researcher defines the objectives of the simulation project. The objectives signify the questions to be answered by the study.
- *Formulate and define the model*: The researcher designs the basic structure and content of the model. The actual system is abstracted into a conceptual model, such as a flow diagram that includes the elements of the system, their characteristics, and their interactions. Banks (1998) recommends beginning the modeling process simply. Add more features, as necessary, until a model of appropriate complexity has been designed.
- *Data Collection*: The researcher identifies, defines, and collects the data that need to be put into the model.
- *Model translation*: The researcher captures the conceptualized model using a simulation language acceptable to the computer being used. Musselman (1998) recommends considering the following guidelines during the model building stage: focus on the problem, start simple and add detail later, curb complexity, maintain momentum, and continue to review the project.
- *Model verification*: The researcher examines the simulation program to be sure that the operational model correctly reflects the conceptual model. McGuire (1998) suggests comparing the model flow with flowcharts. The researcher must confirm with the client that the correct process is being used.

- *Model validation*: The researcher runs the simulation to determine if the output from the model is consistent with the data collected about the actual system. There should not be a significant difference between the two. If there is, "the analyst must find the area of the model that is causing the most deviation from the historical data and use direct observation to find the offending process" (McGuire, 1998, p. 613).
- *Experimentation*: The researcher develops and tests various alternatives that are directly related to the project's objectives. These alternatives represent changes to the existing system and are tested to determine if they improve the system's performance.
- *Interpretation*: The researcher interprets the results of the alternative in terms of their bearings on the project's objectives.
- *Documentation and reporting*: The researcher records the results of the analysis. This will give the client a report on the "alternatives that were tested, the criterion by which the alternative systems were compared, the results of the experiments, and analyst recommendations, if any" (Banks, 1998, p. 18).

There are three aspects particular to stochastic computer simulation that the analyst needs to be aware of when performing verification and validation. They are: random number generation, generation of input variables, and analysis of output data.

Random Number Generation

Stochastic simulation models do not yield the exact theoretical solution of the system under investigation, rather they enable one to find the best workable solution among a set of solutions (Harrell & Tumay, 1995). Sample runs of the output data for a stochastic simulation model only provide an estimate of the true characteristics of the system. Moreover, during each run of the simulation, numerical values of each random input variable must be provided.

To generate sample input values in a stochastic simulation model, a random number generator must be used. The generator is a computer program, which produces values that are uniformly distributed between 0 and 1, at least approximately so. Also, the values generated are assumed to be independent and identically distributed.

However, the sequence of numbers resulting from the random number generator does not meet all the criteria that establish randomness. The numbers generated are deterministic because any given sequence can be reproduced given the starting value. Thus, the numbers generated are actually pseudorandom. Banks (1998) says that there is no need to be concerned, though, since the length of given sequence is quite long prior to repeating itself.

Input Data

The variance for each element in a system being modeled must be represented in some way. If the variables are independent of each other, then one technique is to fit a probability distribution to the data for each variable. If such a distribution is found, the random numbers generated by the computer can be transformed to mimic that distribution. The variables are thus going to be modeled as random variates. Random variates are used to represent, for example: interarrival times, batch sizes, processing times, repair times, and time between failures. (Banks, 1998). Stochastic systems often have time or quantity values that vary from incident to incident. Probability distributions are helpful for predicting the next time, distance, quantity, etc. to use for a particular random variable in the simulation, such as the mean arrival rates for patient types (Harrell & Tumay, 1998).

For many queuing processes, the fitted distribution is quite predictable. For instance, if arrivals are coming from an infinitely large population, occur one at a time, are totally at random, and are completely independent of one another, a Poisson process occurs. The number of arrivals in a certain time interval fits a Poisson distribution and the time between arrivals fits an exponential distribution (Banks, 1998). Banks recommends following this three-step procedure to fit appropriate distributions to the data:

- Hypothesize a candidate distribution.
- Estimate the parameter(s) of the hypothesized distribution.
- Perform a goodness-of-fit test such as the chi-squared test.

Output Data Analysis

Because the input variables are random (arrival times, etc.), then the output measures are also random (throughput times, averaging waiting times) (Harrell & Tumay, 1995). As noted previously, after several simulation runs, the output data for a stochastic simulation model provides only an estimate of the true characteristics of the model. Simulation runs usually do not produce observations that are independent and identically distributed. Thus, the researcher must take care in drawing inferences based on applying traditional statistical methods in the analysis of simulation output. However, there are statistical techniques for computing confidence intervals after *n* simulation runs to determine, for example how close the sample size average ($\overline{X}$) for a given variable is to the true mean (μ).

Areas of Applications

The applications areas of discrete-event simulation are widespread. Documented studies show that simulation has been used for systems studies in many different areas. Among many others they include: manufacturing systems, military systems, transportation systems, and service systems.

Simulation has proven to be an effective tool for modeling manufacturing systems. In one study, cited by Rohrer (1998), the Boeing Company located in Washington was examining the manufacturing process for the new 777 aircraft. An elaborate crane system handled the flow of large parts, such as wings and engines, between assembly processes. Using computer simulation, engineers were able to view the crane movements of large parts with three-dimensional animation. Boeing was able to determine the crane handling capacity and a realistic build rate for the new aircraft.

Simulation has been used successfully in the military for problems including wargaming, acquisition, logistics, and communication. It can been used as "a decision support tool to determine how a battle force should be constituted, how it might be deployed, and how the weapons system should be acquired and maintained" (Kang & Roland, 1998). For instance, wargaming simulation models are used as a safe and inexpensive alternative to live training exercises.

Transportation systems provide a wealth of application for simulation. There are basically five modes of transport for freight and passenger movements. They are: motor vehicles, railroads, air transport, water transport, and pipelines. Simulation studies have been documented that analyze intelligent vehicle and highway systems, and airport/airline operations. In one study at O'Hare International Airport in Chicago, simulation was used to design a baggage handling conveyor system for a new terminal. The purpose of the model was to test several different alternative designs for storing luggage (Rohrer, 1998).

The application of simulation in service systems is also beneficial. Some service systems that have been studied using simulation are: banks, food service, health services, financial services, and entertainment. Many service systems are stochastic, complex, and discrete processes operating in resource-constrained environments (Laughery, Plott, and Scott-Nash, 1998). Thus, discrete-computer simulation provides a means of understanding, analyzing, and optimizing various service systems. For example, in a study cited by Laughery *et al.*, simulation was used to improve the time customers spent in a Japanese bank. In another study conducted by Kharwat *et al.* (1991), simulation was used to investigate restaurant and delivery operations relative to staffing levels, equipment layout, workflow, customer service, and capacity (cited in Harrell & Tumay, 1995). Numerous successful applications using computer simulation in the health services arena have been documented. This type of application is the principle focus of this paper. Many simulation studies of hospital emergency departments will be discussed in the following section.

Simulation in Emergency Departments

Hospital emergency departments are continuously searching for ways to improve the efficiency and performance of their systems. Health care planners, recognizing the need to continuously improve the quality and efficiency of their emergency department (ED) operations, are often required to make changes, sometimes costly ones, to the system without knowing if improvements will result. Indeed, making such complex decisions on a trial-and-error basis in such a complex environment can be not only difficult, but also very costly. With the increasing capability and availability of computers, a growing number of hospitals are using simulation technology to help identify ways to improve the system, especially when there are several alternatives to consider (McGuire, 1997). Managers of health care delivery are finding it necessary to use computer simulation to assist them in the decision-making process. Many successful applications using computer simulation in the health services arena have been documented. The following literature review provides some examples of hospital-related problems simulation can address.

During the 1960's simulation studies in health care systems began to evolve. In 1965, Fetter and Thompson used simulation to construct three models of proposed hospital subsystems: a surgical pavilion, a maternity suite, and an outpatient clinic. The model of the surgical subsystem was designed to allow experimentation with various configurations of special and general purpose operating rooms and with various scheduling policies. The simulation model of a maternity suite was built to predict the facility requirements for various patient loads given a variety of treatment levels. An outpatient model was designed to examine the effect of patient volume on patient waiting times given a generated schedule of appointments for each doctor on each day based on predetermined load factors, appointment intervals, and office hours.

In 1967, Handyside and Morris utilized simulation to determine the bed occupancy rate of emergency patients. They used as input data the mean daily admissions for all patients, the distribution of length of stay for all patients, and the emergency admissions schedule. Many hospitals are faced with the problem of finding inpatient accommodation for patients who need immediate attention. This simulation model tested various rotational admission schedules and how they affected bed occupancy of emergency patients.

Simulation studies have provided administrators with decision support for justifying expansion projects and new facility designs. Schmitz and Kwak (1972) used simulation to examine the amount of operating and recovery space needed for a 144-bed increase at Deaconess Hospital in St. Louis. Zilm, Calderaro, and Del Grande (1976) used simulation to predict the optimum number of operating rooms for a surgical suite.

The subject of patient flow has been studied in many simulation projects. Flagle (1970) tested changing the operations of a busy outpatient clinic in attempt to reduce patient waiting times. He proposed that patient delays could improve by combining certain tasks, thus operating with a parallel flow rather than a serial one. By training the cashier and the registrar in each other's job, bottlenecks were reduced for early patient contacts.

In another study, Alessandra, Grazman, Parmeswaran, and Yavas (1978) developed a computer model to determine how changing staffing procedures would reduce patient waiting times in a family planning clinic of a large Southeastern hospital. Several alternatives were evaluated to see if they improve the observed bottlenecks. A new scheduling policy was recommended for implementation, shifting 35% of the patients scheduled in the morning to the afternoon hours while keeping the present staff of two full-time operating desks.

Hunter, Aslan, and Wiget (1987) designed a simulation model to investigate surgical patient movement in Montefiore Medical Center, located in Bronx, New York. The 1176 bed teaching facility was about to undergo major building renovations and expansions. The expansion included the addition of 17 new operating rooms to replace the current 13 facilities. The hospital administration also wanted to strengthen and expand several surgical subspecialties. The objectives of the simulation study were to:

- Determine the number of Recovery, ICU, and Surgical Patient beds necessary to accommodate varying patient volumes and mixes.
- Determine the results of adding a Stepdown bed system, which s defined as a bed requiring more intensive care than a regular unit bed, but not as much needed for intensive care or the Recovery room.
- Determine resource utilization for surgical patient length of stay variations.
- Allow for future study, including staff and material resources required under each scenario.

The paper only addressed the Neurosurgery model development and conclusions. Similar models were designed for other surgical specialties. The results of the Neurosurgery model indicate that the most effective operational balance to be: 10 ICU beds, 24 Regular beds, 2 Operating rooms, 2 Recovery Room beds, and 4 Stepdown Beds.

Levy, Watford, and Owen (1989) developed a simulation model of a proposed outpatient service center at Anderson Memorial Hospital in Anderson, South Carolina.

The model was designed based on historical data. The results of the simulation were used to determine minimum facility design requirements, based on various expected demands.

Klafehn and Owens (1987) used a simulation model design to examine resource utilization in the pediatric emergency room at the Children's Hospital Medical Center of Akron. They investigated the differences in patient flow using two orthopedic groups versus one orthopedic group. The results indicated that the length of stay for orthopedic patients was significantly reduced when a second orthopedic group was added. However, the addition of the orthopedic room did not significantly reduce the length of stay for all patients in the emergency room.

Badri and Hollingsworth (1992) used simulation modeling for scheduling in a 600-bed Rashid Hospital in the United Arab Emirates. The hospital wished to evaluate: the processes of the current system, the consequences of referring patients with minor ailments to local medical clinics, the effect of classifying patients depending on the severity of their ailments; and to test the impact of reducing the number of resources. Several "what-if" questions resulted from the study. The management team, using computer simulation, selected as the best scenario the one that most significantly reduced resource utilization while keeping the patient mean time in the system within acceptable limits.

In 1997, McGuire conducted a study using health care-specific simulation modeling software to decrease the length of stay in a level II emergency department. The simulation software, MedModel, is a Microsoft Windows based simulation software developed for modeling health care systems. The package was originally produced in 1988 by ProModel Corporation. The software provides built-in graphics specific to health care so that the icons and animation are appropriate to the environment being investigated.

MedModel also provides a built-in programming language, which allow the user to specifically tailor the program to the process they are attempting to model. McGuire tested five alternatives intended to reduce patient length of stay. The final recommendation included combining four of the five scenarios and reduced length of stay by 50 minutes to 107 minutes.

Due to the stochastic nature and complex dynamics of hospital emergency departments, analysts are increasingly using discrete event stochastic simulation as a tool for evaluating emergency care systems. Computer simulation modeling is an effective tool that may assist emergency department managers in many areas such as: lowering costs, reducing patient wait times, improving facility design, scheduling staff, training and educating staff, and testing new equipment. Evidence has shown that simulation modeling is an extremely effective analytical tool in developing solutions that improve the performance of emergency departments. A simulation model allows patient flow, facility layout, staffing, procedure and equipment changes to be tested so that optimal strategies for the ED can be designed and implemented. (Kilmer, Smith, Shuman, 1997). Simulation modeling allows management to anticipate the effects of changes, as well as to examine the current system (Badri, Hollingsworth, 1992). "It is probably the only decision support tool that could be used in such a complex situation" (Badri, Hollingsworth, p. 13).

CHAPTER III

METHODOLOGY

Brackenridge Hospital

There are 22 Trauma Service Areas (TSAs) in Texas, divided geographically by county. Brackenridge Hospital located in Austin is designated in Area O, serving the 13-county Central Texas area. This hospital is part of the Seton Healthcare Network serving as the leading trauma facility in Area O, and offering the highest level of trauma care where the majority of critically injured patients receive care. The facility has level II certification providing comprehensive trauma care for all types of injuries and illnesses, except for seriously burned patients who are stabilized and transported to burn centers. The center has 357 beds for adult patients and 84 beds for pediatric patients. The emergency department is equipped and staffed to treat patients with minor or major conditions, 24 hours a day, 7 days a week. Surgeons and surgical specialists are available around the clock. Because these sub-specialists are not in-house 24 hours a day, Brackenridge is designated level II. A qualified medical social worker is available 24 hours a day to help stabilize psychiatric patients. The center is also the home base for the Star Flight helicopter rescue service, offering pre-hospital care via air ambulances. Brackenridge has a separate children's emergency center developed specifically for injured or ill children.

The adult division of the emergency room treats over 50,000 patients annually. The staff includes physicians, nurses, technicians, residents, and interns. The adult ER is equipped with 10 trauma beds, and 20 treatment beds, three of which are designated for minor care patients, and three of which are for Obstetrics/Gynecology (OB/GYN) and Eye, Ear, Nose, and Throat (EENT) exams. Additionally, the emergency department has a radiology room. The average length of say for outpatient adults in the emergency department is 157.3 minutes and for inpatient adults is 258.3 minutes.

Simulation Software

The simulation software selected to model the adult emergency department at Brackenridge Hospital is MedModel version 3.5. Medmodel is a Microsoft Windows based simulation software developed for modeling and analyzing health care systems of all types. The package was originally produced by ProModel Corporation in 1988. The software provides built-in graphics specific to health care so that icons and animation are appropriate to the environment being investigated. The simulation model depicts a dynamic animated representation of the system and produces various performance measures such as resource utilization rates, waiting times, and throughput times. Additionally, MedModel provides a built-in programming language, which allow the user to specifically tailor the program to the process they are attempting to model.

Steps in the Simulation Study

There are several necessary steps to follow in order to complete a simulation model. The steps used to design this model are presented in Figure 1.

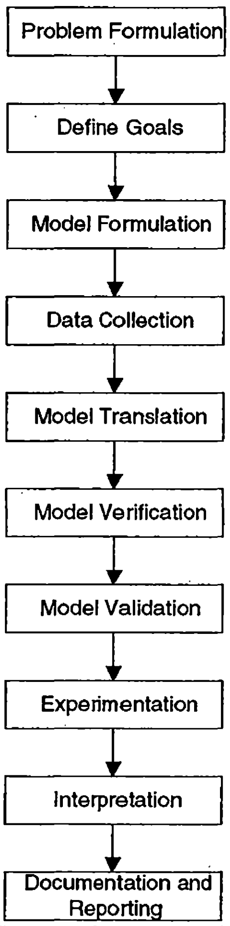


Figure 1. Steps in Building a Simulation Model

Problem Formulation

The problems studied in this simulation project focused on resources utilization rates for doctors, nurses, and technicians, patient waiting times, and patient throughput times. The process simulated was patient flow through the emergency department from patient arrival to discharge or admit. During preliminary meetings, the administrators stated their objectives, so the focus of the project was well understood.

Define the Goals of the Study

The goals of this research project are to capture data, to model the delivery of emergency care within the adult emergency department at Brackenridge Hospital, and to provide estimates of system performance. Proposed analysis issues are: determination of the average patient waiting times by patient type, the average throughput times by patient type, resource utilization rates, and how these times and rates are affected by changing process flows or resource levels.

Formulate and Define the Model

Flow diagrams were constructed to depict patient flow through the entire system. Four of these were designed, illustrating patient flow from the time a patient arrived in the emergency department to the time the patient was admitted or discharged. The flow diagrams were reviewed by clinical managers to check for accuracy. Then, necessary changes were made to reflect their comments.

The first flow chart (presented in Figure 2) illustrates the flow of patients who enter the emergency department through the walk-in entrance. Upon arrival, patients check-in with the triage nurse who begins an initial assessment. The triage nurse assigns patients into one of four categories based on their age and the acuity of their medical needs. These categories are listed as follows in order from most critical to least critical: immediate, urgent, non-urgent, and minor care. The triage nurse performs a complete and thorough assessment of immediate, urgent, and non-urgent patients. The triage process for a minor care patient is completed after the patient is placed in a bed in the Minor Emergency Center (MEC).

The triage nurse transports immediate patients directly to CRASH, the trauma care area, for prompt medical attention. These patients are immediately seen by the CRASH nursing staff for complete vital signs, a thorough assessment, and stabilizing care. The nursing staff initiates appropriate medical procedures based on the patient's chief complaints. The CRASH doctor is promptly informed of all immediate patients and examines these patients within 5 minutes of arrival, provides emergency treatment, performs necessary medical procedures, and orders appropriate tests. The nurses and technicians in CRASH carry out the doctors orders. Senior level residents in surgery, obstetrics-gynecology, pediatrics, and internal medicine, and upper level residents in orthopedics and neurosurgery are in-house 24 hours a day for necessary emergency consultation. Immediate patients are registered at bedside when time permits during the treatment process.

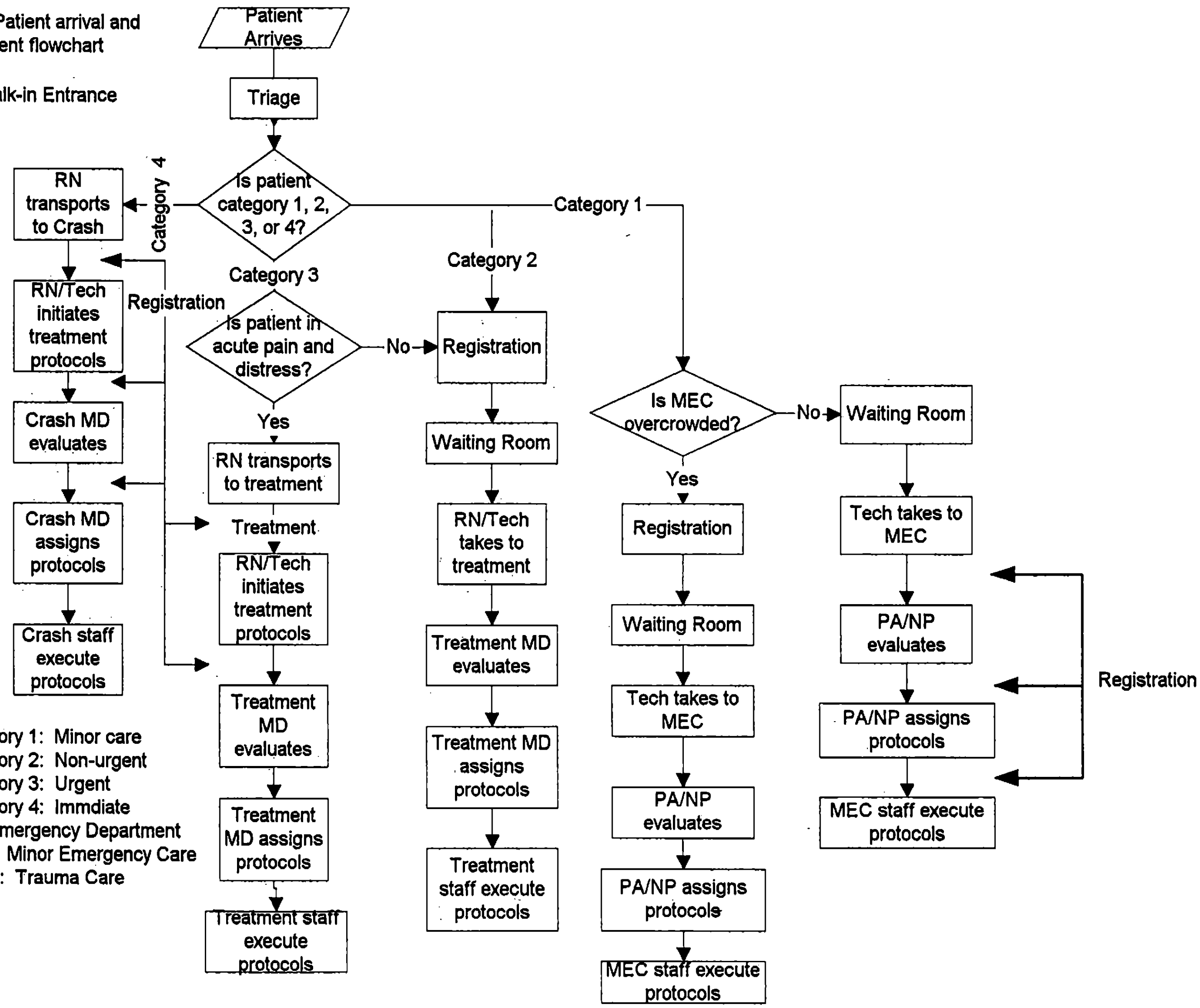
Urgent patients in acute pain and suffering are taken directly to the treatment area after triage and are registered at bedside. Urgent patients who are stabilized and are not suffering from acute pain and distress are sent to the registration desk, then to the waiting room. These patients are always given priority to be taken to the treatment area from the waiting room. Urgent patients follow the same treatment process as immediate patients, except they may have to wait for treatment (depending upon the acuity of their injury or illness) and are sometimes registered at the registration desk.

Non-urgent patients are sent to the registration desk after triage assessment. These patients are taken to the treatment area when a bed is available. Then, a doctor evaluates each patient, performs appropriate medical procedures, and orders necessary tests. The treatment staff then execute the doctor's orders.

If the MEC area is not crowded the MEC technician takes minor care patients to a bed or to the MEC waiting area. Otherwise, MEC patients wait in the triage waiting room until a bed is ready or space is available in the MEC waiting area. Minor care patients are registered at bedside or in the MEC waiting area. The MEC nurse practitioner is responsible for completing the triage process and may supervise the LVN nurse in completion of all triage data. The nurse practitioner evaluates each patient, provides treatment, and orders appropriate tests. The MEC staff carry out these orders.

Figure 2. Patient arrival and treatment flowchart

Walk-in Entrance



Category 1: Minor care
Category 2: Non-urgent
Category 3: Urgent
Category 4: Immdiate
ED: Emergency Department
MEC: Minor Emergency Care
Crash: Trauma Care

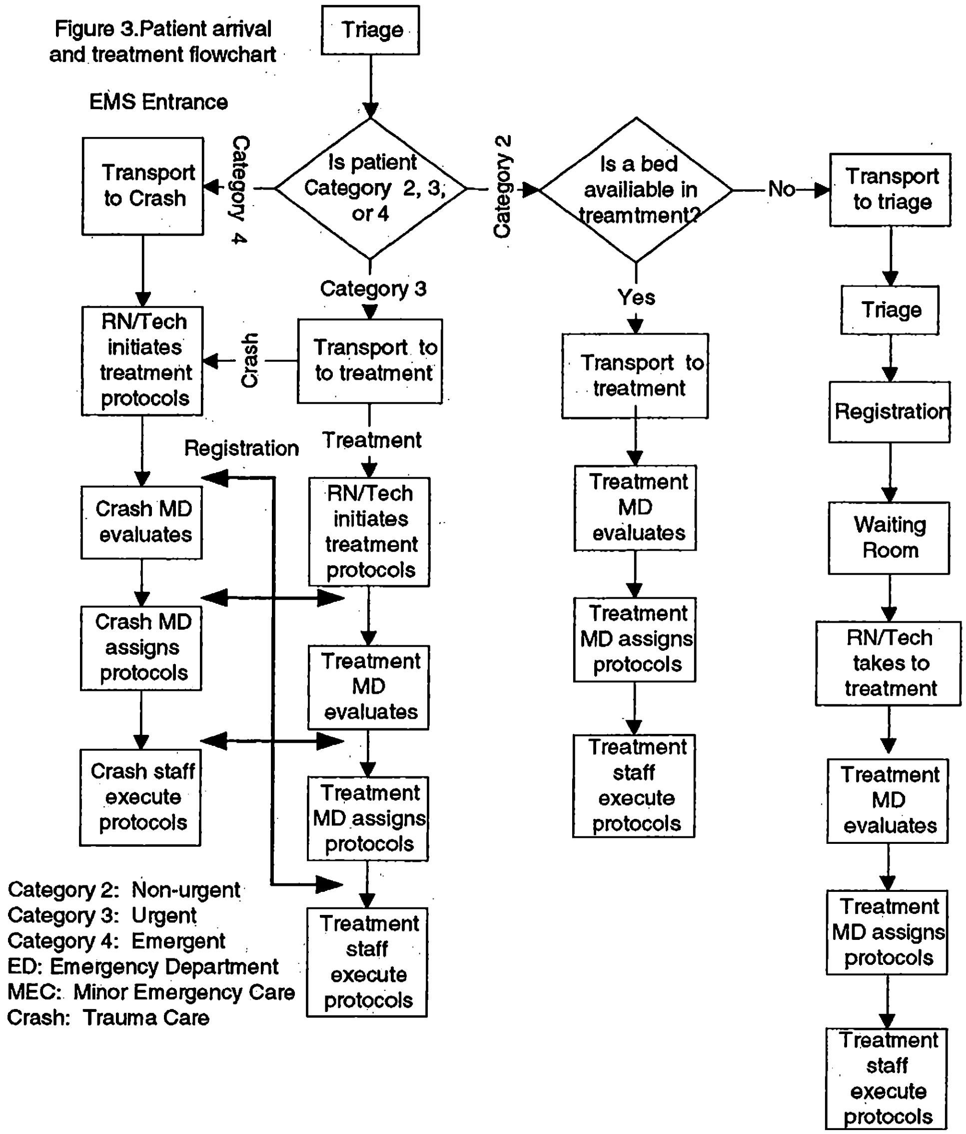


Figure 3 above illustrates the flow of patients who arrive by ambulance or by Star Flight helicopter rescue service. Most patients arriving by ambulance are immediate or urgent patients. These two types of patients are directly taken to the appropriate emergency care area where a nurse immediately triages the patient. The treatment process is the same for these patients as those arriving in the walk-in entrance. Non-urgent patients who arrive in the ambulance entrance are placed in a treatment bed if one is available. Otherwise, these patients must be transported to triage and follow the same process as a non-urgent patient who arrived in the walk-in entrance.

Figure 4. Medical Procedures Flowchart

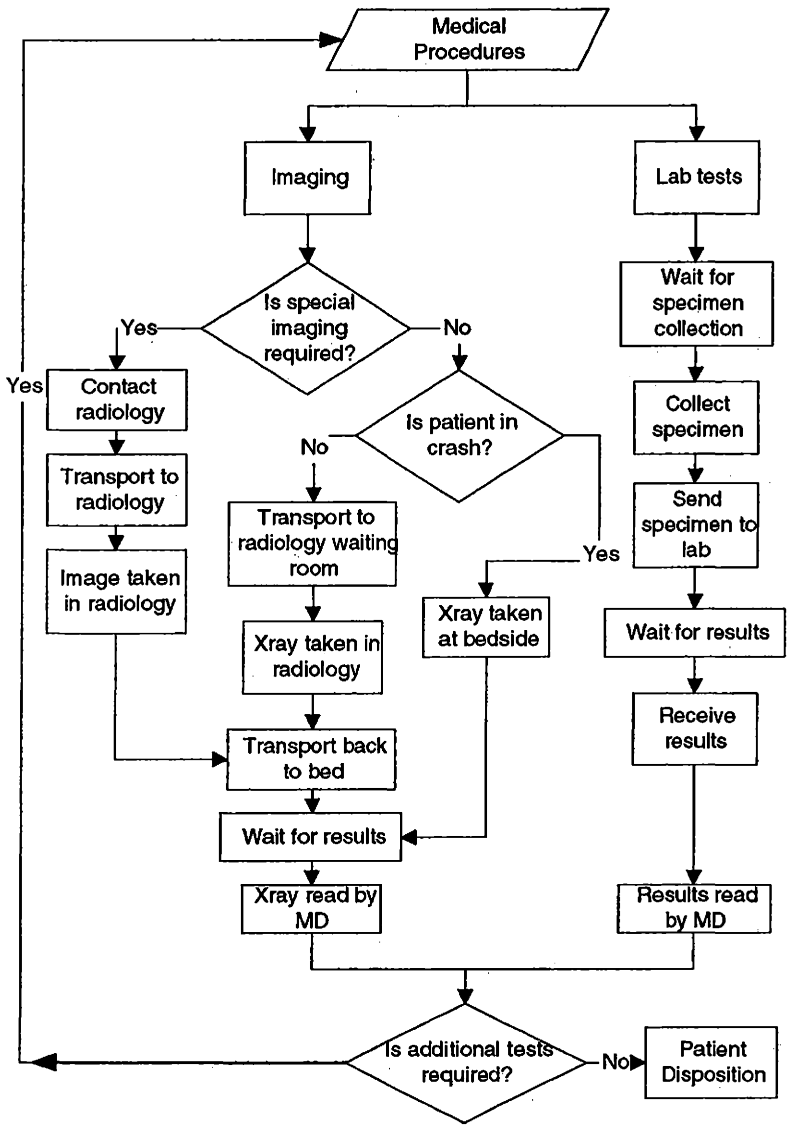


Figure 4 depicts the flow of patients who require imaging or lab work. Minor care, non-urgent, and urgent patients who need x-rays are transported to the radiology waiting room in the emergency department. The x-ray technician transports patients into the radiology room to take x-rays, and then transports them back to their beds. A portable x-ray machine is typically used to take x-rays of immediate patients in CRASH. Patients requiring special imaging, such as computerized tomography and sonograms, are transported to the radiology department to complete these procedures. A technician or nurse transports these patients back to their beds. Blood, urine, and other lab work is completed outside the emergency department. The results are sent back to the emergency department after analysis. Special imaging, x-ray and lab results are all reviewed by physicians or nurse practitioners who then decide if additional tests are required.

Figure 5. Patient Disposition Flowchart

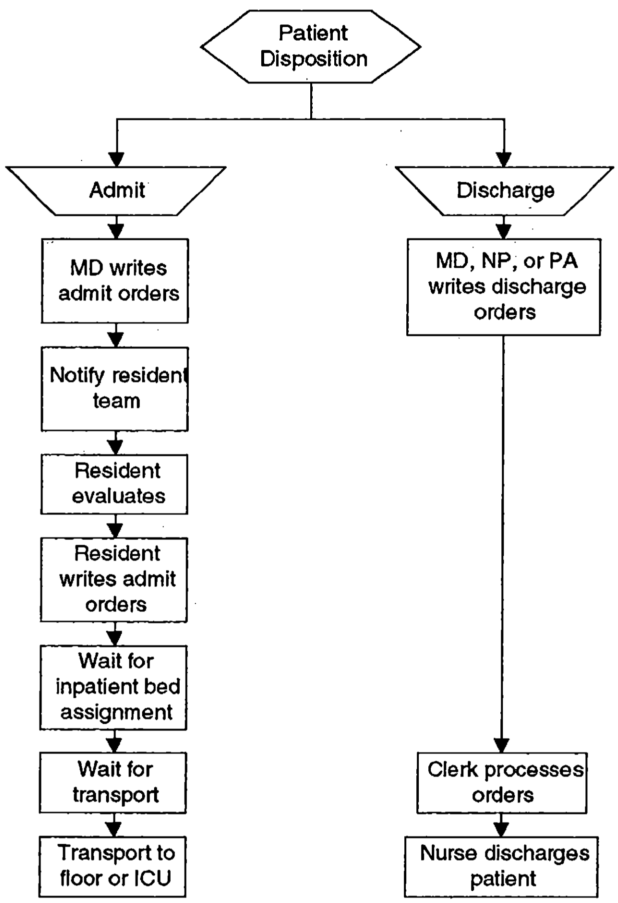


Figure 5 illustrates the patient disposition flow diagram. After all patients have been treated in the emergency department they will either be discharged or admitted. Patients requiring further medical care and/or observation are admitted to Brackenridge Hospital and transferred to appropriate inpatient units or to the intensive care unit (ICU). Otherwise, patients are discharged from the emergency department and referred to an appropriate clinic or specific physician for follow-up care.

Data Collection

The data collection process consisted of using data already generated by the emergency department in ER logs, reviewing patient records, interviewing staff, surveying staff, and direct observations. From these sources, data on the number of patients arriving within each acuity level, scheduling patterns, treatment times, waiting times, and throughput times were collected. The data collected on throughput times for patients Clinical managers reviewed the data collected for verification.

The data used to find the number of patients arriving within each acuity level was collected by reviewing medical records from 11 days total during the months of May, June, and July of 1999. A total of 1776 records were reviewed. Of the 1776 patients who were treated, 19.5 percent were minor care, 50.4 percent were non-urgent, 14.9 percent were urgent, and 15.2 percent were immediate. This data, as well as the percent of admits within each category and the percents of patients arriving in the ambulance and walk-in entrances for each patient type, are presented in Table 1. The researcher also calculated the average length of stay for each patient type from this sample of medical records. The researcher determined the length of stay time for each patient by taking the difference between the time the patient was discharged or admitted to the hospital and the time the patient checked-in with the triage nurse. The emergency department itself gathers data on average throughput times for discharged and admitted patients. However, these times are determined by taking the difference between the time the patient was discharged or admitted to the hospital and the time the patient registers. Thus, the times collected by the researcher more accurately represent the patient's experience.

Table 1. Patient Acuity Levels

Patient Level	Percent	Percent Walk-in	Percent Ambulance	Percent Admits
Minor Care	19.5%	100%	0%	0%
Non urgent	50.4%	87%	13%	4%
Urgent	14.9%	58%	42%	19%
Immediate	15.2%	35%	65%	63%

The arrivals were averaged over 11 days from which medical records were reviewed. Figure 6 depicts the arrival cycles in 2-hour increments for all patient types. Table 2 shows the percent of patients that arrive in the EMS and walk-in entrances in 4-hour increments during a 24-hour cycle. Arrivals percents for minor care patients were estimated separately, since the minor care area is only open from 11:00 a. m. to 11:00 p. m. These times are summarized in Table 3. Arrivals are strongly dependent on the time of day. The busiest time of the day for all patients who arrive in both the walk-in and ambulance entrances is from 9:00 a.m. to 11:00 p.m. By 12:00 a.m., the arrivals sharply decline. The slowest time of the day is from 4:00 a.m. to 8:00 p.m.

Figure 6. Patient Arrival Cycles

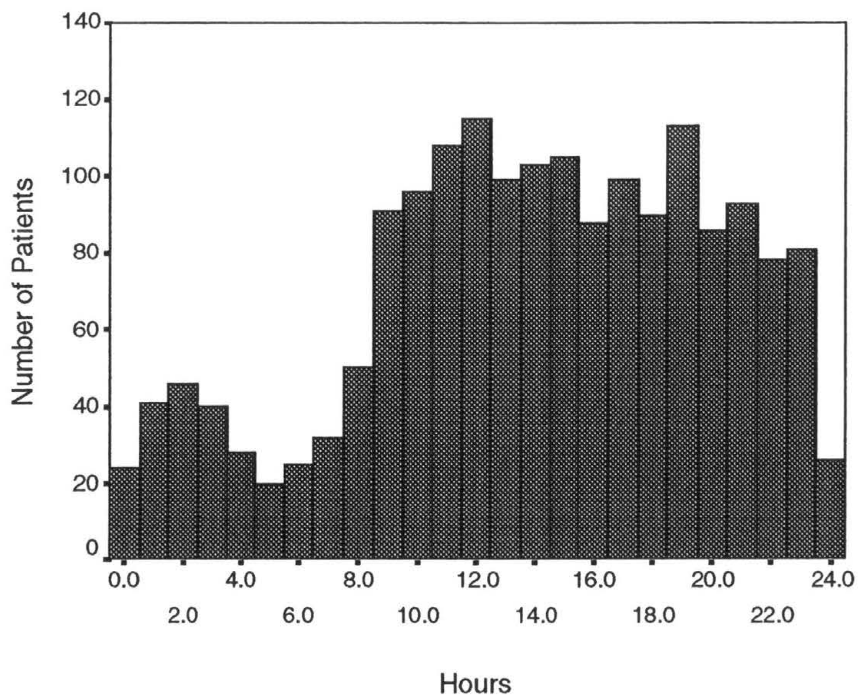


Table 2. Patient Arrivals (%) by Time of Day

Time Period	Patients (Walk-in)	Patients (EMS)
4:00 a.m.	8.6	14.7
8:00 a.m.	7.5	9.8
12:00 p.m.	25.2	15.7
4:00 p.m.	23.1	18.1
8:00 p.m.	21.2	20.6
12:00 p.m.	14.4	21.6

Table 3. MEC Arrivals (%) by Time of Day

Time Period	Patients
11:00 a.m.	17.2
2:00 p.m.	19.2
5:00 p.m.	22.8
8:00 p.m.	23.3
11:00 p.m.	17.5

Data on scheduling patterns for doctors, nurses, and technicians were collected. These schedules were used in the simulation model. The emergency department staffing levels are based on a plan that attempts to anticipate patient volumes and acuity levels. This plan provides minimum, adequate staffing levels present at all times to treat the patient populations predicted from trends and historical data (Brackenridge Emergency Department Staffing Plan). Doctors work one of six eight-hour shifts. There are 3 doctors on shift from 12:00 p.m. to 1:00 a.m., two on shift from 1:00 a.m. to 4:00 a.m. and from 6:00 a.m. to 12:00 p.m., and one on shift from 4:00 a.m. to 6:00 a.m. There is always one doctor designated in CRASH. However, the CRASH doctor does treat patients in the treatment area. The staffing matrix for nurses and technicians is illustrated in Table 4.

Table 4. Staffing Matrix for the Adult Emergency Department

Resource	7:00 a.m.	11:00 a.m.	3:00 p.m.	7:00 p.m.	11:00 p.m.	3:00 p.m.
Triage RN	1	1	1	1	1	1
Charge RN	1	1	1	1	1	1
Treatment RN	2	2	3	3	2	2
PFC RN	1	1	1	1	1	1
Treatment Tech	2	2	2	2	2	2
CRASH RN	2	2	2	2	2	2
CRASH Tech	2	2	2	2	2	2
MEC Tech	0	1	1	1	0	0
MEC LVN	0	1	1	1	0	0
MEC NP	0	1	1	1	0	0

There is always one RN on duty in triage where walk-in patients receive an initial assessment. Charge RN's are primarily responsible for supervising the staff in the adult and children's emergency departments; some of their responsibilities include assisting with patient care and with patient flow, relieving staff for breaks, assigning staff to specific areas, handling patient complaints, and administrative duties. The treatment RN's are designated in the treatment area and are assigned to care for non-urgent and urgent patients in specific rooms. There is always two RN's assigned in CRASH to care for immediate patients. The patient flow coordinator (PFC) RN is primarily responsible for coordinating patient assignments and nursing care in the treatment area. The PFC nurse is also utilized in CRASH when necessary. One treatment technician assists with patient care in the treatment area, and one technician serves as a clerk. This is also true for the two technicians in the CRASH area. The clerk's responsibilities include arranging for patient care in other departments, typing doctor's orders and discharge orders, and answering the phone. There is one technician, one LVN, and one Nurse Practitioner assigned to MEC, which is open from 11:00 a.m. to 11:00 p.m.

Table 5. Resource Treatment Times (minutes)

	Physicians	Nurses	Technicians
MEC Assess	10	5	5
MEC Reassess	6	7	7
Non-urgent Assess	5	7	7
Non-urgent Reassess	5	10	10
Urgent Assess	8	7	7
Urgent Reassess	7	12	12
Immediate Assess	1	33	33
Immediate Reassess	8	11	11

Data on treatment and service times for physicians, nurses, and technicians necessary to build the simulation model were gathered. This information was obtained by on-site observations, interviews, and surveys. Respondents to surveys and interviews were asked to estimate the time needed to initially assess and reassess patients for specific patient types. These times are listed in Table 5.

Data on turnaround times for lab work, x-rays, and special imaging was collected from the laboratory and radiology departments. The percent of patients having these tests completed within each category was found by reviewing medical records. These percents and the average turnaround times for tests completed on each patient type are listed in Table 6.

Table 6. Lab Tests, X-rays, and Special Imaging (%)

Patient Category	Lab Work	X-rays	Special Imaging
Minor Care Patients	6	15	1
Non-urgent Patients	26	25	5
Urgent Patients	49	47	13
Immediate Patients	85	89	30
Average Time (min.)	9	42	44

Model Translation

The process flow logic defined in the flow diagrams during the model formulation phase was used to build the simulation model. Computerized architectural drawings of Brackenridge's floorplans were obtained from the hospital. The hospital floor plans were then cropped and edited in Adobe PhotoDeluxe 2.0 to depict only the adult emergency department; this layout was then imported into MedModel.

After the emergency department's blueprints were opened in MedModel, various modules found in the build menu were used to complete the model translation process. The background graphics module was used to assign graphics, such as gurneys, to specific areas within the emergency department. Other elements used to finish the model included:

- *Locations*: specific areas in the emergency department where entities are routed for processing.
- *Pathway networks*: paths used by entities and resources to travel from one location to another.
- *Entities*: elements processed by the system, such as patients and paperwork.
- *Resources*: people, equipment, etc. that provide services to entities.
- *Variables*: real or integer numbers that track information that is global to the model, such as the number of patients in the system.
- *Attributes*: constructs that assign information, such as patient acuity level or patient arrival time, to specific locations or entities.

- *Macro*: a name for an expression or set of statements that is used frequently in the coding. Macros are created once in the macro editor module, and then the macro's name replaces the code that it represents in the model.
- *Arrivals*: constructs that define the entrance of entities introduced into the system.
- *Arrival cycle*: a pattern of entity arrivals defined over a period of time, such as a day.
- *User defined distributions*: empirical distributions used to allocate entities into specific groups, such as patient acuity levels.
- *Processing logic*: defines entity activity from the time of entry into the system to exit.

Model Verification

Patient flow in the simulation model was examined to be sure that it matched patient flow in the emergency department. The verification process included documenting that patients in the model arrive at the right locations, are treated by the appropriate caregivers for the appropriate distribution of time, receive appropriate care and diagnostic tests, and travel to the correct next location. Patient flow in the simulation was also compared with the flow diagrams created during the model formulation phase. The administrators of Brackenridge's emergency department verified that patient flow in the model correctly reflects the actual system.

Model Validation

The "as-is" model was simulated for one week and replicated twelve times to obtain a total of twelve weeks of data. The first item analyzed in the model was the length of stay times. Relying on McGuire (1998), only those patient types which form a significant percentage of total patient volume (and with sufficient historical data to provide meaningful confidence intervals) were included in the validation process. Since more than half of the patient population is of the non-urgent type, their throughput times were considered the most significant measure of model validation. Results showed no significant difference between the system length of stay times for non-urgent patients as gathered from medical records and the length of stay times generated by the model using a one-sample T-test ($p > .05$). The number of patients within each category was then compared to the numbers found during the data collection phase. The results of a one-sample T-test revealed no significant difference between the two ($p > .05$). Thus, the simulation model promised to provide a reasonable reflection of the real-world system.

CHAPTER IV

EXPERIMENTATION

One of the objectives of this simulation model is to develop and tests various alternatives that are directly related to the project's objectives. These alternatives represent changes to the existing system and are tested to determine if they improve the system's performance. The results of each alternative are tested to determine if any differences exist between the baseline model and the alternative. First, results of the baseline model are discussed.

Baseline Model of Current System

The length of stay time for each patient is determined by taking the difference between the time the patient was discharged or admitted to the hospital and the time the patient checked-in with the triage nurse. The baseline model was simulated for one week and replicated twelve times to obtain a total of twelve weeks of data. The output for this baseline model can be found in Appendix B. The average throughput time for each patient type by mode of arrival was first examined. Immediate patients were separated into two categories, for even though all severely injured patients need immediate care, for some (Immediate 1 Category) it is critical that *no* time is allowed between arrival and treatment. The average length of stay are summarized in Table 7.

Table 7. Average Length of Stay for Each Patient Type (minutes)

Patient Category	Average Time	Standard Deviation	Minimum	Maximum
MEC	120.96	9.68	48.65	259.05
Non-urgent (EMS)	164.63	25.13	44.20	489.02
Non-urgent (Walk-in)	183.90	20.68	48.01	592.86
Urgent (EMS)	174.92	12.56	72.89	455.63
Urgent (Walk-in)	182.12	13.81	72.72	497.63
Immediate 2 (EMS)	226.63	17.60	90.82	422.32
Immediate 2 (Walk-in)	248.93	12.18	85.52	461.71
Immediate 1 (EMS)	243.54	10.01	110.14	359.91
Immediate 1 (Walk-in)	242.28	12.28	133.01	355.19

The next output variable analyzed was the waiting room times for minor care, non-urgent, and urgent patients. Urgent patients had the shortest waiting time because they are always given first priority to be taken to a treatment bed from the waiting room. Immediate patients are always transported directly to a bed in CRASH. Table 8 lists the average time patients waited in the waiting room.

Table 8. Average Waiting Room Times (minutes)

Patient category	Average Time	Standard Deviation	Minimum	Maximum
MEC	35.46	8.73	1.96	154.6
Non-urgent	14.59	10.00	1.08	145.01
Urgent	9.54	2.74	1.12	77.94

Next, the utilization rates of doctors, nurses, and technicians were each analyzed. The average utilization rates for resources in the treatment area account for the time they spend caring for patients, cleaning rooms, and filling out charts. The utilization rates for resources in CRASH and the minor care area only include the time they spend treating patients and cleaning rooms. This explains why their rates are highest. The utilization rates for all resources do not account for other non-treatment tasks, such as nurses preparing lab specimens to be sent to the laboratory or doctors reviewing results of diagnostic tests. The utilization rates are listed in Table 9.

Table 9. Average Utilization Rates for Resources

Resources	Utilization Rate
Treatment Tech	78.02
Clerk	63.83
RN triage	50.52
Treatment RN 1	87.04
Treatment RN 2	83.52
Treatment RN 3	95.70
RN Charge	65.66
RN PFC	72.88
Nurse Practitioner	68.37
MEC Technician	44.06
MEC LVN	53.68
CRASH RN 1	56.60
CRASH RN 2	53.42
CRASH technician 1	43.36
CRASH technician 2	40.21
Doctor 1	65.85
Doctor 2	62.98
Doctor 3	70.99

The utilization rate for treatment RN 3 is the highest of all other nurses. This particular nurse is only on shift from 3 p.m. to 11 p.m., which is the busiest time of the day. Doctor 3 has the highest utilization rate among doctors 1 and 2. This is because Doctor 3 treats patients in CRASH and in treatment, whereas other doctors treat patients only in the treatment area.

Scenario Analysis

The researcher experimented with three alternatives to determine how certain changes might effect overall system performance. The alternatives were all tested and the results were compared to the results of the baseline model to determine if differences were statistically significant (using an indendent-sample t-test in SPSS). The results of these tests can be found in Appendix A. A combination of the most effective alternatives is recommended to the administrators for implementation. The alternatives tested are now discussed.

Scenario I

The first alternative selected was the addition of a treatment technician from 3 p.m. to 11 p.m. The administrators stated they needed this extra technician permanently on schedule. Scenario I was run for the same amount of time as the baseline model. The average length of stay for non-urgent EMS patients decreased by 37.19 minutes and for non-urgent walk-in patients by 31.83 minutes when compared to the baseline model. The changes were found to be significantly different ($p < .001$). The average throughput time for urgent EMS patients did decrease by .48 minutes and for urgent walk-in patients by 7.14 minutes, although the changes were not significant ($p > .05$). The average waiting times in the waiting room for non-urgent and urgent patients decreased significantly by 8.63 and 3.65 minutes, respectively ($p < .01$).

Adding the technician effected the utilization rates for some of the resources working in treatment. The three treatment nurses, the charge nurse, the clerk, the technicians, and the patient flow coordinator share some of the same responsibilities. The utilization rates for these resources decreased, as compared with the baseline model. Table 10 compares the utilization rates of both models.

Table 10. Resource Utilization Rates in Scenario I

Resources	Scenario I	Baseline
Treatment Tech	71.14	78.02
Additional Tech	81.03	Not Included
Clerk	58.88	63.83
Treatment RN 1	83.64	87.04
Treatment RN 2	78.70	83.52
Treatment RN 3	87.91	95.70
RN Charge	60.04	65.66
RN PFC	69.69	72.88

Scenario II

As a second alternative, the possibility of utilizing the radiology waiting room as three treatment rooms was discussed. However, in the meeting at which this scenario was raised, the administrators stated that they had recently started using that room as three holding areas for non-urgent and urgent patients waiting to be admitted. So the effects of this new change were tested instead. First, waiting room times were examined. Non-urgent and urgent waiting room times decreased by 3.45 minutes and 0.24 minutes, respectively. This reduction was not significant ($p > .05$). In addition, throughput times were analyzed for both patient types. These times actually increased for non-urgent patients as a result of the new change, although not significantly ($p > .05$). Table 11 shows the average throughput times for both models. The utilization rates for resources in treatment increased negligibly, as compared to the rates for the baseline model. The effects of implementing scenario II appears not to improve system performance.

Table 11. Average Length of Stay Times in Scenario II (minutes)

Patient Category	Scenario II	Baseline
Non-urgent EMS	172.73	164.63
Non-urgent Walk-in	188.98	183.90
Urgent EMS	174.64	174.92
Urgent Walk-in	185.97	182.12

Scenario III

Scenario III examines the impact of using the radiology room as three treatment areas for minor care patients. This patient type was chosen over non-urgent and urgent patients because their privacy needs are less (the treatment areas are only separated by curtains). The alternative significantly reduced the average waiting room time by 25.23 minutes and the average throughput time by 14.58 minutes for minor care patients ($p < .001$). The average utilization rates for minor care resources increased negligibly, as compared to those in the baseline model. Table 12 shows the utilization rates for the nurse practitioner, the LVN, and the MEC technician for both models.

Table 12. Utilization Rates for Minor Care Resources in Scenario III

Resource	Scenario III	Baseline
Nurse Practitioner	69.68	68.37
MEC LVN	45.45	44.06
MEC Technician	54.38	53.68

Scenario IV

Scenario IV combines both scenarios I and scenario III by adding a treatment technician on shift from 3 p.m. to 11 p.m. and utilizing the radiology waiting room for the treatment of minor care patients. The effects of combining these two scenarios were tested to determine the final impact on system performance. Then, a final recommendation for implementation is made.

By combining both these alternatives, the average waiting room time was significantly reduced by 27.09 minutes for minor care patients, by 8.18 minutes for non-urgent patients and by 3.84 minutes for urgent patients ($p < .05$). The average length of stay for minor care and non-urgent was also significantly reduced ($p < .01$). These times compared to the times from the baseline model are listed in Table 13. The utilization rates for doctors, nurses, and technicians for both scenario IV and the baseline model are listed below in Table 14

Table 13. Average Length of Stay Times in Scenario IV(minutes)

Patient Category	Scenario IV	Baseline
MEC patients	102.80	120.96
Non-urgent EMS	129.50	179.63
Non-urgent Walk-in	155.57	183.90

Table 14. Utilization Rates for Resources in Scenario IV

Resources	Scenario IV	Baseline
Treatment Tech	71.47	78.02
Additional Tech	80.39	Not Included
Clerk	58.48	63.83
RN triage	50.27	50.52
Treatment RN 1	84.02	87.04
Treatment RN 2	79.47	83.52
Treatment RN 3	88.17	95.70
RN Charge	59.89	65.66
RN PFC	69.53	72.88
Nurse Practitioner	67.82	68.37
MEC Technician	44.35	44.06
MEC LVN	52.99	53.68
CRASH RN 1	58.33	56.60
CRASH RN 2	54.57	53.42
CRASH technician 1	44.87	43.36
CRASH technician 2	41.71	40.21
Doctor 1	65.56	65.85
Doctor 2	64.33	62.98
Doctor 3	70.74	70.99

CHAPTER V

CONCLUSIONS

The objectives of this project were to build a computer simulation model of the adult emergency department at Brackenridge Hospital, to evaluate the performance of the existing system, and to test the consequences of potential changes that are intended to improve system performance. The final recommendation includes adding a treatment technician on shift from 3 p.m. to 11 p.m., and utilizing the radiology room for the treatment of minor care patients. Experimentation showed that implementing these changes significantly reduces the average length of stay for both non-urgent and MEC patients. These two patient types combined constitute over 65% of the patient volume. So, it stands to reason that the average length of stay for all adult emergency department patients should decrease. The impact of future changes to the emergency department can be tested using the simulation model. This simulation model serves as a tool for continuous quality improvement because it documents performance measures and can be used to evaluate proposed systems intended to improve performance. An analysis of an alternative system can be conducted by simulating scenarios, before spending funds to implement any, which may prove to be ineffective or inefficient. The bottom line is: this can save administrators time and money.

Lessons Learned

Many lessons were learned during the phases of this simulation project. The project could have been completed sooner had the researcher been aware of the many obstacles that would arise. Some of the lessons learned are now reviewed. Others, who are attempting similar projects, would likely benefit from these observations.

Since the patient records were not in a computer database, the collection of data required reviewing actual patient charts. This was very time consuming. In addition, some data collected was not needed to build the simulation model. The literature review was helpful in determining some of the types of data needed. Perhaps, studying the demonstration models provided in the MedModel package prior to data collection would have helped the researcher choose the necessary data types to collect. An added benefit to reviewing the demonstration models would be to familiarize the researcher with the programs' constructs. Also, the researcher should have planned the design of the spreadsheet before data entry to ensure a user-friendly data set. For instance, the word "yes" was entered into the spreadsheet where a numeric value (such as "1") was needed for use in the statistical software.

To estimate system parameters, feedback from staff members was sought by surveying and interviewing. The survey response was low. Perhaps, handing out surveys personally would have encouraged more staff to respond. If practical, collected data from staff is best through interviews as it lessons the chance of the questions being misinterpreted.

The MedModel program used in this study has some limitations in executing processing logic. For example, the program will read the following logic statement: "Use RN and tech for 10 min or use RN for 10 min". So, if the technician is on shift both the RN and technician should be used by the patients; if the technician is not on shift the patient should use the RN only. After investigation, the researcher found that MedModel would only execute the first part of the "or" statement in this case. This limited the way multiple resources could be used. The researcher replaced this logic with a jointly get statement, but encountered difficulties with this as well. These problems actually prevented the researcher from investigating a scenario proposed by administrators.

Another problem with MedModel arose when using "ghost" entities, which are used to hold a room for patients temporarily leaving the room for imaging tests. The program considered these "ghost" entities as separate patients of the same type and thus included the length of stay for the "ghost" entities when averaging length of stay for patient types. This erroneously reduced the throughput times for each patient type. So, the Log( ) command was used to accurately register times for actual patients instead. However, this command will not log average length of stay for patients of the same type arriving at two different entrances. Therefore, average length of stay times for patient types arriving by EMS had to be logged separately from average length of stay times for patient types arriving in the walk-in entrance. Another limitation of MedModel is that only one entity can be created at a location. For instance, dirty linen and a medical record could not be created for one patient in a treatment room. Some of these problems with MedModel may have been resolved in the newly released version.

Appendix A

Scenario 1

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
WAIT_URG	.00	12	9.5350	2.7420	.7916
	1.00	12	5.8858	2.2436	.6477
WAIT_NON	.00	12	14.5900	10.0032	2.8877
	1.00	12	5.9586	2.7852	.8040

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
WAIT_URG	Equal variances assumed	.546	.468	3.568	22	.002	3.6492	1.0227	1.5281	5.7702
	Equal variances not assumed			3.568	21.170	.002	3.6492	1.0227	1.5233	5.7750
WAIT_NON	Equal variances assumed	2.614	.120	2.880	22	.009	8.6314	2.9975	2.4150	14.8479
	Equal variances not assumed			2.880	12.695	.013	8.6314	2.9975	2.1399	15.1230

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
LOS_NON	.00	12	184.1500	20.6502	5.9612
	1.00	12	152.0708	7.1045	2.0509
NON_EMS	.00	12	164.6342	25.1321	7.2550
	1.00	12	127.4367	10.6728	3.0810

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LOS_NON	Equal variances assumed	2.136	.158	5.089	22	.000	32.0792	6.3041	19.0052	45.1531
	Equal variances not assumed			5.089	13.568	.000	32.0792	6.3041	18.5176	45.6407
NON_EMS	Equal variances assumed	4.989	.036	4.719	22	.000	37.1975	7.8821	20.8510	53.5440
	Equal variances not assumed			4.719	14.843	.000	37.1975	7.8821	20.3817	54.0133

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
LOS_URG	.00	12	182.1161	13.8072	3.9858
	1.00	12	181.6442	10.8657	3.1367
URG_EMS	.00	12	174.9225	12.5654	3.6273
	1.00	12	167.7783	11.6684	3.3684

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LOS_URG	Equal variances assumed	.370	.549	.093	22	.927	.4719	5.0720	-10.0468	10.9906
	Equal variances not assumed			.093	20.848	.927	.4719	5.0720	-10.0806	11.0244
URG_EMS	Equal variances assumed	.069	.796	1.443	22	.163	7.1442	4.9501	-3.1217	17.4100
	Equal variances not assumed			1.443	21.880	.163	7.1442	4.9501	-3.1249	17.4133

Scenario 2

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
WAIT_NON	.00	12	14.5900	10.0032	2.8877
	2.00	12	11.1492	8.0996	2.3382
WAIT_URG	.00	12	9.5350	2.7420	.7916
	2.00	12	9.3000	5.2101	1.5040

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
WAIT_NON	Equal variances assumed	.063	.805	.926	22	.364	3.4408	3.7156	-4.2648	11.1465
	Equal variances not assumed			.926	21.088	.365	3.4408	3.7156	-4.2842	11.1659
WAIT_URG	Equal variances assumed	2.186	.153	.138	22	.891	.2350	1.6996	-3.2898	3.7598
	Equal variances not assumed			.138	16.659	.892	.2350	1.6996	-3.3564	3.8264

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
LOS_NON	.00	12	184.1500	20.6502	5.9612
	2.00	12	188.9817	20.8878	6.0298
NON_EMS	.00	12	164.6342	25.1321	7.2550
	2.00	12	172.7250	23.2903	6.7233

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LOS_NON	Equal variances assumed	.144	.708	-.570	22	.575	-4.8317	8.4791	-22.4162	12.7528
	Equal variances not assumed			-.570	21.997	.575	-4.8317	8.4791	-22.4163	12.7530
NON_EMS	Equal variances assumed	.202	.657	-.818	22	.422	-8.0908	9.8913	-28.6042	12.4225
	Equal variances not assumed			-.818	21.874	.422	-8.0908	9.8913	-28.6110	12.4294

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
LOS_URG	.00	12	182.1161	13.8072	3.9858
	2.00	12	185.9742	12.7114	3.6695
URG_EMS	.00	12	174.9225	12.5654	3.6273
	2.00	12	174.6408	22.1853	6.4043

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LOS_URG	Equal variances assumed	.139	.713	-.712	22	.484	-3.8581	5.4177	-15.0937	7.3775
	Equal variances not assumed			-.712	21.851	.484	-3.8581	5.4177	-15.0981	7.3820
URG_EMS	Equal variances assumed	1.956	.176	.038	22	.970	.2817	7.3602	-14.9825	15.5458
	Equal variances not assumed			.038	17.399	.970	.2817	7.3602	-15.2200	15.7833

Scenario 3

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
LOS_MEC	.00	12	120.9583	9.6826	2.7951
	3.00	12	106.3758	7.2835	2.1026
WAIT_MEC	.00	12	35.4633	8.7356	2.5217
	3.00	12	10.2275	2.7383	.7905

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LOS_MEC	Equal variances assumed	.514	.481	4.169	22	.000	14.5825	3.4976	7.3288	21.8362
	Equal variances not assumed			4.169	20.429	.000	14.5825	3.4976	7.2964	21.8686
WAIT_MEC	Equal variances assumed	8.691	.007	9.549	22	.000	25.2358	2.6427	19.7551	30.7165
	Equal variances not assumed			9.549	13.141	.000	25.2358	2.6427	19.5328	30.9389

Scenario 4

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
LOS_MEC	.00	12	120.9583	9.6826	2.7951
	4.00	12	102.7958	5.6113	1.6198
WAIT_MEC	.00	12	35.4633	8.7356	2.5217
	4.00	12	8.3708	1.7689	.5106

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LOS_MEC	Equal variances assumed	2.900	.103	5.622	22	.000	18.1625	3.2306	11.4627	24.8623
	Equal variances not assumed			5.622	17.640	.000	18.1625	3.2306	11.3654	24.9596
WAIT_MEC	Equal variances assumed	12.216	.002	10.530	22	.000	27.0925	2.5729	21.7566	32.4284
	Equal variances not assumed			10.530	11.901	.000	27.0925	2.5729	21.4814	32.7036

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
WAIT_NON	.00	12	14.5900	10.0032	2.8877
	4.00	12	6.4075	2.7864	.8044
WAIT_URG	.00	12	9.5350	2.7420	.7916
	4.00	12	5.7017	2.0632	.5956

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
WAIT_NON	Equal variances assumed	2.574	.123	2.730	22	.012	8.1825	2.9976	1.9659	14.3991
	Equal variances not assumed			2.730	12.697	.018	8.1825	2.9976	1.6908	14.6742
WAIT_URG	Equal variances assumed	.411	.528	3.870	22	.001	3.8333	.9906	1.7789	5.8877
	Equal variances not assumed			3.870	20.432	.001	3.8333	.9906	1.7698	5.8969

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
LOS_NON	.00	12	184.1500	20.6502	5.9612
	4.00	12	155.5692	9.5303	2.7511
NON_EMS	.00	12	164.6342	25.1321	7.2550
	4.00	12	129.4975	14.7581	4.2603

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LOS_NON	Equal variances assumed	.881	.358	4.353	22	.000	28.5808	6.5654	14.9650	42.1967
	Equal variances not assumed			4.353	15.482	.001	28.5808	6.5654	14.6248	42.5368
NON_EMS	Equal variances assumed	1.646	.213	4.176	22	.000	35.1367	8.4134	17.6884	52.5850
	Equal variances not assumed			4.176	17.780	.001	35.1367	8.4134	17.4451	52.8282

Appendix B

General Report
Output from C:\MedMod3\models\Base.MOD
Date: Dec/01/1999   Time: 12:58:43 PM

Scenario : Normal Run
Replication : Average
Period : Final Report (0 sec to 172.6461667 hr Elapsed: 172.6461667 hr)
Simulation Time : 171.9598333 hr (Std. Dev. 1.708833333 hr)

LOCATIONS

Location Name	Scheduled Hours	Capacity	Total Entries	Average Minutes Per Entry	Average Contents	Maximum Contents	Current Contents	% Util	
Triage wait	171.9597778	100	534	9.456263	0.490802	8.41667	0	0.49	(Average)
Triage wait	1.708839993	0	17.6995	1.127874	0.0733848	1.50504	0	0.07	(Std. Dev.)
Registration	171.9597778	1	747.667	7.185600	0.520973	1	0	52.10	(Average)
Registration	1.708839993	0	30.4163	0.136093	0.0287497	0	0	2.87	(Std. Dev.)
Triage	171.9597778	1	892.5	5.363967	0.464056	1	0	46.41	(Average)
Triage	1.708839993	0	17.1597	0.056802	0.011979	0	0	1.20	(Std. Dev.)
check in	171.9597778	50	1014.5	0.870702	0.0858237	3.5	0	0.17	(Average)
check in	1.708839993	0	25.5574	0.107723	0.0127909	0.522233	0	0.03	(Std. Dev.)
waiting room	171.9597778	1000	747.667	12.817206	0.945448	11	0	0.09	(Average)
waiting room	1.708839993	0	30.4163	8.354263	0.673252	3.71728	0	0.07	(Std. Dev.)
Mec 1	171.9597778	1	56.9167	71.715632	0.394959	1	0	39.50	(Average)
Mec 1	1.708839993	0	3.17543	2.913032	0.012724	0	0	1.27	(Std. Dev.)
Mec 2	171.9597778	1	53.1667	72.701463	0.373859	1	0	37.39	(Average)
Mec 2	1.708839993	0	3.5887	3.325524	0.0172233	0	0	1.72	(Std. Dev.)
Mec 3	171.9597778	1	47.75	74.776382	0.345312	1	0	34.53	(Average)
Mec 3	1.708839993	0	4.35107	2.842380	0.0238524	0	0	2.39	(Std. Dev.)
Trmt 4	171.9597778	1	41.8333	141.942719	0.575607	1	0	57.56	(Average)
Trmt 4	1.708839993	0	2.36771	11.620222	0.0593809	0	0	5.94	(Std. Dev.)
Trmt 5	171.9597778	1	37.9167	144.857128	0.529925	1	0	52.99	(Average)
Trmt 5	1.708839993	0	3.14667	17.988488	0.0563171	0	0	5.63	(Std. Dev.)
Trmt 6	171.9597778	1	34.3333	148.370859	0.490798	1	0	49.08	(Average)
Trmt 6	1.708839993	0	2.83912	22.242743	0.0613629	0	0	6.14	(Std. Dev.)
Trmt 7	171.9597778	1	49.5833	160.410690	0.767559	1	0	76.76	(Average)
Trmt 7	1.708839993	0	3.17543	14.165488	0.0400766	0	0	4.01	(Std. Dev.)

Trmt 8	171.9597778	1	44.5833	163.657099	0.701242	1	0	70.12	(Average)
Trmt 8	1.708839993	0	4.37884	20.950812	0.0641881	0	0	6.42	(Std. Dev.)
Trmt 9	171.9597778	1	52.0833	147.764624	0.742948	1	0	74.29	(Average)
Trmt 9	1.708839993	0	2.96827	14.430310	0.0469182	0	0	4.69	(Std. Dev.)
Trmt 10	171.9597778	1	62.25	133.281850	0.801981	1	0	80.20	(Average)
Trmt 10	1.708839993	0	3.51943	9.040080	0.0356294	0	0	3.56	(Std. Dev.)
Trmt 11	171.9597778	1	72.3333	125.905409	0.877823	1	0	87.78	(Average)
Trmt 11	1.708839993	0	5.19324	10.998256	0.020748	0	0	2.07	(Std. Dev.)
Trmt 12	171.9597778	1	51.5	141.451050	0.703921	1	0	70.39	(Average)
Trmt 12	1.708839993	0	4.27466	9.872543	0.0509103	0	0	5.09	(Std. Dev.)
Trmt 13	171.9597778	1	67.5	127.203635	0.827775	1	0	82.78	(Average)
Trmt 13	1.708839993	0	4.44154	12.203233	0.0280286	0	0	2.80	(Std. Dev.)
Trmt 14	171.9597778	1	56.75	134.715732	0.736759	1	0	73.68	(Average)
Trmt 14	1.708839993	0	3.64629	14.371542	0.0372082	0	0	3.72	(Std. Dev.)
Trmt 15	171.9597778	1	44.6667	152.616710	0.659081	1	0	65.91	(Average)
Trmt 15	1.708839993	0	3.17185	12.709811	0.0533277	0	0	5.33	(Std. Dev.)
Trmt 16	171.9597778	1	39.3333	159.627643	0.606097	1	0	60.61	(Average)
Trmt 16	1.708839993	0	3.14305	15.639315	0.0524698	0	0	5.25	(Std. Dev.)
Trmt 17	171.9597778	1	35	166.440259	0.563663	1	0	56.37	(Average)
Trmt 17	1.708839993	0	2.55841	14.071264	0.0542668	0	0	5.43	(Std. Dev.)
Trmt 18	171.9597778	1	30.75	172.275066	0.512692	1	0	51.27	(Average)
Trmt 18	1.708839993	0	3.07852	13.673562	0.0589036	0	0	5.89	(Std. Dev.)
Trmt 19	171.9597778	1	27.6667	170.388509	0.456602	1	0	45.66	(Average)
Trmt 19	1.708839993	0	3.57601	10.502331	0.0619244	0	0	6.19	(Std. Dev.)
Trmt 20	171.9597778	1	25.5833	170.915873	0.42363	1	0	42.36	(Average)
Trmt 20	1.708839993	0	4.23102	10.000689	0.0751166	0	0	7.51	(Std. Dev.)
Crash 1	171.9597778	1	30.4167	224.608404	0.660415	1	0	66.04	(Average)
Crash 1	1.708839993	0	1.97523	17.602932	0.0437671	0	0	4.38	(Std. Dev.)
Crash 2	171.9597778	1	24.25	227.596509	0.531612	1	0	53.16	(Average)
Crash 2	1.708839993	0	3.04884	18.333716	0.0499461	0	0	4.99	(Std. Dev.)
Crash 3	171.9597778	1	16.75	241.206370	0.39013	1	0	39.01	(Average)
Crash 3	1.708839993	0	2.52713	23.785477	0.0591087	0	0	5.91	(Std. Dev.)
Crash 4	171.9597778	1	14.25	237.845210	0.326219	1	0	32.62	(Average)
Crash 4	1.708839993	0	2.37888	17.479630	0.0450963	0	0	4.51	(Std. Dev.)
Crash 5	171.9597778	1	9.16667	228.621570	0.206388	1	0	20.64	(Average)
Crash 5	1.708839993	0	2.08167	28.673953	0.0687636	0	0	6.88	(Std. Dev.)
Crash 6	171.9597778	1	4.5	262.038188	0.114204	1	0	11.42	(Average)
Crash 6	1.708839993	0	1.62369	45.422887	0.0487168	0	0	4.87	(Std. Dev.)
Crash 7	171.9597778	1	28.25	231.949314	0.634556	1	0	63.46	(Average)
Crash 7	1.708839993	0	1.28806	7.959174	0.0233759	0	0	2.34	(Std. Dev.)
Crash 8	171.9597778	1	20.1667	247.185519	0.48228	1	0	48.23	(Average)
Crash 8	1.708839993	0	1.99241	12.204223	0.0444321	0	0	4.44	(Std. Dev.)
Crash 9	171.9597778	1	12.3333	238.608290	0.284198	1	0	28.42	(Average)
Crash 9	1.708839993	0	2.38683	26.406585	0.0582391	0	0	5.82	(Std. Dev.)
Crash 10	171.9597778	1	1	198.739167	0.0316036	0.583333	0	3.16	(Average)

Crash 10	1.708839993	0	0.953463	180.526161	0.0287987	0.514929	0	2.88	(Std. Dev.)
Desk 1	171.9597778	1	26.5	177.017549	0.455694	1	0	45.57	(Average)
Desk 1	1.708839993	0	2.67989	15.148338	0.0717048	0	0	7.17	(Std. Dev.)
Desk 2	171.9597778	1	24.5	169.448025	0.40192	1	0	40.19	(Average)
Desk 2	1.708839993	0	3.96576	10.578048	0.0714474	0	0	7.14	(Std. Dev.)
Desk 3	171.9597778	1	22.0833	181.493596	0.389317	1	0	38.93	(Average)
Desk 3	1.708839993	0	3.31548	17.389259	0.076028	0	0	7.60	(Std. Dev.)
walk enter	171.9597778	100	964.083	0.000000	0	1	0	0.00	(Average)
walk enter	1.708839993	0	14.0677	0.000000	0	0	0	0.00	(Std. Dev.)
Discharge exit	171.9597778	100	1031.08	0.000000	0	1	0	0.00	(Average)
Discharge exit	1.708839993	0	18.2481	0.000000	0	0	0	0.00	(Std. Dev.)
EMS home	171.9597778	100	233	0.000000	0	1	0	0.00	(Average)
EMS home	1.708839993	0	13.8957	0.000000	0	0	0	0.00	(Std. Dev.)
xray wait	171.9597778	100	277.5	6.331710	0.171164	4.33333	0	0.17	(Average)
xray wait	1.708839993	0	14.3115	1.458642	0.0445048	0.778499	0	0.04	(Std. Dev.)
xray	171.9597778	1	277.5	13.079268	0.35165	1	0	35.17	(Average)
xray	1.708839993	0	14.3115	0.402232	0.0182231	0	0	1.82	(Std. Dev.)
triage q	171.9597778	999999	964.083	0.060000	0.00560688	2	0	0.00	(Average)
triage q	1.708839993	0	14.0677	0.000000	9.44092e-05	0	0	0.00	(Std. Dev.)
Mec wait	171.9597778	100	195.25	34.275570	0.651317	7.58333	0	0.65	(Average)
Mec wait	1.708839993	0	6.03211	8.734500	0.180761	1.31137	0	0.18	(Std. Dev.)
Registration q	171.9597778	999999	747.667	5.624358	0.410624	6.16667	0	0.00	(Average)
Registration q	1.708839993	0	30.4163	1.403973	0.119579	1.19342	0	0.00	(Std. Dev.)
Admit exit	171.9597778	100	156.167	10.984217	0.166325	2.33333	0	0.17	(Average)
Admit exit	1.708839993	0	12.4596	0.496619	0.0157575	0.492366	0	0.02	(Std. Dev.)
EMS enter	171.9597778	25	233	0.000000	0	1	0	0.00	(Average)
EMS enter	1.708839993	0	13.8957	0.000000	0	0	0	0.00	(Std. Dev.)
Crash desk 1	171.9597778	1	0.416667	98.570000	0.00952562	0.416667	0	0.95	(Average)
Crash desk 1	1.708839993	0	0.514929	128.629081	0.012451	0.514929	0	1.25	(Std. Dev.)
Crash desk 2	171.9597778	1	0.0833333	18.305833	0.00178579	0.0833333	0	0.18	(Average)
Crash desk 2	1.708839993	0	0.288675	63.413267	0.00618617	0.288675	0	0.62	(Std. Dev.)
desk 4	171.9597778	1	21.0833	171.790500	0.350912	1	0	35.09	(Average)
desk 4	1.708839993	0	4.50168	16.006851	0.0803818	0	0	8.04	(Std. Dev.)
ct	171.9597778	2	104.833	49.860939	0.506459	2	0	25.32	(Average)
ct	1.708839993	0	6.87331	1.254890	0.0323479	0	0	1.62	(Std. Dev.)

LOCATION STATES BY PERCENTAGE (Multiple Capacity)

Location Name	Scheduled Hours	% Empty	% Partially Occupied	% Full	% Down	
Triage wait	171.9597778	76.21	23.79	0.00	0.00	(Average)
Triage wait	1.708839993	1.16	1.16	0.00	0.00	(Std. Dev.)

check in	171.9597778	92.13	7.87	0.00	0.00	(Average)
check in	1.708839993	1.12	1.12	0.00	0.00	(Std. Dev.)
waiting room	171.9597778	75.24	24.76	0.00	0.00	(Average)
waiting room	1.708839993	7.99	7.99	0.00	0.00	(Std. Dev.)
walk enter	171.9597778	100.00	0.00	0.00	0.00	(Average)
walk enter	1.708839993	0.00	0.00	0.00	0.00	(Std. Dev.)
Discharge exit	171.9597778	100.00	0.00	0.00	0.00	(Average)
Discharge exit	1.708839993	0.00	0.00	0.00	0.00	(Std. Dev.)
EMS home	171.9597778	100.00	0.00	0.00	0.00	(Average)
EMS home	1.708839993	0.00	0.00	0.00	0.00	(Std. Dev.)
xray wait	171.9597778	88.04	11.96	0.00	0.00	(Average)
xray wait	1.708839993	2.37	2.37	0.00	0.00	(Std. Dev.)
triage q	171.9597778	99.44	0.56	0.00	0.00	(Average)
triage q	1.708839993	0.01	0.01	0.00	0.00	(Std. Dev.)
Mec wait	171.9597778	75.72	24.28	0.00	0.00	(Average)
Mec wait	1.708839993	3.32	3.32	0.00	0.00	(Std. Dev.)
Registration q	171.9597778	77.03	22.97	0.00	0.00	(Average)
Registration q	1.708839993	3.34	3.34	0.00	0.00	(Std. Dev.)
Admit exit	171.9597778	84.26	15.74	0.00	0.00	(Average)
Admit exit	1.708839993	1.36	1.36	0.00	0.00	(Std. Dev.)
EMS enter	171.9597778	100.00	0.00	0.00	0.00	(Average)
EMS enter	1.708839993	0.00	0.00	0.00	0.00	(Std. Dev.)
ct	171.9597778	59.08	31.20	9.73	0.00	(Average)
ct	1.708839993	2.68	2.95	1.55	0.00	(Std. Dev.)

LOCATION STATES BY PERCENTAGE (Single Capacity)

Location Name	Scheduled Hours	% Operation	% Setup	% Idle	% Waiting	% Blocked	% Down	
Registration	171.9597778	41.65	0.00	47.90	10.44	0.00	0.00	(Average)
Registration	1.708839993	2.08	0.00	2.87	0.84	0.00	0.00	(Std. Dev.)
Triage	171.9597778	40.64	0.00	53.59	5.77	0.00	0.00	(Average)
Triage	1.708839993	1.03	0.00	1.20	0.49	0.00	0.00	(Std. Dev.)
Mec 1	171.9597778	26.32	0.00	60.50	13.14	0.04	0.00	(Average)
Mec 1	1.708839993	1.32	0.00	1.27	0.92	0.09	0.00	(Std. Dev.)
Mec 2	171.9597778	28.69	0.00	59.74	11.54	0.03	0.00	(Average)
Mec 2	1.708839993	13.32	0.00	9.74	3.89	0.07	0.00	(Std. Dev.)
Mec 3	171.9597778	24.36	0.00	64.18	11.46	0.00	0.00	(Average)
Mec 3	1.708839993	7.36	0.00	4.09	3.65	0.00	0.00	(Std. Dev.)
Trmt 4	171.9597778	21.63	0.00	42.44	35.89	0.04	0.00	(Average)
Trmt 4	1.708839993	2.37	0.00	5.94	5.19	0.10	0.00	(Std. Dev.)
Trmt 5	171.9597778	19.94	0.00	47.01	32.88	0.17	0.00	(Average)
Trmt 5	1.708839993	2.01	0.00	5.63	4.92	0.22	0.00	(Std. Dev.)

Trmt 6	171.9597778	20.17	0.00	50.84	28.97	0.02	0.00	(Average)
Trmt 6	1.708839993	7.32	0.00	6.05	10.52	0.06	0.00	(Std. Dev.)
Trmt 7	171.9597778	46.30	0.00	23.24	30.27	0.19	0.00	(Average)
Trmt 7	1.708839993	3.26	0.00	4.01	3.20	0.38	0.00	(Std. Dev.)
Trmt 8	171.9597778	41.97	0.00	29.88	28.07	0.09	0.00	(Average)
Trmt 8	1.708839993	4.70	0.00	6.42	4.52	0.13	0.00	(Std. Dev.)
Trmt 9	171.9597778	37.55	0.00	25.71	36.69	0.05	0.00	(Average)
Trmt 9	1.708839993	4.00	0.00	4.69	3.49	0.12	0.00	(Std. Dev.)
Trmt 10	171.9597778	38.39	0.00	19.80	41.67	0.13	0.00	(Average)
Trmt 10	1.708839993	2.95	0.00	3.56	3.90	0.27	0.00	(Std. Dev.)
Trmt 11	171.9597778	44.92	0.00	12.22	42.75	0.11	0.00	(Average)
Trmt 11	1.708839993	4.30	0.00	2.07	5.97	0.13	0.00	(Std. Dev.)
Trmt 12	171.9597778	33.25	0.00	29.61	37.10	0.04	0.00	(Average)
Trmt 12	1.708839993	3.16	0.00	5.09	3.99	0.15	0.00	(Std. Dev.)
Trmt 13	171.9597778	38.87	0.00	17.22	43.82	0.09	0.00	(Average)
Trmt 13	1.708839993	1.59	0.00	2.80	3.49	0.14	0.00	(Std. Dev.)
Trmt 14	171.9597778	32.06	0.00	26.32	41.49	0.12	0.00	(Average)
Trmt 14	1.708839993	3.07	0.00	3.72	4.08	0.16	0.00	(Std. Dev.)
Trmt 15	171.9597778	28.30	0.00	34.09	37.59	0.01	0.00	(Average)
Trmt 15	1.708839993	3.92	0.00	5.33	6.16	0.04	0.00	(Std. Dev.)
Trmt 16	171.9597778	24.61	0.00	39.39	35.81	0.18	0.00	(Average)
Trmt 16	1.708839993	2.99	0.00	5.25	5.27	0.27	0.00	(Std. Dev.)
Trmt 17	171.9597778	22.41	0.00	43.63	33.94	0.02	0.00	(Average)
Trmt 17	1.708839993	2.94	0.00	5.43	4.44	0.07	0.00	(Std. Dev.)
Trmt 18	171.9597778	19.61	0.00	48.73	31.54	0.12	0.00	(Average)
Trmt 18	1.708839993	2.60	0.00	5.89	4.87	0.19	0.00	(Std. Dev.)
Trmt 19	171.9597778	17.93	0.00	54.34	27.60	0.13	0.00	(Average)
Trmt 19	1.708839993	2.67	0.00	6.19	5.45	0.25	0.00	(Std. Dev.)
Trmt 20	171.9597778	16.63	0.00	57.64	25.66	0.07	0.00	(Average)
Trmt 20	1.708839993	4.08	0.00	7.51	4.11	0.13	0.00	(Std. Dev.)
Crash 1	171.9597778	47.05	0.00	33.96	18.83	0.17	0.00	(Average)
Crash 1	1.708839993	4.03	0.00	4.38	2.88	0.20	0.00	(Std. Dev.)
Crash 2	171.9597778	39.73	0.00	44.64	15.47	0.16	0.00	(Average)
Crash 2	1.708839993	13.55	0.00	9.64	5.39	0.29	0.00	(Std. Dev.)
Crash 3	171.9597778	33.41	0.00	54.64	11.87	0.08	0.00	(Average)
Crash 3	1.708839993	18.54	0.00	13.83	6.36	0.15	0.00	(Std. Dev.)
Crash 4	171.9597778	31.56	0.00	60.88	7.40	0.16	0.00	(Average)
Crash 4	1.708839993	19.96	0.00	16.85	4.46	0.22	0.00	(Std. Dev.)
Crash 5	171.9597778	13.16	0.00	79.36	7.38	0.10	0.00	(Average)
Crash 5	1.708839993	4.06	0.00	6.88	2.95	0.17	0.00	(Std. Dev.)
Crash 6	171.9597778	6.87	0.00	88.58	4.36	0.19	0.00	(Average)
Crash 6	1.708839993	2.59	0.00	4.87	2.27	0.36	0.00	(Std. Dev.)
Crash 7	171.9597778	50.92	0.00	36.54	12.37	0.16	0.00	(Average)
Crash 7	1.708839993	1.94	0.00	2.34	1.45	0.17	0.00	(Std. Dev.)
Crash 8	171.9597778	37.81	0.00	51.77	10.30	0.12	0.00	(Average)

Crash 8	1.708839993	3.50	0.00	4.44	1.75	0.16	0.00	(Std. Dev.)
Crash 9	171.9597778	21.24	0.00	71.58	7.02	0.16	0.00	(Average)
Crash 9	1.708839993	4.85	0.00	5.82	1.47	0.25	0.00	(Std. Dev.)
Crash 10	171.9597778	1.74	0.00	96.84	1.32	0.11	0.00	(Average)
Crash 10	1.708839993	1.66	0.00	2.88	1.26	0.31	0.00	(Std. Dev.)
Desk 1	171.9597778	20.08	0.00	54.43	25.33	0.16	0.00	(Average)
Desk 1	1.708839993	3.05	0.00	7.17	5.64	0.30	0.00	(Std. Dev.)
Desk 2	171.9597778	16.74	0.00	59.81	23.45	0.00	0.00	(Average)
Desk 2	1.708839993	2.44	0.00	7.14	6.18	0.00	0.00	(Std. Dev.)
Desk 3	171.9597778	16.33	0.00	61.07	22.56	0.04	0.00	(Average)
Desk 3	1.708839993	4.29	0.00	7.60	4.86	0.14	0.00	(Std. Dev.)
xray	171.9597778	33.74	0.00	64.83	1.43	0.00	0.00	(Average)
xray	1.708839993	1.66	0.00	1.82	0.21	0.00	0.00	(Std. Dev.)
Crash desk 1	171.9597778	0.56	0.00	99.05	0.39	0.00	0.00	(Average)
Crash desk 1	1.708839993	0.80	0.00	1.25	0.62	0.00	0.00	(Std. Dev.)
Crash desk 2	171.9597778	0.08	0.00	99.82	0.10	0.00	0.00	(Average)
Crash desk 2	1.708839993	0.27	0.00	0.62	0.35	0.00	0.00	(Std. Dev.)
desk 4	171.9597778	15.13	0.00	64.91	19.93	0.03	0.00	(Average)
desk 4	1.708839993	3.80	0.00	8.04	5.08	0.08	0.00	(Std. Dev.)

RESOURCES

Resource Name	Units	Scheduled Hours	Number Of Times Used	Average Minutes Per Usage	Average Minutes Travel To Use	Average Minutes Travel To Park	% Blocked In Travel	% Util	
Trmt tech	1	161.075625	946.417	7.616167	0.350953	0.597931	0.00	78.02	(Average)
Trmt tech	0	1.56195202	41.4695	0.113516	0.012831	0.025733	0.00	3.36	(Std. Dev.)
Clerk	1	161.1476944	640.75	9.571511	0.059516	0.958496	0.00	63.83	(Average)
Clerk	0	1.516878531	22.4221	0.101400	0.004741	0.085173	0.00	2.40	(Std. Dev.)
Doctor 1	1	157.7420139	1809.92	3.222531	0.222104	0.261515	0.00	65.85	(Average)
Doctor 1	0	1.039136667	52.8212	0.056930	0.004150	0.004408	0.00	1.35	(Std. Dev.)
Doctor 2	1	92.34695833	1011.75	3.215904	0.235132	0.298313	0.00	62.98	(Average)
Doctor 2	0	0.09199042344	39.1248	0.065906	0.004166	0.005637	0.00	1.67	(Std. Dev.)
RN triage	1	171.9597778	1252.33	4.049128	0.112780	0.764146	0.00	50.52	(Average)
RN triage	0	1.708839993	33.3094	0.025337	0.005705	0.046589	0.00	1.36	(Std. Dev.)
Trmt RN 1	1	161.1506528	2016.08	3.794927	0.378546	0.471848	0.00	87.04	(Average)
Trmt RN 1	0	1.515584263	93.706	0.115322	0.014973	0.054314	0.00	2.25	(Std. Dev.)
Trmt RN 2	1	161.2149306	1530.17	4.874000	0.401605	0.505695	0.00	83.52	(Average)
Trmt RN 2	0	1.494939752	44.01	0.086065	0.010489	0.048428	0.00	3.12	(Std. Dev.)
Trmt RN 3	1	53.48308333	509.25	5.595685	0.433091	0.950310	0.00	95.70	(Average)
Trmt RN 3	0	0.1802749794	11.3067	0.133423	0.015783	0.148755	0.00	1.49	(Std. Dev.)
Charge RN	1	161.2825139	1272.25	4.516426	0.479432	0.722847	0.00	65.66	(Average)

Charge RN	0	1.508027502	86.5313	0.093870	0.012545	0.008130	0.00	3.63	(Std. Dev.)
PFC RN	1	77.45359722	1445.92	1.968721	0.368480	0.614251	0.00	72.88	(Average)
PFC RN	0	0.1170528987	58.8472	0.039506	0.012734	0.030031	0.00	2.50	(Std. Dev.)
NP	1	81.35515278	390.5	8.141373	0.407069	0.956091	0.00	68.37	(Average)
NP	0	0.6433089392	12.0642	0.098002	0.022820	0.045496	0.00	1.59	(Std. Dev.)
MEC tech	1	80.513375	658.75	2.819684	0.410844	0.386221	0.00	44.06	(Average)
MEC tech	0	0.4604968119	24.0723	0.053704	0.007404	0.014096	0.00	1.71	(Std. Dev.)
LVN	1	81.82858333	646.083	3.809225	0.270440	0.394201	0.00	53.68	(Average)
LVN	0	0.8562417662	18.3524	0.059183	0.015318	0.013430	0.00	1.06	(Std. Dev.)
Crash RN 1	1	161.2150278	742.5	6.869505	0.511892	0.626967	0.00	56.60	(Average)
Crash RN 1	0	1.494926397	58.6368	0.242580	0.024791	0.036886	0.00	3.31	(Std. Dev.)
Crash RN 2	1	161.2514444	801.25	6.025088	0.422743	0.506158	0.00	53.42	(Average)
Crash RN 2	0	1.495261128	58.1927	0.200588	0.017176	0.026174	0.00	3.93	(Std. Dev.)
Crash tech 1	1	161.1638056	459.25	8.640502	0.478237	0.808185	0.00	43.36	(Average)
Crash tech 1	0	1.510634966	37.8901	0.291984	0.020623	0.029932	0.00	3.84	(Std. Dev.)
Crash tech 2	1	161.661	343.167	10.842934	0.541841	1.137047	0.00	40.21	(Average)
Crash tech 2	0	1.558326469	31.7113	0.433352	0.036100	0.037757	0.00	2.48	(Std. Dev.)
Doctor 3	1	171.9597778	1388.33	4.857284	0.421317	0.374760	0.00	70.99	(Average)
Doctor 3	0	1.708839993	40.3627	0.212344	0.021019	0.023686	0.00	1.47	(Std. Dev.)
Patient Information	1	171.9597778	1465.42	2.233452	0.467704	0.734046	0.00	38.36	(Average)
Patient Information	0	1.708839993	41.1813	0.030440	0.009846	0.005806	0.00	0.97	(Std. Dev.)

RESOURCE STATES BY PERCENTAGE

Resource Name	Scheduled Hours	% In Use	% Travel To Use	% Travel To Park	% Idle	% Down	
Trmt tech	161.075625	74.57	3.45	1.13	20.85	0.00	(Average)
Trmt tech	1.56195202	3.17	0.24	0.13	3.27	0.00	(Std. Dev.)
Clerk	161.1476944	63.43	0.39	0.52	35.65	0.00	(Average)
Clerk	1.516878531	2.39	0.04	0.05	2.38	0.00	(Std. Dev.)
Doctor 1	157.7420139	61.61	4.25	2.12	32.03	0.00	(Average)
Doctor 1	1.039136667	1.24	0.15	0.06	1.36	0.00	(Std. Dev.)
Doctor 2	92.34695833	58.69	4.29	2.27	34.75	0.00	(Average)
Doctor 2	0.09199042344	1.53	0.17	0.14	1.60	0.00	(Std. Dev.)
RN triage	171.9597778	49.15	1.37	1.21	48.27	0.00	(Average)
RN triage	1.708839993	1.32	0.09	0.11	1.37	0.00	(Std. Dev.)
Trmt RN 1	161.1506528	79.04	8.00	1.64	11.32	0.00	(Average)
Trmt RN 1	1.515584263	1.71	0.65	0.11	2.23	0.00	(Std. Dev.)
Trmt RN 2	161.2149306	77.11	6.41	1.35	15.13	0.00	(Average)
Trmt RN 2	1.494939752	2.90	0.31	0.16	2.99	0.00	(Std. Dev.)
Trmt RN 3	53.48308333	88.77	6.93	1.36	2.94	0.00	(Average)
Trmt RN 3	0.1802749794	1.46	0.26	0.19	1.37	0.00	(Std. Dev.)

Charge RN	161.2825139	59.33	6.33	2.86	31.48	0.00	(Average)
Charge RN	1.508027502	3.34	0.31	0.14	3.55	0.00	(Std. Dev.)
PFC RN	77.45359722	61.24	11.65	3.47	23.64	0.00	(Average)
PFC RN	0.1170528987	2.35	0.43	0.36	2.27	0.00	(Std. Dev.)
NP	81.35515278	65.11	3.26	3.61	28.02	0.00	(Average)
NP	0.6433089392	1.46	0.21	0.24	1.69	0.00	(Std. Dev.)
MEC tech	80.513375	38.45	5.61	2.19	53.74	0.00	(Average)
MEC tech	0.4604968119	1.52	0.22	0.08	1.74	0.00	(Std. Dev.)
LVN	81.82858333	50.11	3.56	3.09	43.24	0.00	(Average)
LVN	0.8562417662	1.01	0.25	0.21	1.11	0.00	(Std. Dev.)
Crash RN 1	161.2150278	52.63	3.97	3.25	40.15	0.00	(Average)
Crash RN 1	1.494926397	2.95	0.41	0.26	3.50	0.00	(Std. Dev.)
Crash RN 2	161.2514444	49.88	3.54	2.77	43.82	0.00	(Average)
Crash RN 2	1.495261128	3.69	0.31	0.15	4.01	0.00	(Std. Dev.)
Crash tech 1	161.1638056	41.04	2.33	2.56	54.07	0.00	(Average)
Crash tech 1	1.510634966	3.64	0.23	0.18	3.90	0.00	(Std. Dev.)
Crash tech 2	161.661	38.25	1.96	2.77	57.02	0.00	(Average)
Crash tech 2	1.558326469	2.24	0.27	0.16	2.51	0.00	(Std. Dev.)
Doctor 3	171.9597778	65.29	5.70	1.42	27.59	0.00	(Average)
Doctor 3	1.708839993	1.37	0.18	0.09	1.42	0.00	(Std. Dev.)
Patient Information	171.9597778	31.72	6.64	7.09	54.55	0.00	(Average)
Patient Information	1.708839993	0.79	0.20	0.24	1.12	0.00	(Std. Dev.)

FAILED ARRIVALS

Entity Name	Location Name	Total Failed	
Patient	walk enter	0	(Average)
Patient	walk enter	0	(Std. Dev.)
Mec patient	walk enter	0	(Average)
Mec patient	walk enter	0	(Std. Dev.)
Patient ems	EMS home	0	(Average)
Patient ems	EMS home	0	(Std. Dev.)

VARIABLES

Variable Name	Total Changes	Average Minutes Per Change	Minimum Value	Maximum Value	Current Value	Average Value	
vacuity 1	195.25	50.772246	0	195.25	195.25	94.86	(Average)
vacuity 1	6.03211	1.592980	0	6.03211	6.03211	4.82451	(Std. Dev.)

vacuity 2	655.583	15.355176	0	655.583	655.583	330.011	(Average)
vacuity 2	22.2116	0.511104	0	22.2116	22.2116	12.4404	(Std. Dev.)
vacuity 3	174.833	57.862983	0	174.833	174.833	88.4421	(Average)
vacuity 3	16.0444	5.170276	0	16.0444	16.0444	9.70765	(Std. Dev.)
vacuity 4	95.4167	106.284436	0	95.4167	95.4167	48.3532	(Average)
vacuity 4	12.1615	13.827614	0	12.1615	12.1615	6.44877	(Std. Dev.)
vacuity 5	66.1667	151.127772	0	66.1667	66.1667	33.5134	(Average)
vacuity 5	3.5887	8.035165	0	3.5887	3.5887	2.54582	(Std. Dev.)
vMec	315.667	31.836238	0	3	0	1.10482	(Average)
vMec	18.8936	1.918928	0	0	0	0.0459607	(Std. Dev.)
vTrmt	1507.5	6.810125	0	18	0	10.9877	(Average)
vTrmt	35.6562	0.196863	0	0	0	0.893059	(Std. Dev.)
vTrmt Mec	228.167	44.480181	0	3	0	1.5957	(Average)
vTrmt Mec	11.0358	2.354964	0	0	0	0.173732	(Std. Dev.)
vcounter	2384.33	4.322337	0	54.25	9.83333	24.9859	(Average)
vcounter	38.403	0.073638	0	5.34492	3.12856	2.88104	(Std. Dev.)
vpatient number	1197.08	8.415066	0	1197.08	1197.08	599.643	(Average)
vpatient number	19.649	0.137822	0	19.649	19.649	15.1946	(Std. Dev.)
vOPIP occupied	777.833	12.988706	0	2.5	0	0.23753	(Average)
vOPIP occupied	53.2607	0.880858	0	0.522233	0	0.0174752	(Std. Dev.)
vCrash	323.167	31.873936	0	10.25	0	3.70359	(Average)
vCrash	24.0977	2.382576	0	0.965307	0	0.318595	(Std. Dev.)

LOGS

Log Name	Number Of Observations	Minimum Value	Maximum Value	Average Value	
Mec waiting room time	195.25	1.955000	154.603333	35.463106	(Average)
Mec waiting room time	6.03211	0.005222	28.774567	8.734684	(Std. Dev.)
Non Urgent Waiting room time	612.167	1.087500	145.007500	14.590137	(Average)
Non Urgent Waiting room time	24.4385	0.028324	94.731601	10.003820	(Std. Dev.)
Urgent Waiting room time	135.5	1.121667	77.943333	9.535910	(Average)
Urgent Waiting room time	15.5417	0.035887	28.096401	2.741027	(Std. Dev.)
Mec LOS	195.25	48.647500	259.045833	120.956716	(Average)
Mec LOS	6.03211	2.820381	24.113483	9.684091	(Std. Dev.)
Non Urgent ems LOS	70.0833	44.203333	489.019167	164.633795	(Average)
Non Urgent ems LOS	11.5951	2.680805	111.868471	25.131324	(Std. Dev.)
Non Urgent LOS	585.5	48.011667	592.859167	183.899462	(Average)
Non Urgent LOS	17.8453	2.184577	116.050864	20.676982	(Std. Dev.)
Urgent ems LOS	63.0833	72.889167	455.631667	174.921960	(Average)
Urgent ems LOS	10.9748	7.794109	48.689339	12.564511	(Std. Dev.)
Urgent LOS	111.75	72.718333	497.630000	182.116201	(Average)
Urgent LOS	9.00631	4.413073	36.961269	13.807121	(Std. Dev.)

Immediate Category 2 ems LOS	37.75	90.815833	422.315833	226.625658	(Average)
Immediate Category 2 ems LOS	5.4793	17.304141	62.855410	17.598696	(Std. Dev.)
Immediate Category 2 LOS	57.6667	85.520000	461.707500	248.931392	(Average)
Immediate Category 2 LOS	9.55685	15.871743	70.311661	12.181090	(Std. Dev.)
Immediate Category 1 ems LOS	52.25	110.137500	359.909167	243.537403	(Average)
Immediate Category 1 ems LOS	3.07852	11.080295	19.328924	10.007112	(Std. Dev.)
Immediate Category 1 LOS	13.9167	133.007500	355.188333	242.279188	(Average)
Immediate Category 1 LOS	1.37895	22.603719	48.278716	12.283771	(Std. Dev.)

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