STUDY ON THE EFFECT OF DIFFERENT ARRIVAL PATTERNS ON AN EMERGENCY DEPARTMENT'S CAPACITY USING DISCRETE EVENT SIMULATION

by

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Abstract

Emergency department (ED) overcrowding is a nationwide problem affecting the safety and preparedness of our health care system. Many hospital EDs face significant short and intense surges in demand on a daily basis. However, the surge in demand during disaster event is not short and intense, but it is a sustained one. In order to meet this sudden surge as defined above, hospital EDs need to be more prepared and efficient to cater to increased volume of demand involving huge uncertainties.

This thesis looks at the creation and use of discrete event simulation modeling using ARENA 10.0 software. In this thesis, an attempt is made to show how the different arrival patterns and time durations for which victims keep arriving affect the EDs ability to treat the patients. It is shown, how the model can be used to estimate additional resources that would be required to accommodate additional patients within the ED.

Various shapes of arrival distributions were tested for different time durations. It was found that the arrival distribution with parameters (3, 4), (3, 3), (4, 2) and (2, 4) did not challenge the institutional capacity. In other words, the hospital was able to treat all the patients without compromising the quality of care up to 24 hours. However, distribution with parameter (3, 2), (2, 2), (3, 1), (1, 2), (2, 3), (2, 1), (1, 4), (1, 3), (1, 1) and (0.5, 2) did affect the system performance. Under these distributions, there was at least one patient who was either dead, LWBS or diverted. This indicates the immediacy with which victims arriving under these distributions overwhelmed the limited resources

Our aim was to study, how many more resources would the ED need in order to have zero critical expire, zero Left without Being Seen (LWBS) and zero patients diverted. Arrival distribution (1, 2) was randomly selected to study this objective and it was found that for a 24 hours of simulation run time, an additional of two full trauma resources were required in order to have zero critical expire in trauma rooms area and additional of five ED beds and three nurses were required in treatment area for patients with moderate severity to have zero LWBS. With these additional resources, the ED was also able to treat all the non disaster related patients thereby having zero patients diverted.

The same procedure can be used to determine the number of additional resources ED would require to treat all the victims arriving with the rest of the arrival distribution for different time periods. The simulation model built would help the emergency planners to better allocate and utilize the limited ED resources in order to treat maximum possible patients. It also helps estimate the number of additional resources that would be required in a particular scenario.

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Acknowledgements

Completing my thesis, "STUDY ON THE EFFECT OF DIFFERENT ARRIVAL PATTERNS AND TIME DURATION ON AN EMERGENCY DEPARTMENT'S CAPACITY USING DISCRETE EVENT SIMULATION" would have seemed like a herculean task, if not for all the people who have helped me along the way. I would like to express my sincere gratitude to my major advisor Dr. Malgorzata Rys, for all her encouragement and support throughout the duration of this research.

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Dedication

I would like to dedicate my thesis to
Mom & Dad
Jyoti mom & Dilip papa
Jinesh, Harshit & Shreyas
To my friends and roommates, in alphabetical order
Aditi Shukla
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Thank you all for being there

CHAPTER 1 - Introduction

1.1 Background

Emergency department (ED) overcrowding is a nationwide problem affecting the safety and preparedness of our healthcare system. Hospitals constitute an important part of the healthcare system and the emergency departments within these hospitals play the most important role, as they are the link between out of hospital (e.g. Emergency Medical Services) and hospital resources (e.g., Emergency Departments, Operation rooms, inpatient bed etc.) (J. Lee Jenkins et al., 2006). Many hospital EDs face significant surges in demand on a daily basis because of their commitment to providing unplanned, emergent and nonemergent health care services to all patients who arrive at the ED. Moreover, a recent trend shows that number of emergency rooms and number of hospitals is decreasing in the U.S. Between 1999 to 2000, there have been approximately 500 hospital closings and between 1988 and 1998, 1128 emergency department were closed (AHA, 2001 a).

In a disaster or a mass casualty event, the emergency situation adds up to the everyday complexity already present in the healthcare system due to the pressure faced from the reduced resources. Disaster events produce victims with significant traumatic injuries and thereby challenge the EDs and the hospital emergency response. The surge in demand during such an event is not short and intense, but it is a sustained one. It is quite uncertain as to, at what rate victims will start arriving at a particular hospital's ED to seek medical assistance. During the first 24 hours after 2001 World Trade Center attack; more than 500 victims sought emergency care at Beekman Hospital (four blocks from ground zero) and more than 300 victims sought emergency care at St. Vincent hospital (approximately one mile from ground zero) (Arnold et.al., 2003). The time until arrival of the first victims at the ED following the detonation as well as how long the patients continue to arrive and at what rate have relevance for planning (Arnold et.al. 2003). Also, the frequency and type of injuries sustained in such disasters are not the regular injuries which hospitals see every day. Both these factors further add to the surge issue during a disaster.

In order to meet this sudden surge as defined above, hospital EDs need to be more prepared and efficient to cater to such increased volume of demand involving huge uncertainties.

Some have argued that disasters are just like daily emergencies, only larger. Therefore, they conclude that the best disaster response is merely an expansion of the routine emergency response plan, supplemented by mobilization of extra personnel, supplies, bed space and equipment. Years of field research on medical disasters has shown that this every day system, which we will call the "steady state system", is not designed to be able to respond to emergencies in which there are many casualties and with infrequent injury types (Auf der Heide, Disaster Medicine, 2005 pg 96.). Apart from knowing the minimum number of physical and human resources that would be required to handle such an event, it is quite important for a hospital ED to know how to allocate these limited resources during such an event which, again depends upon the nature and the distribution of injury types amongst the victims.

Disaster preparedness has never been more important to our country than during the past few years as a result of experiences with 9/11 (2001) and hurricanes Katrina (2005) and Rita (2005). Mass casualty disaster response plans have become a priority for many organizations, including hospitals. There are many guidelines and resources available to construct such plans. At the federal level, Federal Emergency Management Agency is the major agency that develops such plans (U.S. Department of Health and Human Services (DHHS), 1996; FEMA, 2003). At the state level, each state government has developed their own emergency plan with respect to their most likely emergency situation (California State, 1998; Indiana State, 2003). Physical simulations or so called "disaster practice drills" are often performed. However, not until a disaster strikes that the capabilities of the plan are truly realized. A typical disaster response plan of an ED to meet sudden surge of emergency patients is explained in detail in section 2.1. As mentioned earlier, such emergency situations overwhelm the limited ED resources and it is of great importance to determine efficient allocation and utilization of these resources. The principle aim of any ED during a disaster is to decrease the critical mortality rate in their hospital and the morbidity associated with the moderately severe patients. While the EDs are catering to the demand of the disaster affected victims, it sure does not relieve them from the everyday non-disaster related emergency calls. If the ED is already running at its capacity and has to divert these calls, then this can be treated as a huge revenue loss for the hospital. Thus, it becomes necessary to determine how many physical resources and medical staff would be required and in what manner should they be allocated to take care of all the victims i.e. without having any mortality, morbidity and diversion of patients.

The main objective of the research is to study the effect of different arrival patterns and the time duration over which disaster-affected victims keep arriving at the ED seeking medical assistance. We will look at an ED's capacity and ability to treat patients in a timely manner without having any mortality and morbidity associated with the disaster-affected victims. The disaster under consideration is a conventional terrorist bombing attack, which includes an open-air bombing environment (bombings that take place in open areas like market place, stadium, open parking lot, etc.) as well as a confined also often called closed-space bombing (bombings that occur in closed / confined places like trains, buses, cars, etc.). One of the other objectives of this research is to study and analyze patient flow and injuries associated with a conventional terrorist bombing attack.

Thus, to further summarize the objectives, this research aims at the following

1. To study and analyze patient flow in the emergency department (ED) during a conventional terrorist attack.
2. The study the impact of different arrival patterns and different time durations for which the victims continue to arrive on the emergency department's capacity.
3. To demonstrate the possibility of using simulation as an effective planning tool for identifying different staff requirements and study the intricacies involved within the hospital departments for a variety of hypothetical conventional terrorist bombing scenario.

The next section gives a brief overview of the type of injuries its mechanism resulting from the conventional terrorist bombing attacks.

1.2 Conventional terrorist bombings

Blast trauma from bombing incidents varies greatly depending upon the physical environment (open air & confined space.), the device and explosive properties. The type of injuries to victims in both bombings is similar but the frequency of each type of injuries is quite different. Although the recent experience with terrorism suggests "expecting the unexpected," an understanding of epidemiology patterns in mass casualty; terrorist bombings provide a rational basis for emergency planning, preparedness and response (Arnold, 2003).

1.2.1 Bombing environments considered in this thesis

1. Open space bombings:

These are the bombings that occur in open spaces like markets, stadiums, fairs, field, parking lot etc. In this setting few hard objects are present to hinder the propagation of the blast wave. Open air bombing can become structural type of bombing if there is any destruction caused to the nearby building. The centennial Olympic park bombing on July 27, 1996 is an example of open space bombing (Lee, 2004).

2. Confined space bombings:

These bombings are the ones that occur in buses, cars, trains, stores which have little space and tight and limited movement. There are plenty of reflecting surfaces which hinder the propagation of the blast wave thereby causing severe injuries in the immediate survivors and large number of on scene deaths (Lee, 2004).

Literature on more detailed and comparative study on both the above mentioned bombing types can be found in an article by Leibovici et al., 1996 in which, he has compared the injury patterns resulting from both type of bombings. Another article by Arnold et al., 2004, discusses the epidemiological outcomes, resource utilization and time until arrival of the first victim to ED following the explosion and how long victims continue to arrive in different types of mass casualty bombing. The next section explains the mechanisms of injury in conventional bombing which will help better understand the nature and severity of different type of bombing injuries.

1.2.2 Mechanisms of blast injury

Mechanism and determinants of physical injury from blasts depends on several factors including the type and size of the blast, the distance of the casualty from the explosion, the effects of environmental pressure changes, the conditions caused by blast pressure and blast winds, and the environment in which the blast occurs (Dire, 2005). Table1 further summarizes the mechanisms of blast injury.

Primary Blast Wave Injury (PBI)

PBI are caused due to the direct impact of the blast pressure wave on the human body. It is mainly due to the under-pressurization or the over-pressurization relative to the atmospheric pressure. PBI most commonly involve air filled organs and air-fluid interfaces. Rupture of the tympanic membranes, pulmonary damage and the air embolization, rupture of gastrointestinal organs and head injuries are the most important primary forms of blast injury (See Table 1). The presence of these injury patterns in a casualty is the evidence of the casualty's proximity to the explosion. Primary blast injuries are most common in confined space bombing, since confined spaces tend to concentrate victims around the detonation point and augment via blast waves reflected off the surrounding surfaces. These types of injuries are considered to be very severe (Dire, 2005).

Secondary Blast Injury (SBI)

Many explosives contain metallic and other fragments. On explosion, these fragments hurl through the air causing penetrating or non-penetrating secondary blast injuries. These fragments are often referred to as shrapnel. As distance from the blast epicenter increases, the effect of the blast itself is reduced, and the effect of fragments and debris propelled by the explosion becomes more important. Secondary blast injuries are more common than the primary blast injuries irrespective of the bombing type. However, the percentage of this type injury is most common in open air setting compared to the confined space type of bombing (Dire, 2005).

Tertiary Blast Injury (TBI)

Tertiary blast injury results from blunt trauma that occurs when the victim is lifted and thrown against the structure by the blast wave or blast wind. It results from the bulk flow away of gas from the explosion. Many blast injuries under this category are difficult to categorize as they may be attributed to more than one mechanism (Dire, 2005).

Quaternary Blast Injury (QBI)

Quaternary blast injuries refer to explosion-related injuries which are not caused by any of the above mechanisms. It encompasses exacerbations or complications of persisting conditions (Dire, 2005).

Table 1. Mechanisms of blast injury

Category	Characteristics	Body Part affected	Types of Injuries
Primary	Unique to High explosives, results from pressurization wave with body surfaces.	Gas filled structures are most susceptible- Lungs, GI tract and middle ear	Blast Lung TM rupture and middle ear damage. Abdominal Hemorrhage and perforation. Globe (eye) rupture. Concussion (Closed Head)
Secondary	Results from flying debris and bomb fragments	Any body part may be affected	Penetrating Ballistics (fragmentation) or blunt injuries Eye penetration (can be occult)
Tertiary	Results from individuals being thrown by the blast wind	Any body part may be affected	Fracture and traumatic amputations Closed and open brain injury
Quaternary	All explosion-related injuries, illnesses or diseases not due to tertiary mechanisms. Includes exacerbation or complications of existing conditions.	Any body part may be affected	Burns (flash, partial and full thickness) Crush injuries Asthma, COPD or other breathing problems from dust ,smoke or toxic fumes - Angina -Hyperglycemia -Hypertension

Source: CDC website available at http://www.bt.cdc.gov/masscasualties/explosions.asp (accessed on 04/07/08)

1.2.3 Epidemiology outcomes of injury by bombing types

Critical analysis of the patterns of injury and mortality from the different bombing types helps understand the demand of medical resources and the overall burden on communities. Arnold et.al, 2003, carried out a comparative study for different bombing types. He found that structural collapse mass casualty bombings tend to produce hundreds to thousands of immediately surviving injured (median 359) and fewer than 500 hospitalized victims (median 85). Confined space mass casualty bombings tend to produce 30 to 100 immediately surviving injured (median 53) and fewer than 50 hospitalized victims (median 25). He also reported that open air mass casualty bombings tend to produce 50 to 150 immediately surviving injured (median 76) and fewer than 509 hospitalized victims (median 18). These epidemiologic patterns suggest that once a terrorist bombing is underway, knowledge of the bombing type may help guide the initial estimates of the need for ED and hospital bed capacity. In addition, according to Arnold, 2003, anticipation of injury rates in patients seeking the emergency care at hospitals may guide initial estimates of which resources will be required. For example, in confined space more primary blast injury will be produced compared to other two types of bombings. In a structural collapse less of primary blast injuries will be produced and more of secondary and tertiary blast injuries will be produced. Open air bombings tend to produce a predominant need for wound care, with a few victims with more serious injuries found virtually in every category. Summarizing, the three types of bombings produce unique patterns of injuries, mortality, hospitalization rates and number of immediately surviving injured seeking hospital care. Table 2 summarizes the bombing characteristics and their impact on hospitals. However, in this thesis we have limited our scope to open air bombings and confined space bombings. The values of percentage distribution of injury types for open air bombing shown in Table 4 will be used as a default throughout the experiment. An example on how the change in the percentage distribution of injury types to a confined space bombings will affect the hospital resources will be shown.

Conventional terrorist bombings tend to produce more “trauma intensive patients” i.e. they provide some mechanism of injury that produces wounds within presenting casualty unlike other forms of disaster which involve use of chemical agents. Patients affected by such an event are usually treated at trauma centers. The next section gives a brief introduction to the different levels of trauma center and a glimpse of trauma center infrastructure in the state of Kansas.

Table 2. Bombing characteristics and anticipated impact on hospitals.

Bombing Characteristics	Implications	Anticipated Impact		
		Number of injured survivors seeking ED care	Injury Frequency	Injury Severity
Blast site close to hospital	-Increased number of injured survivors will arrive at ED. -Decreased EMS transport time.	Increase in numbers arriving at nearby hospital	High number of primary blast injuries, traumatic injuries and many other minor injuries	Variable- More minor and more severe
Open-air setting	-Blast energy dissipated but spread over greater area. -Structural collapse unlikely. -Decrease number of immediate deaths.	Increased. May produce up to 200 injured survivors.	Increased secondary blast injuries	Decreased. More minor injuries
Confined-space setting	-Blast energy potentiated but contained in lesser area. -Increased number of immediate deaths under confined space. -Increased number of injured exposed to blast effects. -Increased effects in smaller space (bus, public room).	Decreased. Usually produces less than 100 injured survivors.	Increased primary blast injury, amputations and burns.	Much more high severity compared to other two.
Structural Collapse setting	-Increased explosive magnitude. -Collateral damage outside structure possible. -Increased number of immediate deaths inside the collapse. -Increased effects with taller building	Variable. -Decreased number from inside collapse. -Increased number from outside structural collapse. -May produce 100's to 1000's of injured survivors.	Increased inhalation and crush injury.	Increased.

Source: Halpern P, Ming-Che T, Arnold J, Stok E, Ersoy G. Mass-casualty, terrorist bombings: implications for emergency department and hospital emergency response (part II). *Prehosp Disast Med.* 2003; 18:235-241.

1.3 Trauma center levels and its infrastructure in the State of Kansas

A trauma center is a hospital equipped to provide comprehensive emergency medical services to patients suffering traumatic injuries 24 hours a day, 365 days per year. Trauma centers were established as the medical establishment realized that such injuries often require immediate and complex treatment, including surgery, to save the patient (Wikipedia, accessed 04/09/08). They are the hospitals distinguished by availability of both physical and personnel resources.

1.3.1 Levels of trauma center

The trauma center is classified into different levels on the basis of availability of both human and physical resources.

Level I: A level I trauma center provides the highest level of definitive and comprehensive care for patients with complex injuries. Emergency physicians, trauma nurses, and surgeons are in-house and immediately available to the trauma patient to direct patient care and initiate resuscitation and stabilization. For more information on criteria for Level I Trauma Centers, see American College of Surgeons, Resources for Optimal Care of the Injured Patient, 1999 (Resources for Optimal Care of the Injured Patient, 1999).

Level II: A level II trauma center provides definitive care for complex and severe trauma patients. Emergency Physician is in-house and immediately available to the trauma patient for direct care and initiate resuscitation and stabilization. A surgeon should be available upon patient arrival in the emergency department. For more information on criteria for Level II Trauma Centers can be found in the American College of Surgeons, Resources for Optimal Care of the Injured Patient, 1999 (Resources for Optimal Care of the Injured Patient, 1999).

Level III: A level III trauma center provides prompt assessment, resuscitation, emergency operation and stabilization for trauma patients or arranges for appropriate transfer to high level trauma designated facility as required. Comprehensive medical and inpatient surgical services are available to those patients who can be maintained in stable or improving condition without specialized care. Emergency physician and nurses are in-house and immediately available to trauma patients. General surgeons are available within 30 minutes of being called to asses, resuscitate, stabilize and initiate transfer (if necessary) of patients requiring trauma care. Level

III trauma facilities in Kansas are approved by Kansas Department of Health and Environment (KHDE) and inputs from Kansas Advisory Committee of Trauma (ADT). The above information is obtained from the Kansas trauma program website. For more information on criteria for level III trauma centers, see Kansas trauma program website (www.kstrauma.org).

1.3.2 Infrastructure of trauma system in State of Kansas

Over half of the Kansas population resides in the 26 counties in North East (NE) region of Kansas, four are designated as urban, five are designated as semi urban, six are designated as densely settled rural, ten are designated as rural and one is considered as a frontier county (Kansas Department of Health and Environment population density groupings based on 2000 census). The distribution of NE trauma region in the state of Kansas is as shown in Figure 1 below. In addition to population diversity, the NE region is unique in diversity of facilities and resources. State of Kansas has five American College of Surgeons verified trauma centers including three level I centers; University of Kansas Hospital (Kansas City, Wyandotte county), Via Christi (Wichita, Sedgwick County) and Wesley (Wichita, Sedgwick County); One level II facility Overland Park regional medical center (Overland Park, Johnson county), and one level III facility, Stormont-Vail Healthcare (Topeka, Shawnee county) (NE Kansas Regional Trauma System Plan, 2002).

The NE region has 34 hospitals within 26 counties. American College of Surgeons verified trauma centers: Level I trauma center, University of Kansas Hospital (Kansas city, Wyandotte county); Level II trauma center, Overland park regional medical center (Overland park, Johnson county); Level III trauma center, Stormont-Vail Healthcare (Topeka, Shawnee county) are located in NE trauma region (See Figure 2 below). As per the State of Kansas trauma system plan, the infrastructure of trauma system in Kansas will rely on the level III trauma, with strong linkage with level I and level II hospitals which is largely due to geography, population distribution and the available resources. Hence, the facility which is considered in this study is a Level III trauma facility (NE Kansas Regional Trauma System Plan, 2002).

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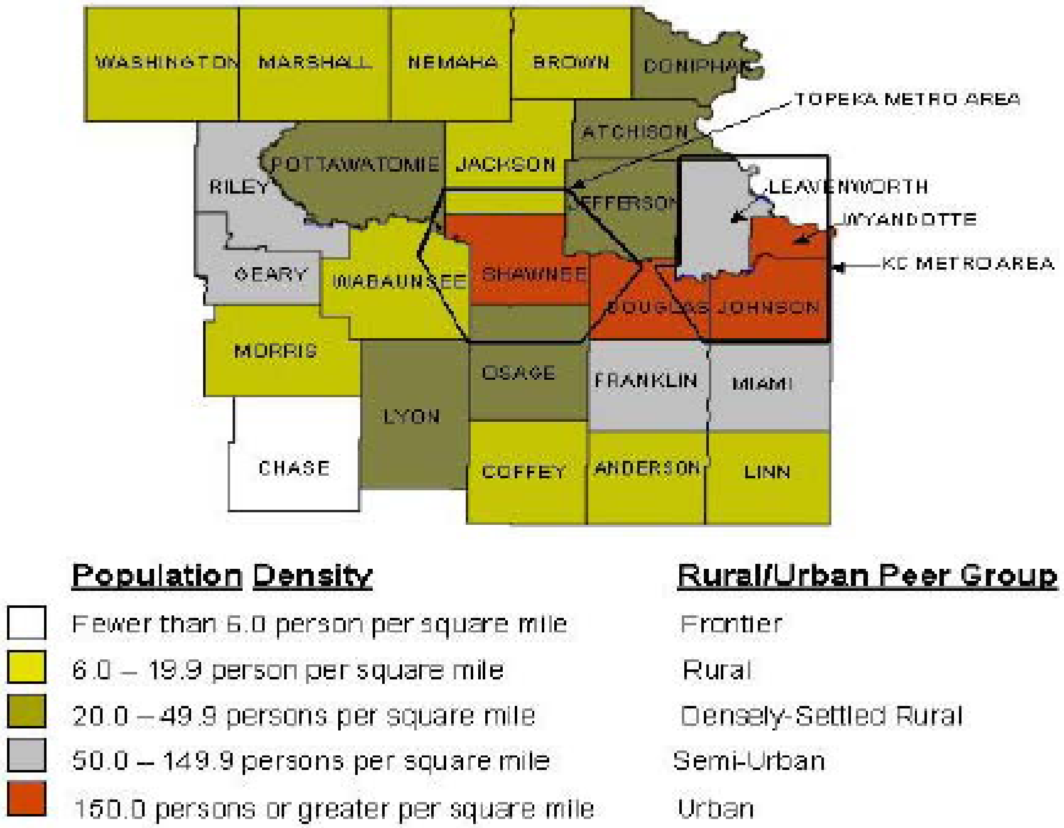

Figure 1. NE trauma region in the State of Kansas

Source: NE Kansas regional trauma system plan 2007

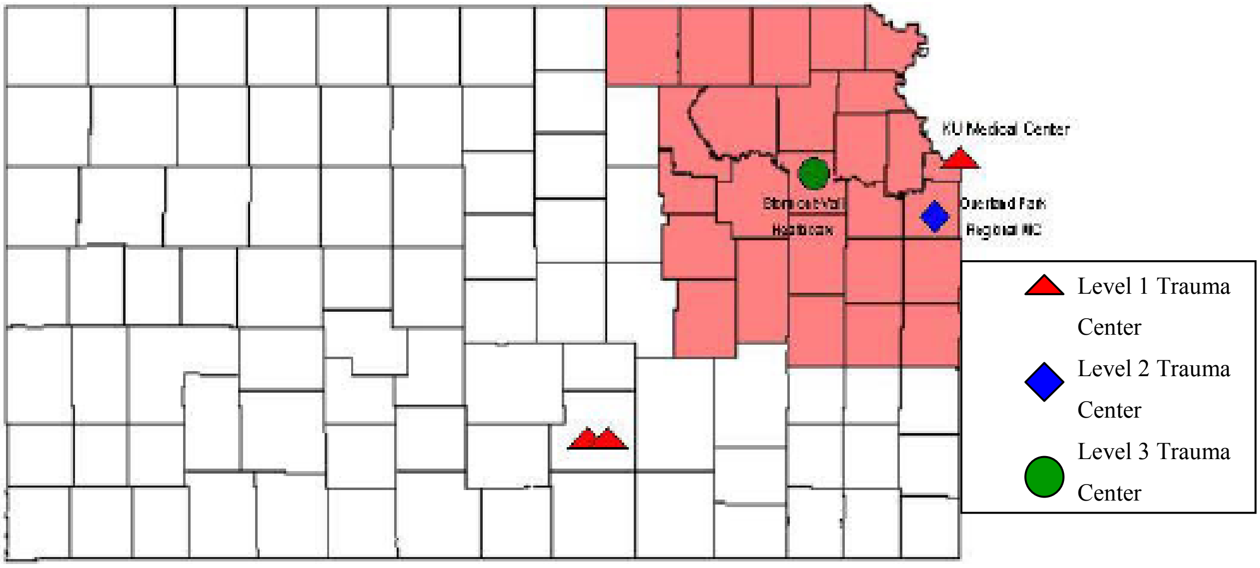

Figure 2. Trauma centers in NE trauma region in the State of Kansas

Source: NE Kansas regional trauma system plan 2007

1.4 Definition of mass casualty or disaster

There are a number of definitions of disaster due to the multidisciplinary nature of disaster planning and response. The World Health Organization (WHO) defines a disaster as “a sudden ecological phenomena of sufficient magnitude to require external assistance.” In one of his paper, “Disaster epidemiology”, Noji states, “From public health perspective, disasters are defined by what they do to people. What might constitute a disaster for one community might not necessarily be considered a disaster in a different community” (Noji, 1996). A more focused definition often used by emergency practitioners is when “The number of patients presenting within a given time period are such that emergency department cannot provide care for them without external assistance” (Disaster Medicine, 2007). Virginia office of emergency medical services define mass casualty event as “incident which generates more patients than available resources can manage using routine procedures” (Green, 2000). This is the definition that will be used for mass casualty and disaster throughout this thesis. Both words may be used interchangeably.

CHAPTER 2 - Literature review

2.1: Overview of a general hospital disaster response plan:

The first priority for any ED faced with the aftermath of an explosion is to activate the hospital disaster response plan in order to mobilize the capacity, equipment, supplies and personnel required by large number of victims. A clear chain of command within the ED staff is initiated by personnel well trained in advance to work together under a mass casualty situation. The Hospital Emergency Incident Command System (HEICS) provides a useful organizational tool for the command and coordination of hospital and ED emergency response. A typical HEICS is as shown in Figure 3. It provides a predictable chain of command, clear lines of communication, prioritized actions, accountability of performance, and harmonized nomenclature (Halpern et al., 2003).

Most emergency departments of hospitals will have at least few minutes from the time they are first notified of the event until the first victim arrives. During this brief period, the ED is immediately cleared of with as many patients as possible through early discharge to home or an admission to the hospital. A predetermined ED evacuation plan is critical as an ED full with the regular patients can lead to a significant confusion. At the same time hospital capacity is also expanded. Hospitalized patients are evaluated for possible disposition home. Elective surgeries are cancelled and the recovery rooms are also cleared. Intensive Care Unit (ICU) patients are also evaluated for possible transfer outs. In the hospital, the triage office, a well-trained surgeon, is responsible for sorting the injured according to their severity of injury. The most critically injured patients are usually sent to the trauma rooms, which are the most highly equipped area in the emergency department, the moderately injured patients are sent to the standard ED beds area and the minimal injured patients are sent to areas other than emergency department. The on call surgeons and specialists are soon called in to be a part of the handling the sudden huge influx of the patients (Kalemoglu, 2005). The patient disposition within the hospital may change depending upon a particular hospitals disaster response plan. A typically mass casualty flow during such an event is as shown in the Figure 4.

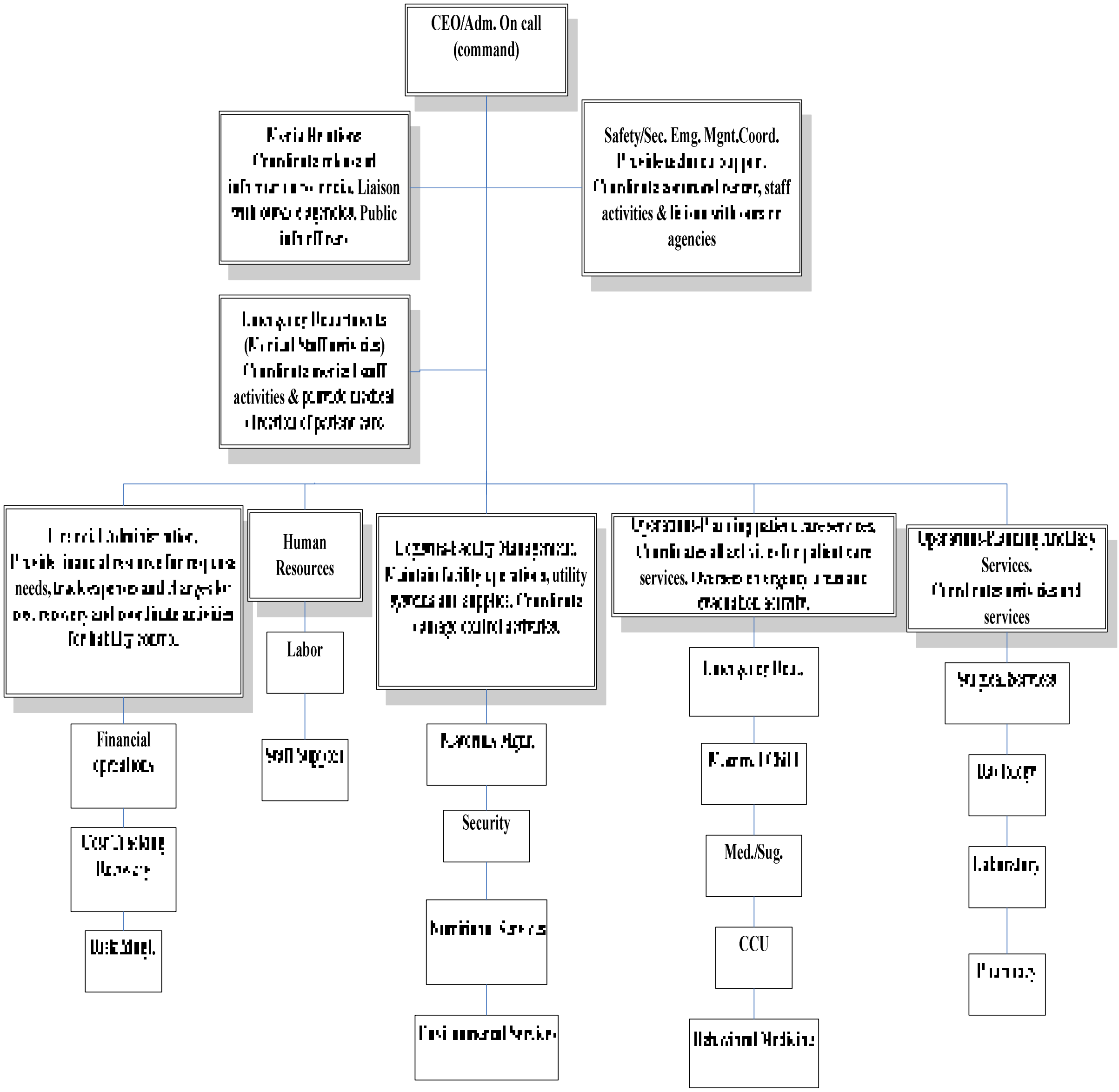

Figure 3. Hospital emergency incident command system

Source: Stormont-Vail Healthcare (Level III trauma Center), Topeka

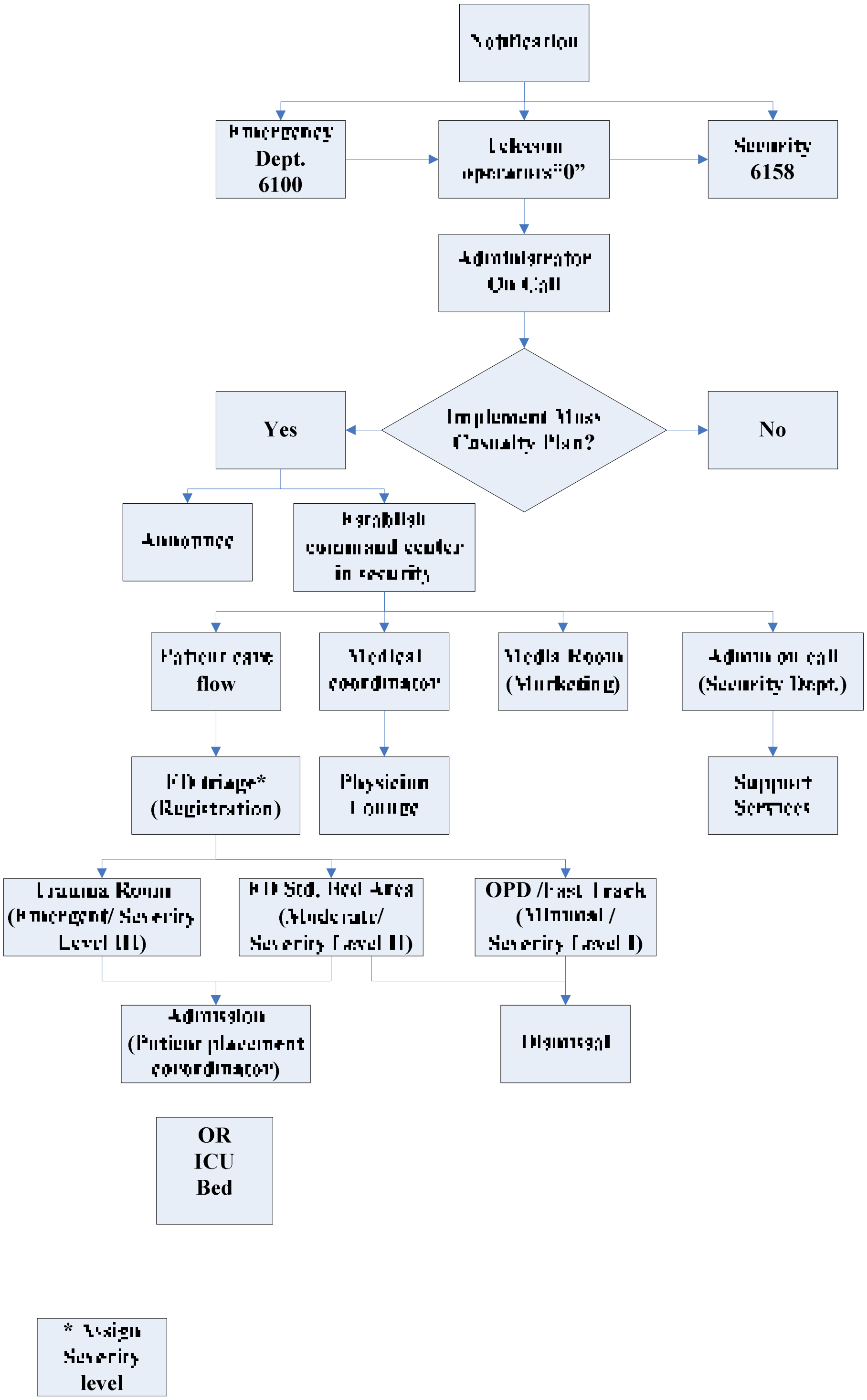

Figure 4. Mass casualty flow chart

Source: Stormont-Vail Healthcare (Level III trauma Center), Topeka

2.2: Validity of disaster planning assumptions

Just because a hospital has prepared a written disaster response plan does not mean the hospital is prepared for a disaster. Hospitals perform disaster drills often to practice their response to a disaster based on the plan that they have documented. Many hospital administrators concede that, although disaster plans are necessary for hospital accreditation, they are relatively unworkable in practice. The reason being that many of the assumptions made during the planning of emergency / disaster response are invalid (Auf der Heide, 2006). Some common, often incorrect assumptions are:

1. Studies of previous disaster provide a good data for future incidents.
2. Communication systems will remain intact.
3. Casualties will be transported to hospital appropriate of their needs and in such a way that no hospitals receive disproportionate numbers.
4. The most serious casualties will arrive first.

Each of the above stated assumptions are explained in detail in the following sections (2.2.1-2.2.4)

2.2.1 Studies of previous disaster does not always provide a good data for future incidents

The nature of disaster studies makes the collection of good, meaningful data very difficult. Most of the disaster medical planning has been conducted on sudden, single impact disasters. There in no way that you can choose a single location to collect data. The existence of countless variables that exist makes it difficult to perform a controlled experiment to collect good data. Hospitals often have a difficult time keeping track of patients and recording data that would be useful in post disaster analysis. In a study performed by Mohammed et.al, 2005 on "Impact of London's terrorist bombing on Royal London Hospital", it was found that a large number of patients arrived at the hospital with varying degrees of injury in a very short time period. This large number of patient influx resulted in difficulties with documentation as providing lifesaving care was more important than documenting the data. The number of people killed, injured and the frequency of injury in patients will differ from one bombing to another as these numbers depend upon variables such as target population, bombing intensity, bombing environment, method of delivery, distance of victims from the site etc (Arnold, 2003). All of these variables make it difficult to collect accurate disaster data and difficult to extrapolate that data to determine how a similar disaster would affect a different community. Better record keeping and data collection during disasters will help developing more accurate disaster plans (Auf der Heide, 2006).

2.2.2 Communication systems are often unreliable during mass casualty events

Communication is most important in successfully carrying out the disaster plan. Unfortunately, in almost every disaster lessons on failure of communications is learnt over and over again due to its repetitive nature. There are various reasons for their failure. It may be due to damage to the existing radio equipment or telephone lines are damaged. Unfortunately, even if these equipments and communication lines are intact, the circuits will be almost overloaded and unusable due to the heavy influx of incoming and outgoing calls. In London bombing that happened in July 2005, shortly following the attack, the mobile phone networks across London failed, and the internal telephone lines at one of the receiving hospitals became blocked due to the volume of calls that were being made. As a result, there was a lack of information communicated from the scene of the bombings. The internal pager system in the hospital also failed and went offline. As the events escalated, difficulties with communication also increased. The communication between various departments within the hospital was lost and this made the system pretty much inefficient and slow as senior house officers had to become runners between the various departments carrying the delivery of messages (Mohammed et.al, 2005).

All these communication problems must be considered in disaster planning, as they are most likely to occur (Auf der Heide, 2006).

2.2.3 Most casualties are transported to the closest or most familiar hospitals

It is often challenging in disasters to make best use of available medical resources. Majority of the survivors often seek medical assistance from the hospital that is closest to the disaster site. The disaster research center study found that in 75% of cases, more than half of the casualties were transported to the closest hospital. It is very common for planners to assume that Emergency Medical Services (EMS) will distribute the victims evenly amongst all the hospitals available in disaster area, which is actually not the case (Auf der Heide, 2006). This problem can be solved by having ambulances to avoid transporting victims to hospitals close to disaster site. Another approach might be to determine how many casualties each hospital will initially be sent (Auf der Heide, 2006).

2.2.4 Minor casualties arrive first

All the casualties will not arrive at the same time to seek medical assistance at the emergency department. The patients usually arrive in two waves to the hospital. The first wave consists of the victims that are with minor injuries usually termed as “walking wounded”. The more serious casualties arrive later, generally after 30 to 60 minutes after the disaster strikes (depending upon the distance of hospital from site) (Emergency Operation Plan, Solano County EMS, 2004)*. Those suffering the worse injuries may be not capable of self transporting themselves and may be waiting for ambulance assistance on site to transport them to the hospital, while few of them may be covered in piles and debris if there is a structural collapse accompanying the explosion, unable to seek help and waiting for ambulance transportation. This results in emergency departments becoming busy with treating minor casualties while the severely injured arrive later (Auf der Heide, 2006).

The next section reviews various approaches taken in modeling hospitals operations with a focus on work associated with the used of discrete event simulation modeling.

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*http://www.co.solano.ca.us/resources/EMS/Mass%20Casualty%20-%20Explosives.pdf

2.3: Modeling of hospital operations

A variety of methods used for modeling hospital operations are found in the literature. Conceptual models provide a high level sketch of hospital operations. Deterministic mathematical models, such as linear programming and dynamic models are used for resource allocation in hospital/healthcare. Queuing theory models are used to capture the stochastic nature of arrivals. Control theory and system dynamic models are capable of describing both steady state and transient behavior. A detailed literature review on the above mentioned models is well summarized in Paul, 2006. This thesis uses discrete event simulation modeling technique to model the ED operations. Literature review of articles using the discrete event simulation modeling approach will only be summarized.

2.3.1: Discrete event simulation modeling:

Quantitative models lack the capability of modeling complex systems, such as hospital operations, whereas discrete event simulation is a useful method capable of modeling detailed functioning of hospitals. The main use of discrete event simulation in healthcare industry is for simulating the patient flows and problems related to resource allocation. Patient flow can be further broken down to patient scheduling and admissions, patient routing and flow schemes and resource scheduling (Paul, 2006).

Cote, 1999 developed simulation model to examine the influence of examining room capacity and patient flow on the four performance measures (room utilization, room queue length, examining room's occupancy and patient flow time). Weng and Houshmand, 1999 conducted a simulation study for a local clinic. In addition to standard performance measures (throughput, time in system and queue times and lengths), they also measured the cash flow. By simulating different scenarios of staff size, they were able to find the best size that maximizes patient throughput while minimizing both the patient flow time and cost.

Lowery and Davis, 1999 used a trial and error approach to determine the operating room requirements. They varied the number of operating rooms and the operating room schedule, and found that the realistic target is to keep operating room utilization in between 80 % to 85 %.

Baesler, 2003 used simulation modeling technique for estimating maximum possible demand increment in an emergency room of a private hospital in Chile. The model was used to create a curve for predicting the behavior of variable patient's time in system and estimate the maximum possible demand system can absorb. He also used design of experiments principle in order to define the minimum number of physical and human resources required to serve this demand.

Hirshberg et al., 1999 developed a simulation model to analyze the utilization of surgical staff and facilities during an urban terrorist bombing incident. The model developed by them is based on the emergency plan of the 1400-bed university hospital in Israel. The model predicts that the admitting capacity of the hospital depends primarily upon the number of available surgeons and defines an optimal staff profile for surgeons, residents, and trauma nurses. Hirshberg, et.al, 2005 used the computer simulation modeling technique in another study performed by him which involved examining the effect of casualty load on level of trauma care in a multiple casualty incident and to define the surge capacity of the hospital trauma assets. The arrivals in both scenarios were modeled as a Poisson process. However, the patient arrivals during disaster are not constant and steady but are dynamic. The system is likely to follow a transient period under the high arrival rates. Consequently, steady-state performance measures of normal operations are inadequate in disaster modeling.

Patvivatsiri, 2006 & 2007 used simulation modeling technique to determine the emergency room preparedness for a bioterrorism event. The objective of this work was to analyze patient flow throughout the treatment process, assess the utilization of ER resources, evaluate the impact of hypothetical bioterrorist attack and determine the appropriate resource and staff levels for a bioterrorism scenario. The simulation model for the hospital was built using professional simulation software Flexsim 2.6. However, the limitation of this work is that it assumes a constant rate of arrival over a period of time, which actually is not quite true as the patient arrivals during such an event, is dynamic and not constant.

Paul, 2006 used a transient modeling approach using simulation modeling technique to model the behavior of the system and allow real-time capacity estimation of hospitals of various size in an earthquake situation. The parameters of the exponential model are regressed using outputs from the designed simulation experiments. He has used the simulation metamodeling approach in order to overcome the drawback of running multiple simulation runs to establish statistical confidence intervals and the necessity to try and model each of the hospitals individually. The results reported, based on his work, are said to be useful for design or improvement of hospital facilities for disaster planning. The work also focuses on developing a method for estimating patient arrival rate. The research done by Paul is specific to earthquake scenario. A natural extension to this research as reported in his future work is to model the hospital operations under other emergency situations such as conventional terrorist bombing attack, where the types of injuries and the patient arrival patterns are different from those in an earthquake setting. Consequently the patient routing and the processing times are also different.

From the above literature review, it is clear that there have been studies carried out for a variety of manmade disasters like bioterrorism, conventional bombing and for natural disasters like earthquake. However, some of these studies have modeled arrivals using Poisson distribution process which assumes a constant arrival rate. Arrivals in disasters are dynamic and not constant. As mentioned earlier, the time of arrival of the victim to the ED and the time for which they keep coming to ED post disaster hold relevance in planning. This study seems to be the first to analyze the effect of different arrival patterns and time durations on the emergency department's capacity.

CHAPTER 3 - Methodology

A computer simulation model was created using Arena version 10.0 to simulate ED operations for a mass casualty event to study the objectives of this work. In order to build the model, information on the number of physical and human resources that would be available at a particular hospital, patient routings between different hospital departments, and service times at each of these departments was required. The number of physical resources like trauma rooms, ED beds, X-ray machines, Computed Tomography (CT scan) machines and the Operation Rooms (ORs) that would be available to treat the patients coming to the hospital facility were established based upon the information provided from the Stormont-Vail Healthcare which is a level III hospital located in Topeka. The probabilistic routing of patients within each department along with service times at each of the departments used in the model were based upon the best available estimates provided by the expert at the Stormont Vail Healthcare. In this section the assumptions made in building the model and the details of how the simulation was created are explained.

3.1: Modeling Assumptions

In creating the simulation certain assumptions were made. Not all assumptions would hold true to any of the hospital during a mass casualty event. Few basic assumptions are explained below and other assumptions are explained in the modeling details section as the model is explained.

3.1.1 Assumption 1-Non-disaster related patient volumes

The rate at which non-disaster related patients show up at the emergency department will be the same as that faced by a level III trauma hospital during the everyday operation called the steady state, non-disaster time period. The arrival rate of these patients is assumed to be constant throughout the day, and to be unaffected by disaster.

3.1.2 Assumption 2-Disaster related patient classification and attributes

It is quite common for the disaster affected victims to suffer from multiple traumatic injuries; however it is assumed that each patient retains its type classification attribute throughout his/her stay in the ED.

3.1.3 Assumption 3-Level of care for patients

In order to serve maximum number of victims and to do the greatest good for the community, hospitals in case of disaster situations choose to alter the level of care provided to the victims. For example, if the hospital personnel realize that the resuscitation bays (also called shock room or trauma rooms) that are available are not large enough to treat the critical patients, they might decide to treat patients in improvised bays which could be located in the standard ED bed area. If there are not enough beds to treat patients with moderate severity, they might decide to put beds in the hallway where patients are treated on gurneys instead of the standard beds. In this manner, they would expand the capacity of the hospital to treat such a huge volume of patients. However, in our model it is assumed that the level of care given to the critical patients is the same as the standard level of care. All medical personnel are assumed to have the similar level of expertise in treating the victims. All facilities in the hospital like the OR, Radiology Lab and the ED are assumed to have the similar capabilities. The critical patients are assumed to be treated only when the trauma bed and the treatment trauma team are available all together. However, the patients in ED area can be treated either by nurse or emergency physician depending upon the availability of either of them.

3.1.4 Assumption 4-Accepting non disaster related call of severity level 2 and 3

The model assumes that, if the time the next hospital resources available for treatment is less than the expiration time assigned to the victim, then the victim is diverted to a different facility else is taken into the ED for treatment. This assumption is modeled and the statistics on number of normal everyday calls (also referred as the non disaster related calls) diverted is collected. However, no such assumption is made for normal call patients with everyday severity level 1 (patients with minor sprain, strain, minor cuts etc.) as they are not going to die if timely treatment is not provided to them. They are only going to experience a longer wait time. These patients are sent to the Outpatient Department (OPD) area for their treatment.

3.1.5 Assumption 5-Treatment priority between disaster and non-disaster related victim

In a disaster situation, in order to maximize the admitting capacity and treat more disaster affected patients, hospitals usually have policies to cancel outpatient surgery, inpatient surgery and make the beds available for treatment of disaster affected patients by discharging the inpatients with stable conditions to another facility or to their homes thereby giving more priority to the disaster affected victims. The model assumes that the disaster victim will be given the highest priority for treatment over the non-disaster victim throughout the model. For more information on expansion of hospital capacity refer section 2.1

3.1.6 Assumption 6-Service times and expiration times

Since the exact service times of treatment processes cannot be determined, a triangular distribution was used in modeling in order to allow the range of the service times as a form of the minimum, maximum and the most likely duration for the treatment activities. The best estimates of service time in each of the areas were obtained from Mr. Harrison Scott, Trauma Program coordinator at Stormont-Vail Health care. The values for service times used in the model can be found in the Appendix A.

3.1.7 Assumption 7-Routing of patients between stations

All the entities moving through the system are transported using ROUTE block with the next STATION block specified which represents a particular area within the hospital. Travel times will definitely be associated with the movement of patients within the hospital facility. However, they will be dependent upon the distance between various departments of the hospital under consideration. As no information on this was available, the travel times in our model are assumed to follow a uniform distribution with minimum and maximum values. The assumed values are used in the model can be found in Appendix A.

3.1.8 Assumption 8-Patient flow and resource reservations

The model assumes that the patients with severity level 3 are treated in the highly equipped trauma area within the emergency department while those with severity level 2 are treated in the standard ED bed area. The severity level 1 patients are treated in area other than ED mainly the fast track or Outpatient department (OPD). Radiography is found to be the most common and major bottleneck in the flow of patients out of emergency department. Failure to appreciate restrictions to these essential services can produce chaos in emergency department resulting in suboptimal care and unnecessary mortality and morbidity (Emergency Operation Plan, Solano County EMS, 2004). Thus, some hospitals during disasters reserve the use of CT scan services for critically injured patients (Hirshberg, 1999). Thus, the model further assumes the use of CT scan for the severity level 3 patients and that of X-ray for the use of severity level 2 patients.

Emergency departments handle almost all of the emergency cases. After a disaster, ED is the first patient receiving facility in the hospital where the severity of patients and their treatment plan is determined. Emergency department plays the key role in disaster situation, as it is the link between the in-hospital resources and out of hospital resources. Every injured patient in a disaster situation has to visit emergency department first and based upon the treatment plan and evaluation is routed to other facilities within the hospital. In disaster situation, ED care is centered on stabilization measures in accordance with the trauma life support principles (Dire, 2005). The capacity of ED largely determines the total number of patients that a hospital can treat. In addition to the initial stabilizing treatments, diagnostic image testing is also important as they help determine the severity of injury, which further help in determining the treatment plan. During such disaster, in which victims suffer from traumatic injuries, immediate lifesaving surgeries are required to be performed in OR. The OR is always a critical resource in hospitals even during normal times. After the surgery some patients might be required to go to ICU and once their condition is stabilized, they are transferred to the inpatient bed area. Thus, we can see that ED, Diagnostic imaging and OR are the most critical facilities which are relevant in rescuing the patients. Thus, our model will only focus on the ED, which is divided into different areas for the treatment of patients with different severities, the diagnostic imaging lab, which consist of CT scan and X-ray facility and the OR. The inpatient bed and ICU and other facilities of the hospital are not included in the scope of the model. The hospitals usually have the policies to discharge or transfer patients to alternative care sites to increase the inpatient bed capacity. The capacity of ICU is also increased by transferring the patients who are less severe to a facility with lower care. Thus, our model assumes that these two facilities are not a bottleneck. See section 2.2.1 for detail hospital disaster response plan.

3.1.9 Patient groups

Injuries resulting from the disaster are traumatic in nature. The routing of the patient within the hospital depends upon more detailed injury types. Different patients will require different resources for different amount of time. Hence, it becomes necessary to identify the patient types in disaster. In this research the disaster under consideration is conventional bombing which does not include the nuclear/dirty bombs. Arnold et al., 2003 lists the distribution of injury types for confined space bombing and open space bombing. Since this data is collected from 44 different bombings and are not consistent, the total of these averages does not sum up to hundred. Also, considering that there may be patients who are suffering from more than one injury.

Table 3. Injury distribution by bombing type

	Confined Space	Open Air
Pulmonary contusion (%)	3 (2-4)	0 (0-0)
Pneumothorax (%)	13 (5-19)	2 (0-3)
Blast lung Syndrome (%)	11 (1-38)	3 (0-5)
TM rupture (%)	32 (20-53)	2 (0-5)
Intestinal perforation (%)	4 (4-4)	0 (0-0)
Penetrating Soft tissue (%)	54 (34-55)	91 (72-100)
Penetrating Eye (%)	2 (2-3)	0 (0-2)
Penetrating abdomen (%)	2 (2-3)	2 (1-3)
Fracture (%)	14 (11-25)	2 (2-6)
Open Fracture (%)	6*	3 (2-22)
Intracranial (%)	3 (2-4)	1 (1-2)
Liver or Spleen (%)	7 (3-10)	1 (1-1)
Burn (%)	23 (20-27)	0 (0-0)
Crush (%)	-	0 (0-0)

* Data from one bombing

- Data not reported

Source: Arnold J et al., Mass casualty, terrorist bombings: Epidemiological outcomes, resource utilization, and time course of emergency needs (Part I). Prehospital Disaster Medicine 2003; 18(3):220-234

In order to use the above percentage distribution in the model to define the distribution based on patient types, a conservative estimate of the percentages of injury shown in Table 3 above is made so that their total is 100. The result is shown in Table 4. The calculations for these estimates can be found in Appendix C. The patients who have similar needs and go through the same treatment procedure are grouped into different patient type categories. The patients under this category are assumed to be arriving by ambulance to the hospital for treatment. Thus, the ambulance patients in the model are divided into the categories listed below. The patients who are capable of self transporting themselves are modeled as "Walking wounded" and are created separately in the model.

The patient routings within the hospital facility are based upon the treatment procedures mentioned in the "*Greenberg's text Atlas of emergency medicine*" for all the categories except for the first three type of injuries. Treatment algorithms given in "*Disaster Medicine by Hogan*" were used to determine the routing within the hospital facility for the first three injury types. The flow charts for each of the patient type are attached in Appendix C.

Type 1: Head injury

These patients require immediate life saving surgery and are triaged as “Immediate”. This group includes patients with open/closed head injury, skull fracture, and intracranial injury. They are routed through the shock room area in the ED, and depending upon their condition (stable/unstable) are required to go directly to OR if stable else they are routed to CT scan for further evaluation and then are sent to OR. This group of patients includes victims suffering from open head wound, closed head wound, intracranial pressure and skull fracture.

Type 2: Respiratory distress

These patients require immediate treatment initially in ED and are then eventually shifted to ICU. Thus, once treated in ED shock room area, these entities are disposed off the system, as ICU is not considered in the model. This group includes patients with blast lung syndrome, pneumothorax and pulmonary contusion.

Type 3: Gastrointestinal injury

These patients require immediate life saving surgical procedures. They are routed in the similar fashion as the *type 1* patients. The injuries included in this group are abdominal hemorrhage, penetrating abdominal injuries, intestinal perforations and injury to liver and spleen.

Type 4: Penetrating eye injury

These patients require to go to the ED shock room area for initial treatment and evaluation and then are routed to CT scan and depending upon the results are sent to OR or ICU. Patients who are routed to ICU are again disposed off the system. Group includes ruptured globe injury, and intraocular foreign body injury.

Type 5: Tympanic Membrane ruptures (TM rupture)

These patients are triaged as “Immediate” as this injury occurs to victims who are closer to the blast site. There are chances that these patients might also suffer from respiratory distress as this injury also occurs in victims who are closer to the blast site. These patients are not required to undergo surgery. After the initial evaluation in the ED shock room area, they are either sent to ICU or disposed off to bed.

Type 6: Penetrating soft tissue

These patients are triaged as “Delayed” as they can wait for few hours before getting the surgery done. They are routed to ED standard bed area and then are sent to X-ray lab for evaluating the severity and extent of injury and depending upon the X-ray result are sent to OR. The rest are either admitted to inpatient area or sent home. This group includes victims with puncture wounds; sever lacerations, abrasion and contusions.

Type 7: Orthopedic

These patients are also triaged as “delayed” and follow the same treatment route as the *type 6* patients.

Type 8: Burn

Patients with flash burn and other types of moderately sever burns are included in this group. They follow the same route as the *type 6 and 7* patients.

Table 4. Injury distributions by bombing type used in the model

	Confined Space (%)	Open Air (%)	Patient group
Head injury (%)	2	1	Type 1
Respiratory distress (%)	16	4	Type 2
Gastrointestinal (%)	8	2	Type 3
Penetrating Eye (%)	1	1	Type 4
TM rupture (%)	18	1	Type 5
Penetrating Soft tissue (%)	30	85	Type 6
Orthopedic (%)	12	5	Type 7
Burn (%)	13	1	Type 8
Total	100	100	

Values mentioned in Table 4 above, will be used as one of the inputs in the model to determine the number of each type of patients entering into the designed system.

3.1.10 Severity of injury

In order to assign the correct treatment priority, it is required to determine the severity level of the patient's injury. For this model, injury severity is divided up into three categories. Table 5 summarizes the definition of severity levels. It is assumed that patients suffering from primary blast injuries are assigned severity level 3 and those suffering from secondary / tertiary blast injuries are assigned severity level 2. Thus, patient *type 1 to 5* is assigned severity type 3 and *type 6 to 8* is assigned severity type 2. The walking wounded is assigned severity level 1. Thus, the percentage mix of each of these patient types further determines the percentage mix of injury severity levels.

Throughout the experiments it is assumed that the patient mix is from an open air bombing event and hence the percentage distribution of injury types mentioned in Table 4 for open air bombing is used. The percentage of non disaster victims who fall in each type of category was assigned based upon the information gathered on normal everyday patient profiles from Mr. Harrison Scott, Trauma Program Coordinator at the Stormont-Vail Healthcare, which is a level III trauma center located at Topeka, Kansas. The percentage distribution of severity levels of non-disaster related patients can be found in Table 7 in section 3.2.5.1

Table 5. Severity level of injury

Severity level of injury	Description
Level 1	Patients with minor injuries who are capable of self transporting themselves to the hospital. These patients require basic medical and do not require hospitalization.
Level 2	Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life threatening status
Level 3	Injuries that pose immediate life threatening condition if not treated adequately and expeditiously within few hours.

Source: Emergency war surgery: Third United States Revision, 2004

3.1.11 Hospital resources

The system must be initialized with the amount of physical and personnel resources a particular hospital might have available immediately to treat the victims. The hospital modeled is a level III trauma center. The number of available physical and personnel resources must be an input to the model. There are essentially two types of beds considered in the model, trauma beds and the standard ED beds. The number of X-ray machines, CT scan and the number of ORs and the number of medical personnel as assigned in each of the treatment areas can be changed depending upon the capacity of these resources in the hospital under consideration. The resource element in the model allows the user this flexibility. According to information provided by Mr. Scott Harrison, Trauma Program Manager, Stormont-Vail trauma level III trauma center located at Topeka, Kansas; the hospital has 20 standard ED beds, two fully equipped trauma rooms, four X-ray machines, two CT scan machines and 14 ORs. However, during a disaster situation, two Standard ED rooms are converted to Trauma rooms, which take care of critically ill patients. Out of the remaining 18 ED beds, only 15 are made available for use, as three of the ED rooms are not suitable for use. It is further assumed in our model that the trauma rooms area which is designated as the treatment area for severity level 3 patients are staffed by two general surgeons, two trauma nurse and two registered nurses which make up the two trauma teams containing each one of them and can be made available immediately. The trauma team members can vary from hospital to hospital. According to Mr. Scott, the standard bed ED area, which in our case is assumed to be designated as the treatment area for severity level 2 patients is staffed by two emergency physicians and 10 registered nurses taking care of 15 beds in this area and the OPD/ fast track i.e. the area other than ED, where the severity level 1 patients are treated is staffed by six registered nurses. Thus, overall initial physical and human resources available are summarized in Table 6 below and will be used as the initial capacity available for treatment.

Table 6. Treatment area wise available resources for initial simulation run

	Resource	Capacity
Trauma room area for severity level 3 patient	Trauma Beds	4
	Trauma surgeon	2
	Trauma nurse	2
	Registered Nurse	2
Std. ED beds area	ED beds	15
	Emergency Physician	2
	Registered Nurses	10
OPD area/Fast Track	Registered Nurses	6
X-ray	Machines	4
CT-Scan	Machines	2
OR	Rooms	14

3.2: Model Design

Before explaining the model design, it is essential that following definitions be clarified.

- *Trauma room area:* This represents the section within the ED where patients with severity level 3 are treated. This area is staffed by a trauma team, which consists of a general surgeon, a trauma nurse and a registered nurse care.
- *ED standard beds area:* This represents the area within the ED where patients with severity level 2 are treated. The beds in this area are standards ED beds. This area is staffed by the emergency physician and registered nurses who form the treatment team in this area.
- *OPD/Fast track:* Area other than ED where severity level 1/walking wounded patients are treated. This area is staffed by registered nurses.
- *Time until treatment:* It is defined as the time the patient waits for a treatment to begin. In other words, it is the time the patient waits first to see the medical personnel in Trauma room, ED standard beds area or OPD. It does not include the wait time after the treatment has begun, for example, the delay in getting lab reports. It is assumed that once the treatment begins the patients can be considered stabilized.
- *Survivability time / expiration time:* It is defined as the maximum time a patient can wait before the treatment begins. It can also be called as “Time until death” for critical patients and “Left without been seen (LWBS) for patients with moderate injury”.

In the next section, we shall discuss each and every section of the simulation model in detail along with assumptions made in modeling. Figure 5 below shows the flow chart of the patient care used in the model.

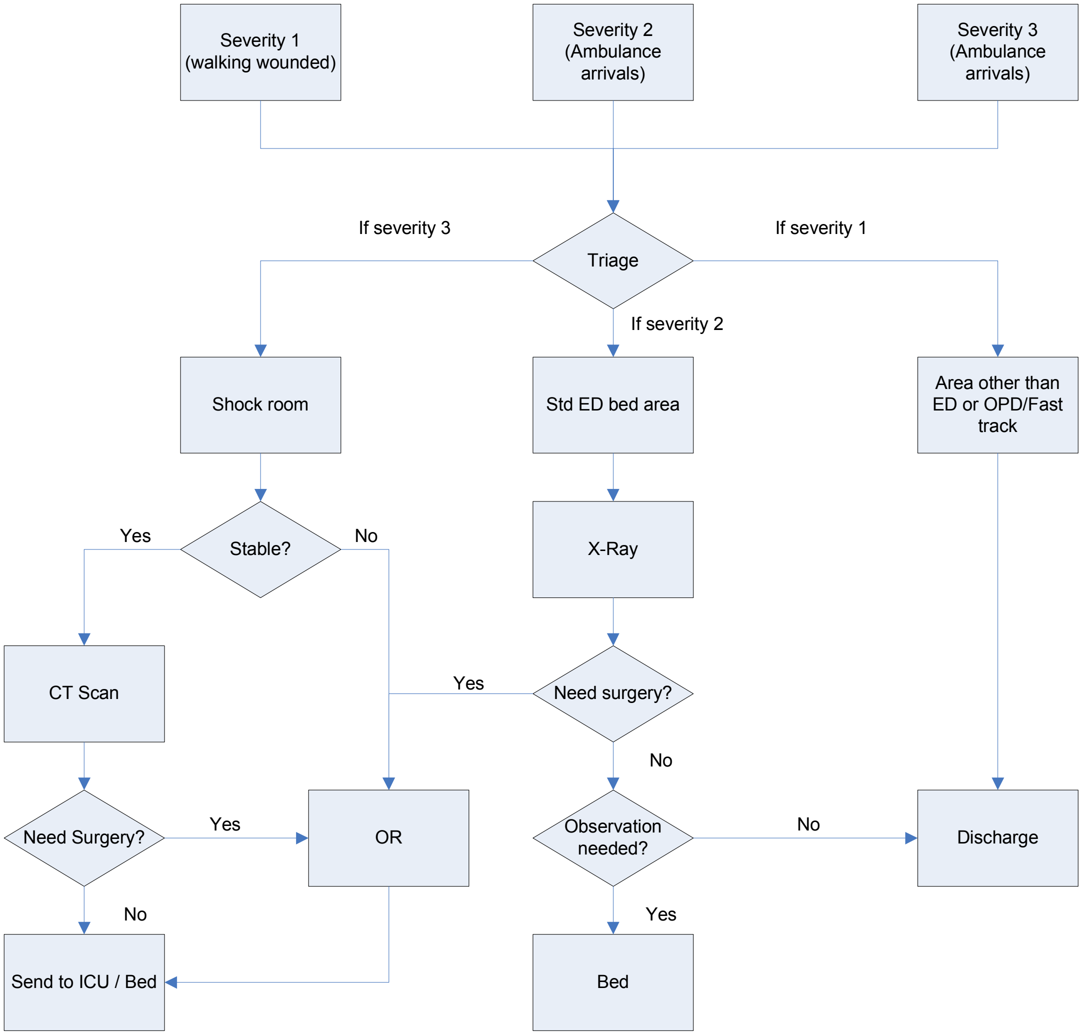


Figure 5. Patient flow chart

3.2.1 Arrival process

The process begins when patients arrive at the hospital. The model assumes that the disaster victims arrive through one of the two ways: Walk-in and ambulance. Thus, two different CREATE blocks exists for generating each of the two types of arrivals in the model. The CREATE block generating "Walk-in" and the "Ambulance" patients assumes to follow an exponential distribution with mean λ, which follows a gamma distribution with scale and shape parameter. Gamma distribution is found to be one of the most flexible distributions in the literature. This distribution can take different shapes depending upon the shape and the scale parameter chosen. Hence, the gamma distribution is used to model the delays that it would impose on the system.

Experience has shown that victims arrive in early 15 to 30 minutes post event, and later greater than 30 minutes (Emergency Operations Plan, Solano County EMS, 2004). The arrival expression for the "Walking wounded" is fixed throughout the experiments to EXPO (GAMMA (25, 1.25)), which represents the expected delay imposed by these patients. The Gamma parameters used in the above expression are obtained from Sullivan (2008), which is inline with the observation made by Emergency Operations Plan, Solano County EMS, 2004. The focus of this work is to analyze the impact of different arrival patterns of ambulance arrivals which constitutes of severity 2 and 3 victims thus the expression used in the CREATE block was a variable.

Once created, each of the entities from the two above mentioned CREATE blocks are assigned attributes severity level, patient type and victim type. The victim type attribute represents whether the patient is a disaster or non-disaster related victim. It is assumed in the model that walking wounded patients are those with minor injuries and hence are assigned severity level 1. The patients arriving by ambulance are assumed to be those with severity levels 2 and 3 and hence entities generated from this CREATE block are assigned severity levels 2 and 3. The percentage distribution between the two severity levels for ambulance arrivals is derived from the percentage distribution of patient types as explained in section 3.2.2. Once the severity of injury is determined, expiration time attribute which represents the survivability time as explained in section 3.2.5 must be assigned to the victims with severity level 2 and 3. The survivability time / expiration time is based on the distribution: TRIA (60, 80, 120) for patients with level 3 severity and TRIA (90, 240, 270) for level 2 severity patients. These times are the best estimate provided by Mr. Scott, Trauma Program coordinator at Stormont-Vail. The expiration time attribute for patient with level 1 injury is not considered, as they are not suffering from life threatening injuries and hence not going to die. The number of patients entering the system through each type is then counted and all the victims are routed to TRIAGE station, which is a setup just outside the emergency department.

The occurrence of disaster does not release the hospital from treating "everyday emergency" patients. Thus, another CREATE block is used to create the everyday emergency patients. It is assumed throughout the simulation that everyday emergency patient follow a constant arrival rate and follows a Poisson distribution process. These entities are created according to the expression EXPO (Time between arrivals). This expression needs to be initialized by the user before the simulation run. The value in this expression should be assigned based on the historic data and can be calculated by taking 1440 (the number of minutes in a day) and dividing it by the average number of patients arriving at the hospital each day. This gives the average number of minutes between each arrival. Daily patient arrivals statistics obtained from Stormont Vail healthcare, Level III trauma center situated at Topeka is used to calculate the average patient arrival rates for running the model. The hospital has on an average 132 patients per day. Thus, the arrival process is modeled as an exponential with a mean of 10.99 minutes. These patients are also assigned the severity type, victim type (Attribute victim type = 0 represents non-disaster related victims) and the expiration type attributes in a similar manner as that of the disaster victims. The percentage distribution of severity types of normal everyday patients was assigned based upon the data available from the ED. Table 7 summarizes the percentage distribution based upon the severity types for the normal everyday emergency patients. This distribution may vary based upon the frequency of each of these patients seen by a particular hospital. The model allows the flexibility to change this percentage as well. The expiration times assigned to patients based upon the severity types is summarized in Table 8 below. These times were verified with the hospital previously mentioned before using them in the developed model.

Table 7. Percentage distribution of severity type for normal everyday emergency patients

PATIENT TYPE	% DISTRIBUTION
Severity level 1	30
Severity level 2	65
Severity level 3	5

Table 8. Expiration times for patients based on severity types

Patient type	TRIANGULAR DISTRIBUTION (Min. Average, Max)
Severity level 2 patient	(90,240,270)
Severity level 3 patient	(60,80,120)

3.2.2 Triage process and treatment area assignment

All the patients created are then sent to the triage area, which is staffed by a triage team, consisted of a general surgeon and a triage nurse. All the patients arriving at this station wait for the surgeon or the triage nurse in a common queue. Once either of the members on triage team is available, the patients undergoes a triage process which is modeled as a DELAY process following an exponential distribution with a mean of 0.5 minutes. This expression is based upon the observation about the average triage time made by Hirshberg et.al, 1999. The triage process in hospital is a process of sorting the injured according to their severity of injury. The most severely injured (level 3) are then routed to a well equipped area in emergency department, which in our case is the trauma room area. Patients with severity level 2 are routed to the standard bed area of emergency department and the minimally injured with severity level 1 to the OPD/ fast track.

It is assumed in this model, that the decision to accept the "everyday emergency patients" will depend upon the time the resources within the ED will be next available to treat these patients. This decision is true only for emergency patients with severity level 2 and 3, severity level 1 patients (patients with minor cuts, lacerations, sprain, strain etc.) are always accepted and are sent to the OPD area for further treatment. In order to keep a track of the time the resources will be next available, a variable named "Time until resource will be next available" was defined. An example of calculation of this time for severity level 3 emergencies is as shown.

Time until resource will be next available for level 3 severity = Current number of patients in shock room queue x service time in that area.

Similar expression was used to determine the next available time for severity level 2 with values equal to that of the standard emergency beds area. The entity, which represents patients in the model, is then sent to the BRANCH block, which periodically compares the expiration time with the time stored in the defined variable. If the expiration time is less than the current time, which is calculated based on the above shown calculation and is stored in that variable, then the entity is disposed off and counted as “number diverted” else, it is routed to the particular area within the ED based upon the severity type.

3.2.3 Treatment process for patients with severity level 3

Once the victim enters the trauma room area, they are counted using the COUNT block. A BRANCH block separates the disaster and non-disaster related victim. The disaster related patient is sent to the critical expire count logic and the non disaster related wait in a single queue for the trauma resources to be available which consists of a bed, trauma team that consists of a trauma surgeon, trauma nurse and a registered nurse. The model assumes that the disaster victims are given the highest priority in any queue, which they have to wait until their final disposition. It is assumed that the victim will wait in queue till the bed and the complete trauma team is not available for his/her treatment.

The disaster related patients are assigned an attribute id called “angle”, which is assigned the value of the counter which records the number of patients entering the area. The entity is then duplicated using a DUPLICATE block and the duplicate entity is sent to the critical expire logic and the original I sent to the same queue where they wait for the resources to be available. The duplicate entity is then assigned an attribute called “angelshockroomno”, which carries the same attribute as the “angel” attribute. The duplicate entity is then delayed for a time equal to “TRIA (60, 80,120)-TNOW”. After this delay time, the duplicate entity checks to see if the original entity is still waiting in the queue, by checking to see if the queue has an entity who’s angel attribute is equal to the duplicate’s angelshockroomno attribute

If the original entity is found in the queue, the duplicate entity removes those entities from the queue whose expiration time has exceeded the current simulation time, TNOW and are disposed off the system at this point and recorded as "critical expire" else it is just disposed. Once the entity seizes the required resources, a TALLY block records the "Time until treatment for severity level 3" which is equal to the waiting time accumulated by the patient from the time it entered into the system till was first seen by the full trauma team. The processing times in the trauma room vary depending upon the stability of the patient (conscious or unconscious). It is assumed in the model that 27% of patient entering the trauma rooms area are unstable and the remaining 73% patients are stable. These percentages are based on the data provided in Hirshberg, 1999. It is further assumed that the unstable patients undergo rapid evaluation and are routed to OR and the stable patients spend more time in the trauma room, and then undergo additional imaging studies and are sent to CT scan (Hirshberg, 1999). It is assumed that once the patient leaves the trauma room area, he/she never returns to the trauma room for getting his/her imaging reports evaluated. The model allows capturing first available surgeon available on trauma team to evaluate the results in the CT scan area and will further decide patient's routing within the hospital. The model assumes that the CT scan resources are reserved for the use of severity level 3 patients only. The unstable patients based upon their injury types are sent either to OR or ICU. From the treatment protocols designed for patient based upon the injury type (Refer Appendix C), it is known that the patients type 2 (Respiratory distress) and 5 (TM rupture) only require to go to ICU from shock room. A BRANCH block sends patient type 2 and 5 to ICU and the rest are sent to OR. The stable patients who underwent CT scan, depending upon the result are sent either to OR or ICU. Only 25% of the patients undergoing CT scan are assumed to go to OR and hence only 25% of the entities leaving the CT scan area are routed to OR and the rest are disposed off from the system. The routing probabilities between trauma room, CT scan and OR are based upon the information obtained from Mr. Harrison Scott, Trauma Program coordinator at Stormont-Vail Health care.

3.2.4 Treatment process for patients with severity level 2

Upon entering the standard ED beds area, the patient waits in a queue for the bed to be available. Before seizing the bed, those patients from the queue whose expiration time, which in this case can be defined as the waiting tolerance time has exceeded the current simulation time are removed. These removed patients are disposed off from the system are counted as "Left without being seen" (LWBS). The logic similar to that explained in section 3.2.5.4. The means by which these patients are transported to other hospital and the decision on, which facility should the patient be sent to, depending upon the time left and the distance between the two hospitals is excluded from the scope of the model. Upon seizing the available bed, the patient further waits in a different queue for a physician or a nurse to be available to treat the patient. It is assumed that the nurses are capable of performing similar treatment operations as performed by the physicians. As per the treatment procedure, all patients coming into the standard ED beds area are required to undergo an X-ray to further evaluate the severity of their injury. It is assumed that the patient will not return the ED area, once he/she leaves to X-ray. The model assumes that emergency physician 1 out of the two available is designated as a follow up emergency physician. Based upon the imaging results, they are either sent to OR, inpatient bed or are discharged. It is assumed that of all the patients entering the X-ray area, only 20% undergo surgery in OR and the rest are either discharged or admitted to the inpatient area. Thus, the remaining 80% are disposed off from the system at this point. The percentage mentioned above is based upon the information provided by Mr. Harrison Scott, Trauma Program coordinator at Stormont-Vail Health care.

3.2.5 Treatment process for patients with severity level 1

The patients with severity level 1 are routed to area other than emergency department like OPD / fast track which are staffed with registered nurses who take care of these patients. The treatment of these patients involves giving them some oral or injected medications. They are given the drug prescription and are discharged home.

3.2.6 Model verification and validation

Once model is built, it needs to be verified and validated. Verification is the process of determining whether the simulation model has been correctly translated to a computer program as intended by the programmer. Animation was used to verify the simulation model. The model was run several times closely watching the animation. This led to the discovery of several errors, which were subsequently corrected.

While the verification aspect refers to the computer code, validation as mentioned by Law and Kelton, 2002, is the task of ensuring if the model behaves as the real system. All the inputs used in the model including the service time distributions, probabilistic routings of patients within the model were used based upon the estimated information received from Stormont-Vail healthcare. The output obtained after the simulation runs were inline with our intuition. For example, with the increase in wait times, the count for critical expire for severity level 3 patients also increased which is quite intuitive. Many more results were noticed to check if the simulation model gave results as were expected by us. This further strengthened our belief in the developed model. See Lisa, 2006 & 2007 for more information on validation and verification of simulation model.

3.2.7 Running the simulation

After initializing the simulation by inputting the required information, the simulation can be run to study the effects of different arrival rates under different time durations for which the victims affected by the disaster seek emergency help on the ED's capacity. During simulation run, the statistics on the values of each variable can be collected. The results of the variables that were of interest were only recorded on the output file. These were, the time until treatment for severity type 2 and 3. Tallies were used to record this statistic. Tallies were also used to determine time spent by patients in each of the facilities. The utilization of various physical resources and medical surgeons, physicians, trauma nurses, and the registered nurses was automatically recorded by the simulation. Counters were used to determine the number of everyday calls that were diverted, and the number of critical expires and the victims count of LWBS for patients with moderate severity (level 2).

CHAPTER 4 - Simulation Experiment & Analysis

4.1 Study of effect of various arrival patterns on the system performance

Once the model was built, verified and validated, it was used to run experiments with the input parameters. The input parameter to study was the arrival distribution of the victims arriving by ambulance. As explained previously, the victims arriving by ambulance are those of severity type 2 and 3, which would be requiring the critical resources of the emergency department. The aim of running this experiment was to study, which kind of arrival patterns is sensitive to the ED's capacity and which is not.

In disasters, patient arrivals are highly dynamic, and the arrival rate of patient's changes continuously from time to time hence it is difficult to estimate the exact arrivals of patients to the hospital. A surge in the patient volume occurs few hours following a disaster. This volume of patients then fades away over the later hours and eventually calms down. Although this general trend can be found in many disasters, the exact shape of arrivals varies from disaster to disaster. The amount of delay the arrivals pose on the system is important factor as it determines the immediacy with which such events affect the critical resources of the hospital.

Considering the aforementioned issues, the arrivals were modeled as exponential distribution with a mean of λ, which follows a gamma distribution with shape parameter α and scale parameter β, which is expressed as, EXPO (GAMMA (β, α)). Gamma distribution was selected as it offers the flexibility of having different shapes of distribution by changing the scale and the shape parameter. The next section gives a brief overview of gamma distribution.

Another important factor, which affects the performance of the ED, is the duration for which the ED under consideration is under the impact of the disaster. Studies have demonstrated that in the first 12 hours post incident; half of the victims seek emergency department treatment, thus directly affecting utilization rates and demand for ED capacity during these mass casualty incidents (Kalemoglu, 2005). In 1993 World Trade Center bombing, only 50% of injured survivors arrived at the EDs within 3.5 hours of the blast (Arnold, 2004). In 2001 World Trade Center attack, injured survivors with minor injuries continued to arrive to EDs more than 24 hours after the attack (Arnold, 2004). Thus, from above information we can conclude that for any disaster, the first 24 hours are of critical nature during disasters affecting EDs capacity to treat the patients, as almost all of the victims would be requiring treatment within the first day. Mass casualty incident as mentioned previously are likely to overwhelm the capacity of the individual

EDs and perhaps all the EDs capacity in the community. In most of the hospital disaster plans, staff augmentation is addressed in a variety of ways including extending hours of present staff and calling in additional staff. It is quite essential for hospitals to estimate the number of additional resources they would require to take care of the disaster affected victims. Thus, it is vital for a hospital develop a reliable plan to face the event, which is full of uncertainties. In this work, the capacity of the ED is defined as the maximum number of patients the ED can treat with the available resources, without having critical expire, LWBS and diverted everyday emergency patients.

Thus, from above we can conclude that, understanding arrival pattern and the duration of the arrival of victims are both critical and have relevance for planning as this would help hospital emergency managers to respond more effectively. A simulation experiment was designed to explore various different scenarios involving the arrival distribution and the duration of the arrivals to study their effect on key performance parameters which in our case were: number of “critical expire”, “number of everyday patients diverted” and the “number of left without being seen” and finally the resource utilization.

4.1.1 Overview of Gamma distribution

The Gamma distribution models a random variable that is restricted to non-negative values. The general form of Gamma distribution has two parameters namely, the shape parameter α and scale parameter β. The parameter α has the greatest effect on the shape of the distribution. With $\alpha = 1$, the distribution is the exponential distribution. As the value of α increases, the mode moves away from the origin and the distribution becomes more peaked and symmetrical. As α increases in the limit, the distribution approaches the Normal distribution. The scale parameter, β (sometimes defined in terms of rate parameter, which is inverse of the scale parameter i.e. $1/\beta$) just adjusts the mean of Gamma. The larger the scale parameter; the bigger is the spread of the distribution and vice versa. Figure 6 below shows the illustrative Gamma density functions.

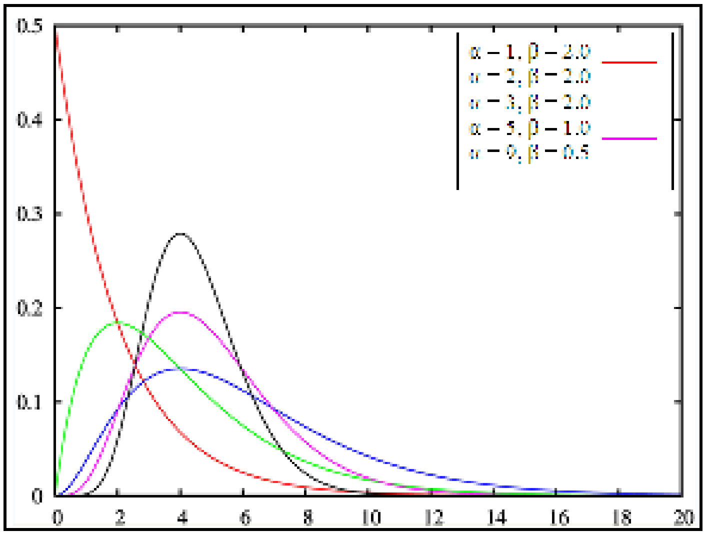


Figure 6. Illustrative gamma density functions

Source: http://en.wikipedia.org/wiki/Gamma_distribution

Parameters of Gamma distribution

Scale parameter = β

Shape parameter = α

Mean = $\alpha \beta$

Variance = $\alpha \beta^2$

4.1.2 Design of Experiment

In order to perform the study, various combination of α and β parameters were chosen to see which of the arrival patterns affect the key performance parameters of interest. In order to study the ED's capacity under different arrival patterns and time durations, experiments were run with 14 combinations of the shape and scale parameter for four different time periods. The combinations of shape and scale parameter used for the experiment are shown in Table 9. All these 14 combinations were run for a period of 6 hrs, 12 hrs, 18 hrs and 24 hrs to see the effect of the arrival pattern and time duration on ED's capacity. The shapes of each of these distributions can be seen in the graphs attached in Appendix D.

Table 9. Combinations of shape parameter and scale parameter used in the experiment.

		Scale parameter value (β)	Shape parameter value (α)	Mean =(α) (β)	Variance = (α) $(\beta)^2$
Set 1	Input 1	3	4	12	36
	Input 2	3	3	9	27
	Input 3	3	2	6	18
	Input 4	3	1	3	9
Set 2	Input 5	2	4	8	16
	Input 6	2	3	6	12
	Input 7	2	1	2	4
Set 3	Input 8	1	4	4	4
	Input 9	1	3	3	3
	Input 10	1	1	1	1
Set 4	Input 11	4	2	8	32
	Input 12	2	2	4	8
	Input 13	1	2	2	2
	Input 14	0.5	2	1	0.5

After running all the 56 models, the next step involved identifying the arrival distribution, which did not affect the ED's capacity, i.e. under these distributions the ED was able to treat all the patients arriving at the ED seeking medical help. These were the arrival distributions, which resulted in zero critical expire, zero LWBS and zero diverted patients. As mentioned earlier, the walking wounded along with 30% of non-disaster related patients are sent to OPD. These patients, routed to OPD are assigned severity level 1. Of the disaster affected patients, 9% are routed to trauma room area. The 5% of non-disaster related patients are routed to trauma area, depending upon the time they would have to wait for first available trauma resource (Refer section 3.2.5.2). 91% of disaster affected victims are sent to the standard ED beds area. 65% of the non-disaster related victims are sent to ED area depending upon the time the patient has to wait for the first available ED (Refer section 3.2.5.2). Table 10 below summarizes percentage of patients routed to different areas.

Table 10. Percentage distribution of patients routed in different treatment areas within ED

% of patients routed to each of these areas	Trauma room / Shock room	Std. ED beds area	OPD
Non-Disaster related patients	5%	65%	30%
Disaster affected patients	9%	91%	Walking wounded

4.1.2.1 Experiment 1

Objective

To study the effect of different arrival patterns for different simulation run times of six hours, 12 hours, 18 hours, and 24 hours.

Methodology

The simulation model was run with all 14 combinations listed in Table 9. Each combination was run for simulation run times of six hours, 12 hours, 18 hours, and 24 hours. This resulted in 14 x 4 = 56 combinations. Each of these combinations was run for 30 replications. The aim was to see, out of the 56 combinations, which resulted in zero critical expires, zero LWBS, and zero patients diverted. The system was initialized by inputting the resource capacities mentioned in Table 6.

Results and Discussion

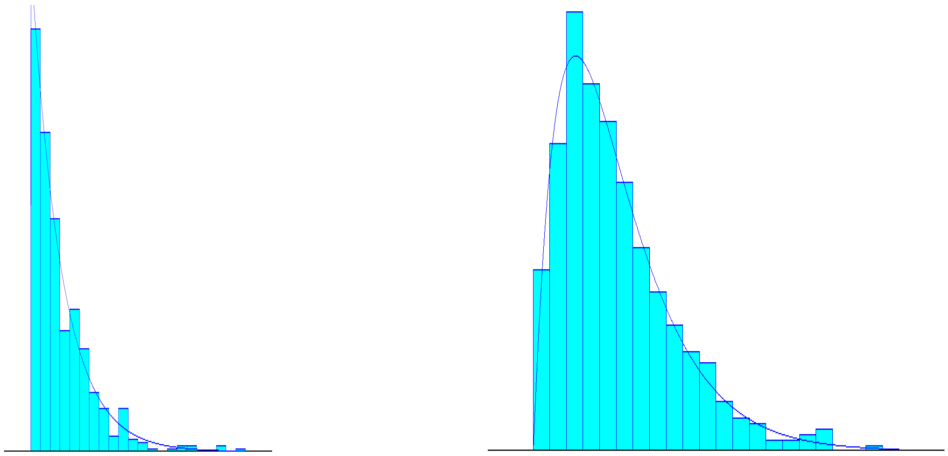
It was found that for the six hours of simulation run time, distributions with parameters (3, 4), (3, 3), (3, 2), (2, 4), (2, 3), (4, 2), and (2, 2) resulted in zero critical expires, zero LWBS, and zero patients diverted. Distributions (3, 1), (1, 2), (0.5, 2), (2, 1), (1, 4), (1, 3), and (1, 1) resulted in greater than zero critical expires, LWBS, and patients diverted. When the same model was run for a simulation run time of 12 hours, it was found that distributions (2, 2) and (2, 3), which met the criteria for six-hour simulation run times did not meet the criteria when run time was extended to 12 hours. Similarly, the model was run for an 18 hour run length and a 24 hour run length. It was found that distribution (3, 2), which met the criteria in six- and 12- hours run times did not meet the 18- and 24-hour simulation run times. Thus, it was found that distributions (3, 4), (3, 3), (2, 4), and (4, 2) were the only distributions which resulted in zero critical expires, zero LWBS, and zero patients diverted under all simulation run lengths. Thus, it can be concluded that these distributions did not affect the ED’s ability and capacity to treat patients affected by the disaster, coming in under these arrival patterns. Further, it can be concluded that the shape of the arrival distribution affects the ED’s capability to treat patients and bears relevance in planning. Figure 7 shows the shape of some of these distributions and the rest are attached in Appendix D. Table 11 shows the simulation result for all 14 combinations for a simulation run time of 6 hours. Simulation results for 12 hours, 18 hours and 24 hours can be found in Appendix E. Table 12 shows the critical expire count, LWBS, patients diverted and waiting time for severity level 2 and 3 people.

Table 11. Simulation results for 14 scenarios for simulation run time period of 6 hours

Arrival distribution	34	33	32	31	24	23	21	14	13	11	42	22	12	0.5,2
Number of disaster victim	43	53	72	137	58	76	195	104	131	374	60	104	197	374
Number of non disaster victim	35	34	34	34	33	35	34	34	35	34	34	34	34	33
everyday patients diverted	0	0	0	0	0	0	0	0	0	10	0	0	0	10
Time until seen severity 1 (min)	3.64	3.57	3.53	3.63	3.63	3.53	3.64	3.54	3.52	3.61	3.64	3.49	3.46	3.62
Nurse utilization OPD	21.84	23.3	24.07	24.57	22.61	22.19	21.74	21.85	20.18	21.77	23.62	22.35	22.52	21
Time until seen severity 2 (min)	4.95	5.01	5	5.21	4.98	5.01	5.93	5.02	5.05	24.44	5.04	5.04	5.62	24.25
LWBS	0	0	0	0	0	0	3	0	0	60	0	0	1	64
ED bed utilization	14.09	16.34	20.71	37.21	17.41	22.4	54.28	28.94	37.03	93.5	17.96	29.34	54.23	94.25
EP1 utilization	49.68	49.85	51.67	67.36	51.79	53.68	82.92	61.22	66.72	95.28	51.58	49.77	82.05	95.63
EP2 utilization	15.48	19	25.5	46	21.2	27.48	64.66	35.04	46.35	94.05	21.11	35.74	65.17	94.64
N1 utilization	19.3	22.77	28.35	48.54	24.55	30.69	67.54	38.89	49.64	96.57	25.37	41.31	69.9	97.32
N2 utilization	18.78	23	28.42	48.81	23.79	31.76	67.35	38.95	49.96	96.65	24.88	38.19	68.26	97.06
N3 utilization	19.24	22.24	29.66	49.84	23.22	31.34	68.93	40.46	47.77	96.46	26.17	39.12	69.81	97.05
N4 utilization	19.3	21.72	27.52	47.73	23.48	29.14	67.26	38.26	48.65	96.01	23.4	39.66	67.46	96.76
N5 utilization	18.13	21.67	26.94	48.42	22.93	29.88	66.62	38.55	47.9	95.64	23.52	39.5	67.93	96.62
N6 utilization	18.81	20.99	26.73	48.03	22	28.36	66.9	37.43	48.21	95.5	22.4	38.35	67.67	96.42
N7 utilization	17.92	21.58	27.87	47.76	22.22	28.2	65.94	36.55	47.31	95.36	21.97	37.16	66.1	96.24
N8 utilization	17.53	20.44	26.62	46.61	22.38	28.68	65.21	35.95	48.01	95.42	23.16	37.65	66.42	95.65
N9 utilization	18.3	20.58	25.54	45.84	22.6	28.04	65.36	35.64	47.1	94.91	22.32	35.47	65.84	95.47
N10 utilization	16.65	20.41	24.87	45.71	19.64	28.68	64.91	36.76	45.38	94.87	22.51	37.09	66.4	95.38
Time until seen severity 3 (min)	9.41	10.44	11	15.14	9.91	12.37	25.14	16.55	15.23	53.36	10.07	14.84	21.19	44.61
critical expire	0	0	0	1	0	0	4	1	1	11	0	0	3	11
Shock room utilization	11.69	13	17.48	26.23	14.79	17.36	36.16	24.2	26.95	44.87	12.92	24.22	33.75	44.04
Trauma surgeon utilization	25.17	28.06	37.94	56.26	32.12	37.37	76.84	52.47	58.13	91.52	28.13	51.88	72.78	90.22
Trauma nurse utilization	23.38	26.01	34.97	52.46	29.59	34.73	72.33	48.41	53.91	89.74	25.84	48.45	67.51	88.09
Nurse in trauma area utilization	23.38	26.01	34.97	52.46	29.59	34.73	72.33	48.41	53.91	89.74	25.84	48.45	67.51	88.09
Triage team utilization	5.3	6.16	7.13	11.94	6.71	7.4	15.59	9.27	11.6	22.8	6.44	9.46	15.48	27.61
CT scan utilization	9.99	10.23	14.65	20.24	11.68	12.55	28.74	21.27	22.71	35.51	10.74	18.61	20.02	36.84
X ray utilization	87.35	89.28	91.82	93.79	90.94	92.31	93.94	92.86	93.17	94.49	91.2	93.03	93.77	94.27
OR utilization	18.23	19.3	18.03	20.57	17.25	19.98	20.89	21.4	20.77	5.62	17.87	20.98	20.74	5.02
MEAN	12	9	6	3	8	6	2	4	3	1	8	4	2	1
VARIANCE	36	27	18	9	16	12	4	4	3	1	32	8	2	0.5

Table 12. Diversion, LWBS and critical expire counts for 6 hrs.

Arrival distribution	**3,1**	**0.5,2**	**2,1**	**1,4**	**1,3**	**1,2**	**1,1**
Number of disaster victim	137	374	195	104	131	197	374
Number of non disaster victim	34	33	34	34	35	34	34
everyday patients diverted	0	10	0	0	0	0	10
Time until treatment severity 2	5.21	24.25	5.93	5.02	5.05	5.62	24.44
LWBS	0	64	3	0	0	1	60
Time until treatment severity 3	15.14	44.61	25.14	16.55	15.23	21.2	53.36
critical expire	1	11	4	1	1	3	11



Shape of Gamma density (3, 1) Shape of Gamma density (1, 2)

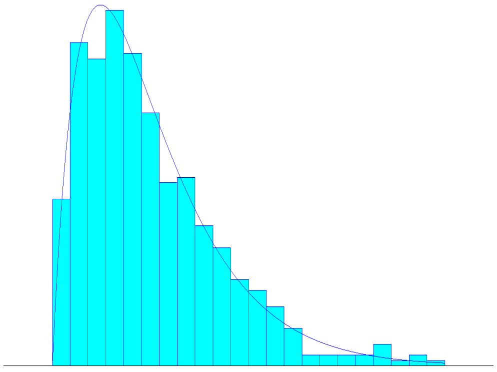


Figure 7. Gamma density shape for (3, 1), (1, 2) & (0.5, 2)

Experiment 2

Objective

To estimate the number of additional resources that would be required to get the critical expires count, LWBS, and patients diverted to zero.

Methodology

Out of all distributions which resulted in greater than zero critical expires, LWBS, and patients diverted, distribution (1, 2) was selected to show how the model can be useful to reallocate and estimate the additional resources that would be required to get zero critical expires, zero LWBS, and zero patients diverted under this arrival distribution. In experiment 1, it was found that nurse utilization in the OPD area was just about 23%. This means there was an excess capacity in this area and registered nurses were under-utilized, while in the trauma room area, under this distribution there were three critical expires and there was at least one LWBS patient in the standard ED beds area. Thus, in order to increase utilization in the OPD area and to reduce the number of critical expires count and LWBS, the initially available six registered nurses from the OPD area were reallocated, (one to the trauma rooms area and one to the ED beds area) making only four nurses available in the OPD area for treatment. Also, out of the initially available four trauma rooms, only two were utilized as there were only two trauma teams available for treatment in that area. Thus, by adding one trauma surgeon and one trauma nurse, an additional third trauma team was made available for treatment in that area. The simulation was run again for 30 replications, each of six hours. Table 13 summarizes the resource profile of the base model and the model discussed above.

Table 13. Resource profile for experiment 2 (6 Hours)

ED Treatment Areas	Resources	Initially Available Capacity	Model with Reallocation and Addition of Resources
Trauma room area for severity level 3 patients	Trauma beds	4	4
	Trauma surgeon	2	3
	Trauma nurse	2	3
	Registered nurse	2	3
ED standard beds area for severity level 2 patients	ED beds	15	15
	Emergency physician	2	2
	Registered nurse	10	11
OPD area for severity level 1 patients	Registered nurse	6	4

Results and discussion

Increasing resources in the trauma room to three did reduce the critical count to two from the initial count of three, but not to zero. The increase in the number of nurses from 10 to 11 in the ED area did not reduce the LBWS count at all, indicating a need of additional resources at some point in time in both treatment areas. Thus, the above simulation model was rerun for 30 replications, each for a simulation run length of six hours, by reducing the four nurses in the OPD area further to two and moving the two nurses, one in trauma rooms' area and the other in the ED beds area. In order to make the fourth trauma room available for treatment, an addition of one trauma surgeon and one trauma nurse was made in the trauma room area. Addition of the resources in the trauma rooms area reduced the critical expires count to zero; however, an additional ED bed was required to be added in the standard ED beds area to reduce the LWBS count to zero. The resource profile of the base model and the model that resulted in zero critical expires, LWBS, and zero patients diverted (which, we call the optimal model) for arrival distribution of (1, 2) and simulation run length of six hours is shown in Table 14

Table 14. Resource profile: base model vs. optimal model

ED Treatment Areas	Resources	Initially Available Capacity	Model with Reallocation and Addition of Resources
Trauma room area for severity level 3 patients	Trauma beds	4	4
	Trauma burgeon	2	4
	Trauma nurse	2	4
	Registered nurse	2	4
ED standard beds area for severity level 2 patients	ED beds	15	16
	Emergency physician	2	2
	Registered nurse	10	12
OPD area for severity level 1 patients	Registered nurse	6	2

In a similar fashion, for arrival distribution (1, 2), the number of additional resources required to get zero critical expires, zero LWBS, and zero patients diverted for different simulation run length was estimated. The results of additional resources required compared to the initially available resources in each treatment area for distribution (1, 2) for simulation run lengths of 12 hours, 18 hours, and 24 hours were found. Table 15 shows the optimal resource profile for six hours, 12 hours, 18 hours, and 24 hours simulation run lengths.

Table 15. Summary of additional resource requirement for different simulation run time for arrival distribution (1, 2)

ED Treatment Areas	Base Model		6 hrs	12 hrs	18 hrs	24 hrs
	Resource	No.	No.	No.	No.	No.
Trauma room area for severity 3 patients	Trauma beds	4	4	6	6	6
	Trauma surgeon	2	4	6	6	6
	Trauma nurse	2	4	6	6	6
	Registered nurse	2	4	6	6	6
Std. ED beds area	ED beds	15	16	19	20	20
	Emergency physician	2	2	2	2	2
	Registered nurse	10	12	13	13	13
OPD area	Registered nurse	6	2	2	2	2

Table 16 shows simulation results from the base model and the optimal model for six hours. Adding two treatment nurses and one ED bed in the standard ED beds area for treatment of patients with severity 2 reduced "time until first seen" for severity level 2 patients from 5.62 minutes to 5.18 minutes i.e., reducing it by approximately 7%, and thereby getting the LWBS count to zero. The paired t-test found that the difference in means was statistically significant at 0.05 alpha level.

Adding two additional trauma teams to be available for the previously unutilized trauma rooms helped increase the utilization of trauma rooms and also reduced the "time until seen" of patients with severity level 3 from 21.19 minutes to 10.13 minutes i.e., a reduction of approximately 53%, which resulted in a zero critical expires count. The paired t-test for the time until seen for severity 3 patients found that the difference in means was statistically significant at 0.05 alpha level. Reducing nurses in the OPD area from an initial of six to two increased the OPD nurse utilization from 22.52% to 65.65%. The paired t-test found that the difference in means was statistically significant at 0.05 alpha level. Detailed results on this experiment can be found in Table 17. The results for 12, 18 and 24 hours is attached in the Appendix F.

Thus, the above results show that the capacity of the ED is not only dependent upon the physical resources available but also on the human resources available to treat the patients in a timely manner. Wait times are also affected by the number of available resources and are also dependent upon the arrival distribution. Thus, we can conclude that the capacity of the hospital cannot be estimated alone with the number of available beds, but is also dependent upon the number of human resources available for treatment and the arrival distribution and wait times experienced by the patients.

Table 16. Simulation results for experiment 2

	Base Model (6 hrs)	**Optimal Model (6 hrs)**	**Percent Change**	**T-test Results from ARENA Output Analyzer**
Time until first seen (severity level 2) in minutes	5.62	5.18	-7.82	Means are significantly different at 0.05 alpha level.
Time until first seen (severity level 3) in minutes	21.19	10.13	-52.19	Means are significantly different at 0.05 alpha level.
OPD nurse utilization (%)	22.53	65.65	191.51	Means are significantly different at 0.05 alpha level.

Table 17. Simulation results for experiment 2 (base vs. optimal) for distribution (1, 2) for the first 6 hours.

	Arrival distribution	Base model	Optimal model	% changed
	Number of disaster victim	197	197	
	Number of non disaster victim	34	33	
	Everyday patients diverted	0	**0**	
	Time until seen severity 1 (minutes)	3.46	10.37	199.7
	Nurse utilization OPD	22.52	65.65	191.51
	Time until seen severity 2 (minutes)	5.62	5.18	-7.82
	LWBS	**1**	**0**	
Utilization of resources in treatment unit for severity level 2 patients	**ED bed utilization**	54.23	49.82	-8.13
	EP1 utilization %	82.05	72.69	-11.40
	EP2 utilization %	65.17	56.53	-13.25
	N1 utilization %	69.90	57.19	-18.18
	N2 utilization %	68.26	59.23	-13.22
	N3 utilization %	69.81	60.05	-13.98
	N4 utilization %	67.46	59.05	-12.46
	N5 utilization %	67.93	59.42	-12.52
	N6 utilization %	67.67	58.52	-13.52
	N7 utilization %	66.10	56.66	-14.28
	N8 utilization %	66.42	59.59	- 10.28
	N9 utilization %	65.84	59.70	- 9.32
	N10 utilization %	66.40	56.91	- 14.29
	N 11 utilization %		58.12	
	N12 utilization %		56.46	
	Time until seen severity type 3 (minutes)	21.19	10.13	-52.19
	Critical expire	**3**	**0**	
Utilization of resources in treatment unit for severity level 3 patients	**Shock room utilization %**	33.75	41.55	23.11
	Trauma surgeon utilization %	72.78	44.92	-38.28
	Trauma nurse utilization %	67.51	41.55	-38.45
	Nurse in trauma area utilization %	67.51	41.55	-38.45

4.1.2.3 Experiment 3

Objective

To study the effect of change in the patient mix on resource utilization and wait times in different treatment areas.

Methodology

The optimal model of arrival distribution (1, 2) for simulation run length of 24 hours was used in this model for studying the objective of this experiment. The model was run for 30 replications with a simulation run length of 24 hours and with percentage distribution of patient types from a confined-space bombing (See Table 18).

Table 18 . Injury distributions by bombing type

	Confined Space (%)	Open Air (%)	Patient group
Head injury (%)	2	1	Type 1
Respiratory distress (%)	16	4	Type 2
Gastrointestinal (%)	8	2	Type 3
Penetrating Eye (%)	1	1	Type 4
TM rupture (%)	18	1	Type 5
Penetrating Soft tissue (%)	30	85	Type 6
Orthopedic (%)	12	5	Type 7
Burn (%)	13	1	Type 8
Total	100	100	

Results and discussion

It was found that, utilization of trauma rooms increased from 29.6% (open-air bombing) to 92% (confined-space bombing). Wait times in this area also increased from 9.59 minutes (24 hours optimal model with open-air bombing patient-injury mix) to 32.21 minutes for confined-space bombing. Standard ED beds area utilization was reduced to 26% (confined-space injury mix) from 40% (open-air injury mix). Wait times in this area did not change significantly. Thus, knowledge of the type of bombing that has occurred plays a significant role in planning. Knowing the type of bombing environment would help planners to allocate limited resources in treatment areas where the demand for them would be high. For example, in this experiment, it was found that there will be more demand in the trauma rooms area compared to the standard ED beds area; thus hospitals can plan to convert a few of the ED rooms into improvised trauma rooms, making them available for treatment of critical patients.

The simulation results are as shown in Table 19.

Table 19. Simulation results from effect of patient injury mix

Arrival distribution	24 hrs optimal model with open air injury mix	24 hrs optimal model with confined space Injury mix.
Number of disaster victim	762	772
Number of non disaster victim	133	131
Everyday patients diverted	0	4
Time until seen severity 1	11.74	11.41
Nurse utilization OPD	65.83	62.83
Time until seen severity 2	5.15	5.02
LWBS	0	0
ED bed utilization	40.2	26.09
EP1 utilization	73.63	63.23
EP2 utilization	53.92	35.09
N1 utilization	55.27	36.77
N2 utilization	55.36	36.41
N3 utilization	55.74	36.52
N4 utilization	54.69	35.99
N5 utilization	54.89	35.45
N6 utilization	54.91	35.27
N7 utilization	55.27	36.06
N8 utilization	54.34	35.57
N9 utilization	55.38	35.93
N10 utilization	54.63	36.17
N11 utilization	53.91	36.52
N12 utilization	55.05	35.25
Time until seen severity 3	9.59	32.21
critical expire	0	124
Shock room utilization	29.58	91.91
Trauma surgeon utilization	32.27	96.71
Trauma nurse utilization	29.58	91.91
Nurse in trauma area utilization	29.58	91.91
Triage team	15.49	15.72
CT scan utilization	37.69	95.74
X ray utilization	98.44	98.17
OR utilization	37.42	46.21

4.1.3 Additional Results

Areas other than the three treatment areas within the ED were also modeled, including x-ray, CT scan, and OR. It was found that CT scan was not a bottleneck when the patient-injury mix was from an open-air bombing. However, in experiment 3 where the patient-injury mix was changed to confined-space bombing, it was found to be a bottleneck. X-ray was found to be the most common bottleneck irrespective of bombing type. Operating rooms were not found to be a bottleneck as there were 14 operating rooms initially available to perform surgery on patients.

Strategies to eliminate radiography as a bottleneck would include bringing in portable x-ray machines to the emergency department and restricting essential services like CT scans for only the most severely injured patients. Another policy that could be adopted to reduce the load on the x-ray machines would be to allow the use of CT scans for patients with moderate injuries when all the victims with severe injuries have stopped arriving. Only when there are no critical patients in the queue waiting for CT scans, can the CT scan be used by the moderate-severity patients. Table 20 and Figure 8 summarize the results of effect of change in patient mix on utilization of these resources.

Table 20. Utilization of X-ray, CT scan and OR for two types of bombing

Arrival distribution (1,2)	**Open air bombing injury mix**	**Confined space bombing injury mix**
CT scan utilization	37.69	95.74
X ray utilization	98.44	98.17
OR utilization	37.42	46.21

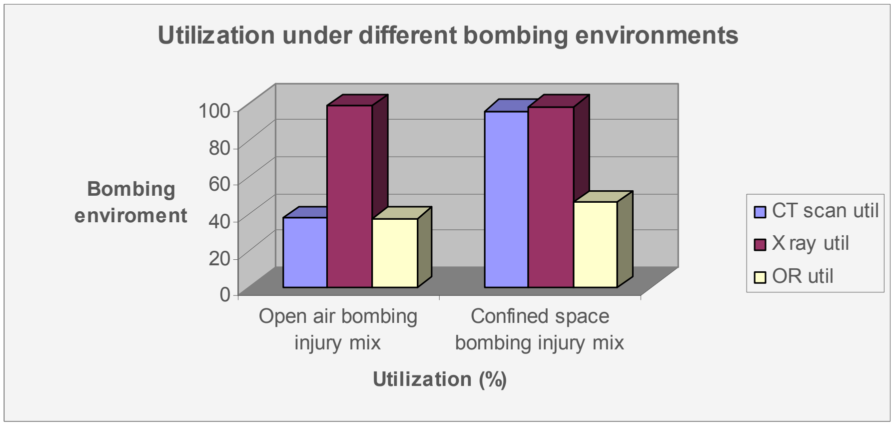


Figure 8. Graphical representation of Table 20

4.1.4 Regression analysis between wait times and critical expire and LWBS

It is quite intuitive that higher the waiting time, the more number of people expiring of severity level 3 and higher the count for LWBS for severity 2 patients. In order to explore the relationship between the wait times by severity type and the critical expire and LWBS counts, a regression analysis was performed using the data points obtained from the simulation experiments on both parameters by severity type. It was found that for both severity types there exists a positive correlation between the parameters. The regression was performed using Minitab version 14.0. The R^2 value of 99.8% was reported for regression performed between wait times for severity level 2 and LWBS counts and that of 98.7% for severity 3 and critical expire count. Thus, the high R^2 values suggests that the predictor variable "time until treatment" accounts for all the variation in the response Y, which in our case is the critical expire count for severity type 3 and LWBS for severity 2 patients. It can thus be concluded that there exists a linear association between the two parameters.

CHAPTER 5 - Conclusion

Simulation is an excellent tool to model different types of environments. Simulation proves to be powerful and effective tool for emergency preparedness and disaster planning. Traditionally, planning for mass casualty event is typically based upon the lessons learnt from disaster drills or an experience from the past disaster. However, not until the disaster strikes the capability of the plans developed from this exercise is realized. Computer simulation allows the disaster response plans to be run under different scenarios and is a useful tool in planning the allocation and utilization of the resources. It allows the planner to analyze a wide variety of "what if" scenarios without involving much of time and money. It can aid in identifying the overestimation or underestimation of resources identified during the physical disaster drills.

This study is an attempt to show, how different types of arrivals, patterns of injury and the time duration for which the disaster victims keeps arriving has an impact on the performance of the system. The surge capacity as traditionally defined is the ability of the system to accommodate the huge volume of patients that exceeds the routine daily capacity of the hospital. However, in our work surge capacity is defined in terms of the arrival pattern and the duration for which they keep arriving at the hospital. The ability of the hospital to accommodate these patients under various arrival patterns over different time durations without compromising the level of care is what we called the maximum capacity of the system.

Various shapes of arrival distributions modeled by using the two parameter (Scale and Shape) gamma distribution were tested for different time durations. It was found that the arrival distribution with parameters (3, 4), (3, 3), (4, 2) and (2, 4) did not challenge the institutional capacity. In other words, the hospital was able to treat all the patients without compromising the quality of care up to 24 hours. However, distribution with parameter (3, 2), (2, 2), (3, 1), (1, 2), (2, 3), (2, 1), (1, 4), (1, 3), (1, 1) and (0.5, 2) did affect the system performance. Under these distributions, there was at least one patient who was either dead, LWBS or diverted. This indicates the immediacy with which victims arriving under these distributions overwhelmed the limited resources

Our aim was to study, how many more resources would the hospital need in order to have zero critical expire, zero LWBS and zero patients diverted. Arrival distribution (1, 2) was randomly selected to study this objective. With the initial available resources, we could see that no patients were diverted in the first 6 hours. However, there was at least 1 LWBS and three critical expire during the first six hours. In order to get the critical expire count, LWBS and patients diverted count to zero, an addition of one ED bed and two registered nurses was needed in the treatment area for patients with injury severity level 2, thereby reducing the LWBS count to zero. Additionally, two trauma teams were required to get the critical expire count to zero. The resource profiles in the base case and the optimal cases for distribution (1, 2) for different simulation run time are summarized below in Table 21.

Table 21. Summary of additional resource requirement for different simulation run time for arrival distribution (1, 2)

	Base Model		6 hrs	12 hrs	18 hrs	24 hrs
	Resource	**Capacity**	**Capacity**	**Capacity**	**Capacity**	**Capacity**
Trauma room area for severity 3 patients	Trauma beds	4	4	6	6	6
	Trauma Surgeon	2	4	6	6	6
	Trauma Nurse	2	4	6	6	6
	Registered Nurse	2	4	6	6	6
Std. ED beds area	ED beds	15	16	19	20	20
	Emergency Physician	2	2	2	2	2
	Registered Nurse	10	12	13	13	13
OPD area	Registered Nurse	6	2	2	2	2

However, after adding these resources when the model was run for 12 hours of simulation run under the same arrival distribution, it was found that the resources added during the first six hours were not sufficient to take care of all the patients if the time period was extended to 12 hours. During the 12 hour simulation run, additional of four ED beds and three nurses were required in the standard ED bed area and additional of two trauma rooms with two trauma teams were required in order to accommodate and treat all the patients.

The trauma resources added for the 12 hour simulation run was found to be enough to take care of all the victims of severity level 3 between the 12th and the 18th hour. However, additional one ED bed and was required to treat all the patients with severity level 2 arrived during the 18 hour simulation to reduce the LWBS count to zero.

The resources added in the trauma room area during 12 hours simulation run were found to be enough to treat all victims arriving under the simulation of 24 hours and those added in ED area during the 18 hours run were found to be sufficient to treat all the victims with severity level 2 in the ED area.

Thus, we can say that there was no need of additional resources between 18th and 24th hour post incident under the arrival distribution (1, 2).

Similarly, the model can aid in determining the number of additional resources hospitals would require to treat all the victims arriving with the rest of the arrival distribution for different time periods. To conclude, the simulation model built would help the emergency planners to better allocate and utilize the limited hospital resources in order to treat maximum possible patients. It also helps estimate the number of additional resources that would be required in a particular scenario.

The study also suggest that, the underlying cause of having a patient die in the system or get diverted or LWBS is availability of the resources to take care of the victims which in turn affects the "time until first seen". A regression analysis was performed to explore the relationship between the "time until first seen" and the critical expire and LWBS counts and it was found that it follows a liner trend. Moreover, the arrival patterns and the duration of time the victims keep coming also have a significant impact on the "Time until first seen" i.e. the wait times. Thus, the arrival pattern and the time duration, the number of resources available and the wait times are the three main factors that determine the capacity of the hospital and bear relevance to disaster planning.

Apart from the arrival times and the duration for which the victims arrive at the hospital, the type of bombing can aid the emergency planners to estimate what kind of resources would be required to treat the patients affected by a particular type of bombing. Depending upon the type of bombing the frequency of different injuries within the victims would change. This would thus affect the resource utilization and patient flow within the hospital. An example of this is shown in section 4.2.1. From Table 26.0, we can see that the victims affected by the confined space bombings placed a huge demand on the trauma resources. Thus, indicating a need of additional resources in this area.

5.1 Improvements and Future work

There are many improvements, which can be made in the model. The most important being relieving the assumption made during building the model. Many assumptions made might not be in line with the actual protocols and procedures of a given disaster response plans of a particular hospital. The model assigned the priority to treat the victims that were affected by the disaster over the non disaster affected patients in each of the treatment areas. However, in real life situation, such decision would be based upon many factors like severity within the patients, the age of the patient and his chances of survival. Thus, the model can be further improved by incorporating these real life situations in assigning the treatment priorities to the patients. These improvements would help to increase the validity and its ability to be used as a decision making tool.

The model currently focuses on the ED treatment areas, CT scan, X-ray and the OR facility of the hospital. The model can be expanded by including the ICU and the inpatient bed in the scope to identify the role in estimating the capacity of the system. The current model does not take into consideration the number of sub specialists surgeons that would be required in the OR to perform the operations on the victims. This can be another possible area of future research. This research can be extended to model the utilization of critical equipments like ventilators. This will involve more detailed simulation modeling, but will benefit the hospital management in deploying the resources dynamically. The current model assumes that all the facility within the hospital is fully operational and no damage has occurred to the hospital. There is a possibility that level of functioning of the hospital could be affected by the attack. If the information on maximum resources that the hospital can add to treat the patients is available, then how to effectively divert the patients to other nearby hospitals when all the additional available resources are fully utilized is also a possible direction for future research. The current model does not take into account the effect of over triage on patient wait times and critical mortality. The possible future work can be to study the effect of overtriage and undertriage on patient wait times, critical mortality and LWBS and the utilization of the resources.

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Appendix A - Treatment, Service and Travel Times used in the model

List of service times in different treatment areas and diagnostic areas used in the Model. These times follow a Triangular distribution with minimum, maximum and most likely values. The times used were based upon the best available estimate provided by Mr. Harrison Scott, Trauma Program Coordinator at Stormont-Vail Health care, Topeka, Kansas, USA.

Table A 1. Treatment and service times used in the simulation model

Treatment area	Triangular Distribution of Service time (min)
Trauma Room (Stable patients)	TRIA(5,30,60)
Trauma Room (Unstable patients)	TRIA(15,60,120)
ED standard bed area treatment time	TRIA(2,15,30)
CT scan Service time	TRIA(5,20,45)
CT scan evaluation time	TRIA(2,5,8)
X-Ray Service time	TRIA(15,30,60)
X-ray evaluation time	TRIA(2,3,7)
OR Service time	TRIA(45,120,300)

The minimum and maximum values are assumed values and are not based upon any real data. The assumption was made as no data was available and to take into account the travel times associated with transport of patients within the hospital.

Table A 2. Travel times between various departments used in simulation model

From	To	Minimum Value (min)	Maximum Value (min)
Arrival	Triage	1	2
Triage	Trauma room	6	9
Triage	ED std bed area	2	4
Triage	OPD	1	3
Trauma room	CT scan	1	3
CT scan	OR	6	9
ED	X-ray	1	3
X-ray	OR	6	9

Appendix B - Calculation for injury percentages used in the model

Arnold et al. 2003, lists the distribution of injury types for confined space bombing and open space bombing. Table 1-B above shows the injury frequency rates as given in Arnold, 2003. It gives the mean and the range for each of the injury types. Since this data is collected from 44 different bombings and are not consistent, the total of means does not sum up to hundred. Also, considering that there may be patients who are suffering from more than one injury. In order to use the above mean values of percentage distribution in the model to define the distribution based on patient types, a conservative estimate of the percentages of injury was required to be made. Patients who have similar medical needs and go through the same treatment are grouped into several different categories. The patient routings within the hospital facility are based upon the treatment procedures mentioned in the "*Greenberg's text Atlas of emergency medicine*" for all the above categories except the first three type of injuries. Treatment algorithms given in "*Disaster Medicine by Hogan*" were used to determine the routing within the hospital facility for the first three injury types. The flow charts for each of the patient type are attached in Appendix C.

Type 1: Head Injury

This group of patients includes victims suffering from open head wound, closed head wound, intracranial pressure and skull fracture. The total percentage under this group is equal to 1% for open air and 3% for confined space (See Table 1-B)

Type 2: Respiratory Distress

This group includes victims with pneumothorax, pulmonary contusion and blast lung syndrome. The total percentage under this group sums to 5% (0% + 2% + 3%) for open air and to 27% (3% + 13% + 11%) for confined space (See Table 1-B)

Type 3: Gastrointestinal injury

This group includes victims with intestinal perforation, penetrating abdomen and injuries to liver and spleen. The total percentage under this group sums to 3% (0% + 2% + 1%) for open air and 13% (4% + 2% + 7%) for confined space (See Table 1-B)

Type 4: Penetrating eye injury

This group includes patients suffering from eye injury, which includes the penetrating eye injuries caused by the objects hurling in air. The total percentage under this group sums to 0% for open air and 2% for confined space (See Table1-B)

Type 5 Tympanic Membrane ruptures (TM rupture)

This group includes patients suffering from TM rupture caused due to blast injury. The total percentage under this group sums to 2% for open air and 32% for confined space (See Table1-B)

Type 6 Penetrating soft tissue injury

This group includes victims with major cuts and puncture wounds. The total percentage under this group sums to 91% for open air and 54% for confined space (See Table1-B).

Type 7 Orthopedic

This group includes victims with open and closed fracture along with victims suffering from crush injuries. The total percentage under this group sums to 5% (3% + 2% + 0%) for open air and 20% (14% + 6%) for confined space (See Table1-B).

Type 8 Burn

This group includes victims with flash burns resulting from the blast. The total percentage under this group sums to 0% for open air bombing and 23% for confined space (See Table1-B).

The revised percentage distribution based upon the above groupings can be found in Table 2-B.

Table B 1. Injury distribution by bombing type

	Confined Space	Open Air
Pulmonary contusion (%)	3 (2-4)	0 (0-0)
Pneumothorax (%)	13 (5-19)	2 (0-3)
Blast lung Syndrome (%)	11 (1-38)	3 (0-5)
TM rupture (%)	32 (20-53)	2 (0-5)
Intestinal perforation (%)	4 (4-4)	0 (0-0)
Penetrating Soft tissue (%)	54 (34-55)	91 (72-100)
Penetrating Eye (%)	2 (2-3)	0 (0-2)
Penetrating abdomen (%)	2 (2-3)	2 (1-3)
Fracture (%)	14 (11-25)	2 (2-6)
Open Fracture (%)	6*	3 (2-22)
Intracranial (%)	3 (2-4)	1 (1-2)
Liver or Spleen (%)	7 (3-10)	1 (1-1)
Burn (%)	23 (20-27)	0 (0-0)
Crush (%)	-	0 (0-0)

* Data from one bombing

\- Data not reported

Source: Arnold J et al., Mass casualty, terrorist bombings: Epidemiological outcomes, resource utilization, and time course of emergency needs (Part I). Prehospital Disaster Medicine 2003; 18(3):220-234

Table B 2. Revised injury distribution by bombing type

	Confined Space (%)	Open Air (%)	Patient group
Head injury (%)	3	1	Type 1
Respiratory distress (%)	27	5	Type 2
Gastrointestinal (%)	13	3	Type 3
Penetrating Eye (%)	2	0	Type 4
TM rupture (%)	32	2	Type 5
Penetrating Soft tissue (%)	54	91	Type 6
Orthopedic (%)	20	5	Type 7
Burn (%)	23	0	Type 8
Total	174	107	

As it can be seen from Table 2-B, the total percentages is greater than zero, hence a conservative estimate was made in order to sum the above percentages to 100 for both the bombing types. The percentages were calculated using the relation of if x% of injuries (these are the values mentioned in Table 2-B for each type of injuries) contribute to 107%, then what % contributes to 100%. For example, in case of Type 6 for open air, 91% of injuries accounts for the total 107%, then 85% of Type 6 will account for the total of 100% ([91 % x 100 %] / 107 %). Similar approach was established to adjust the rest of percentages. The result is as shown in Table 3-B.

Table B 3. Injury distribution by bombing type used in the model

	Confined Space (%)	Open Air (%)	Patient group
Head injury (%)	2	1	Type 1
Respiratory distress (%)	16	4	Type 2
Gastrointestinal (%)	8	2	Type 3
Penetrating Eye (%)	1	1	Type 4
TM rupture (%)	18	1	Type 5
Penetrating Soft tissue (%)	30	85	Type 6
Orthopedic (%)	12	5	Type 7
Burn (%)	13	1	Type 8
Total	100	100	

Appendix C - Treatment algorithm for each patient type

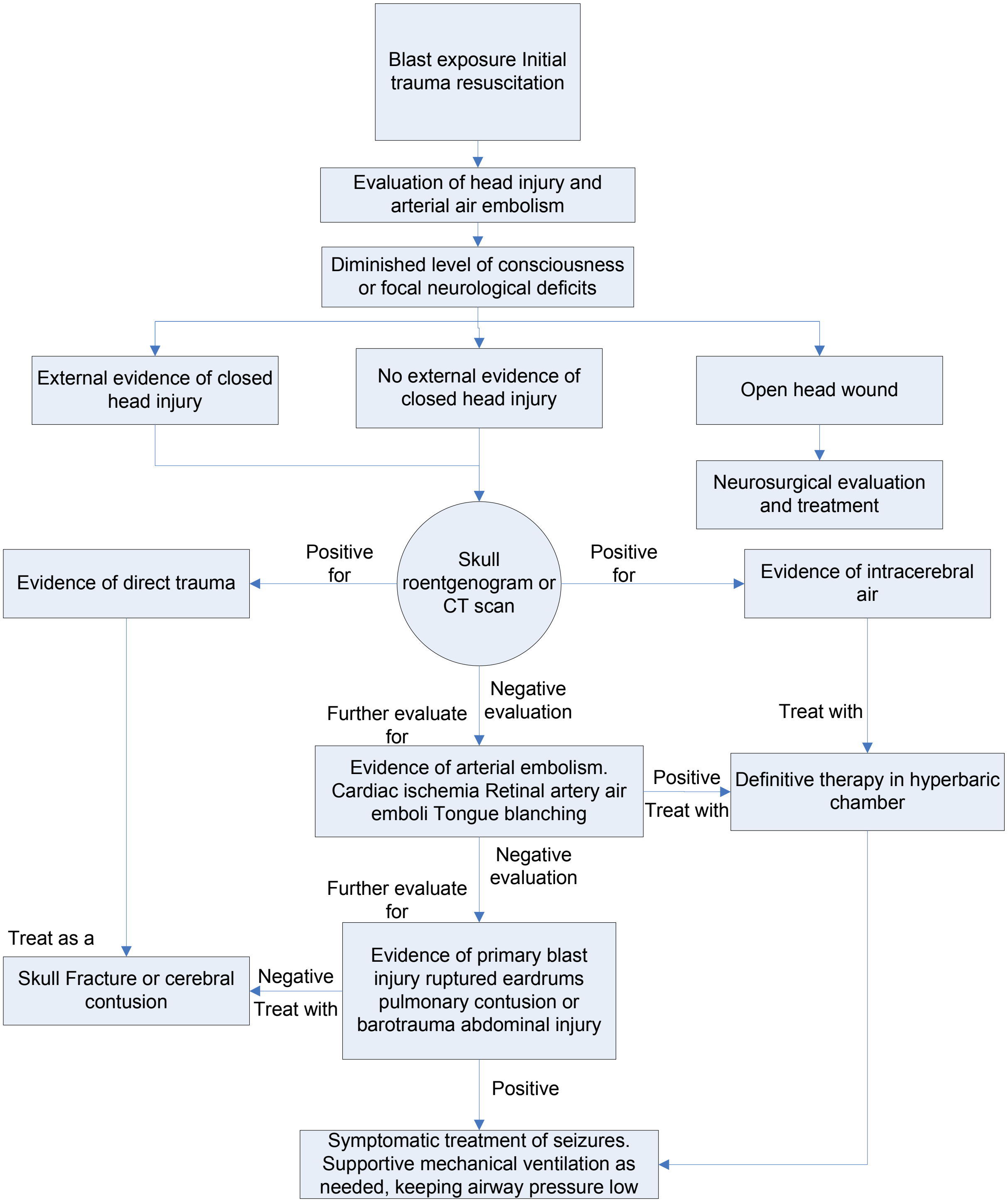
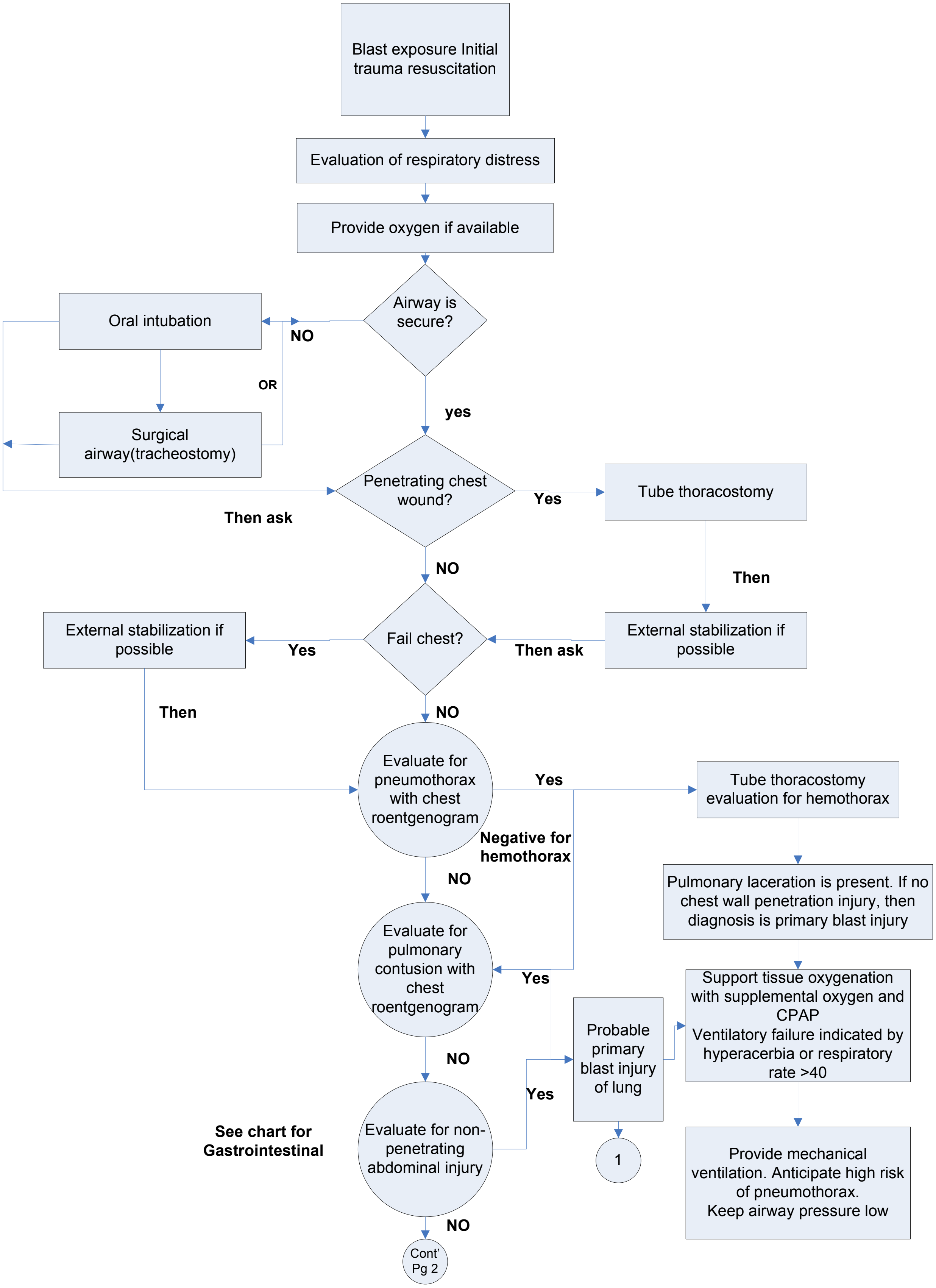


Figure 1-C. Treatment flow chart for head injury (Type 1)

Source: Disaster Medicine, 2007, pg. 373


Blast exposure Initial trauma resuscitation
Evaluation of respiratory distress
Provide oxygen if available
Airway is secure?
NO
Oral intubation
OR
Surgical airway(tracheostomy)
yes
Penetrating chest wound?
Then ask
Yes
Tube thoracostomy
Then
NO
External stabilization if possible
Yes
Fail chest?
Then ask
External stabilization if possible
Then
NO
Evaluate for pneumothorax with chest roentgenogram
Yes
Tube thoracostomy evaluation for hemothorax
Negative for hemothorax
NO
Pulmonary laceration is present. If no chest wall penetration injury, then diagnosis is primary blast injury
Evaluate for pulmonary contusion with chest roentgenogram
Yes
Support tissue oxygenation with supplemental oxygen and CPAP
Ventilatory failure indicated by hyperacerbia or respiratory rate >40
Probable primary blast injury of lung
NO
Yes
1
See chart for Gastrointestinal
Evaluate for non-penetrating abdominal injury
Provide mechanical ventilation. Anticipate high risk of pneumothorax.
Keep airway pressure low
NO
Cont' Pg 2

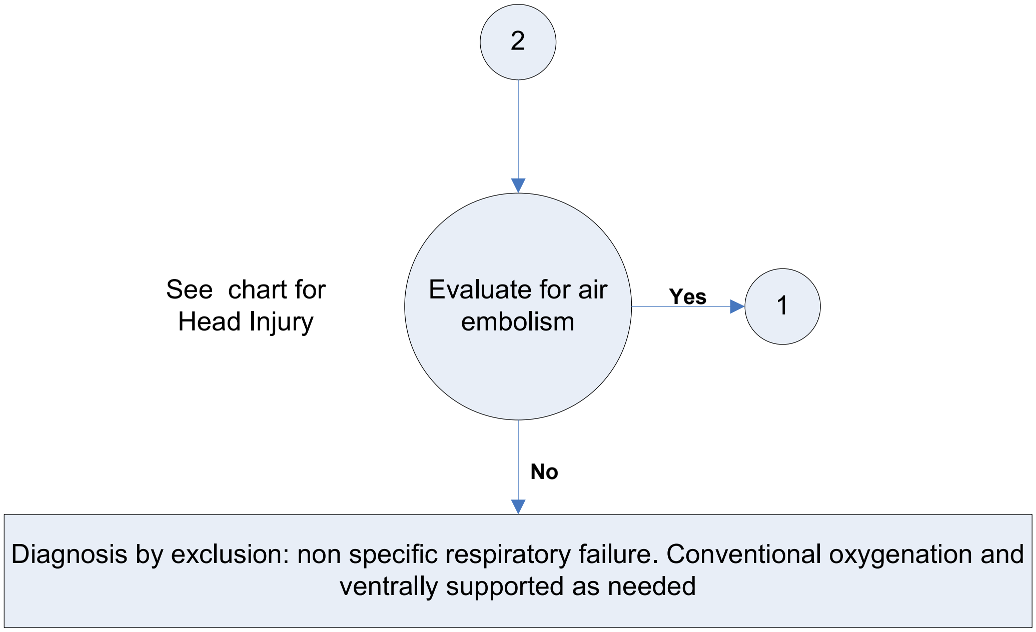


Figure 2-C. Treatment flow chart for respiratory distress (Type 2)

Source: Disaster Medicine, 2007, pg. 371

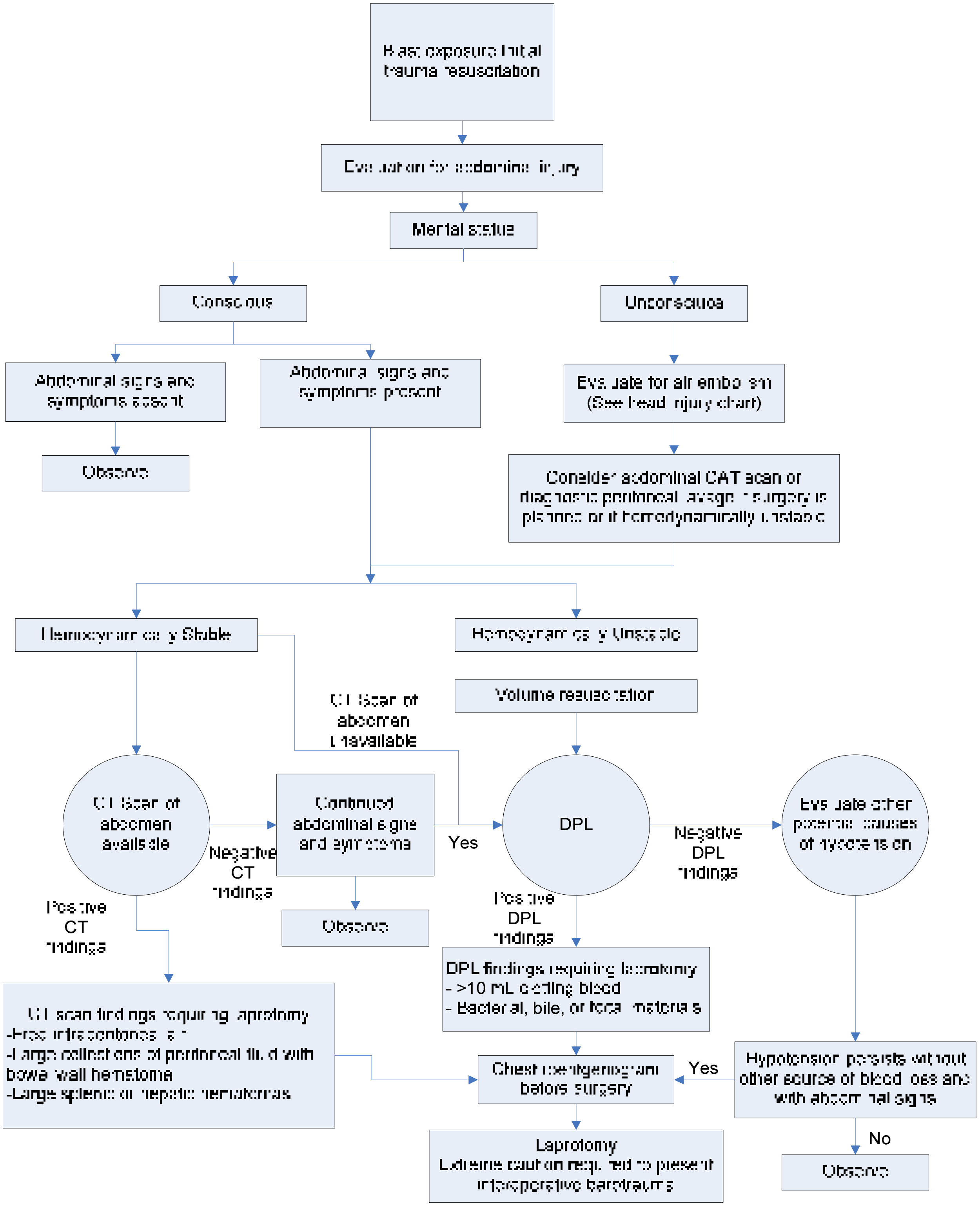


Figure 3-C. Treatment flow chart for gastrointestinal injury (Type 3)

Source: Disaster Medicine, 2007, pg. 374

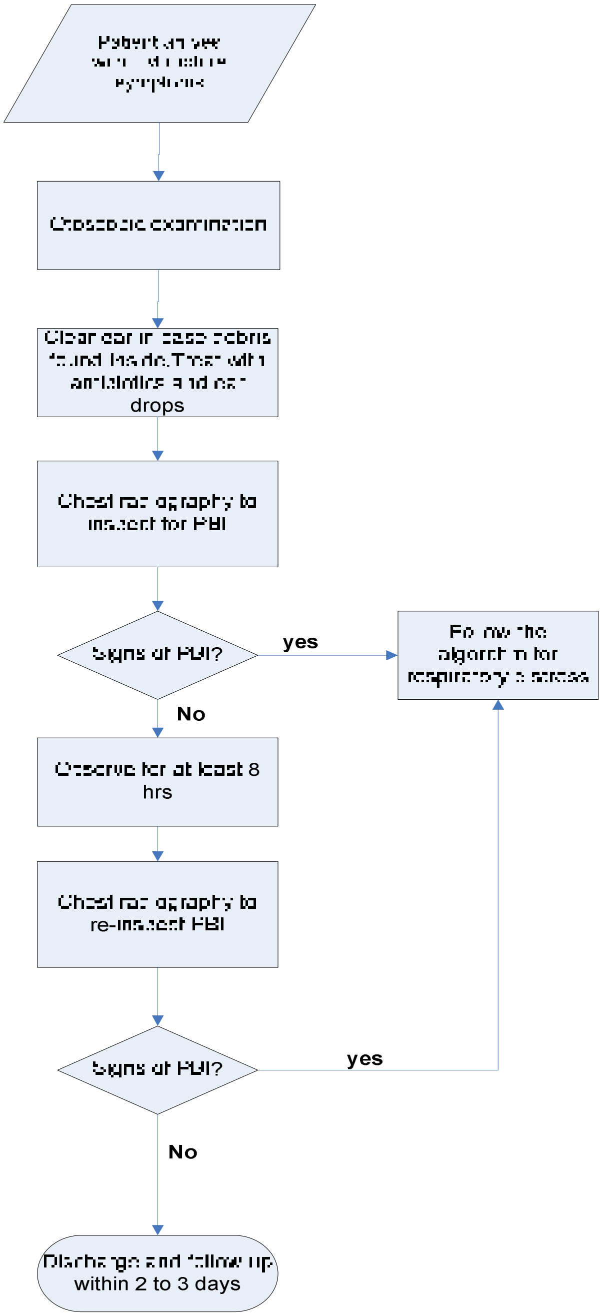


Figure 4-C. Treatment flow chart for TM rupture (Type 5)

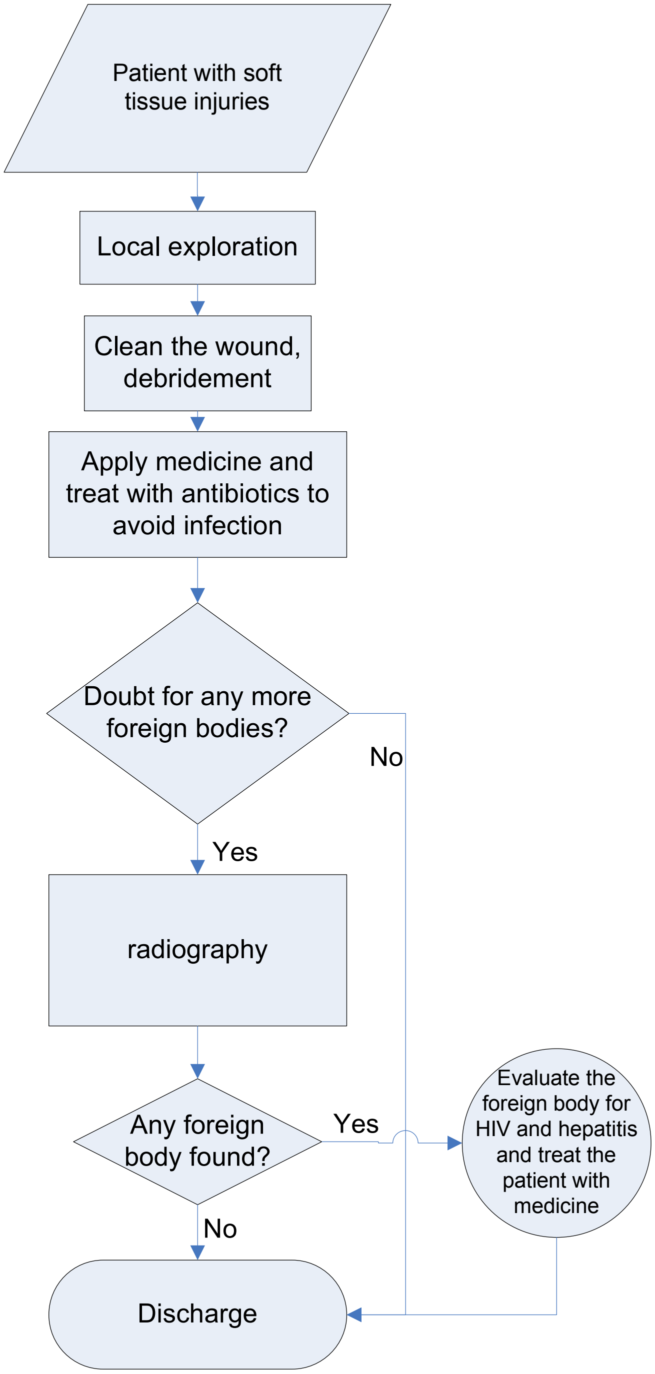


Figure 5-C. Treatment flow chart for penetrating soft tissue (Type 6)

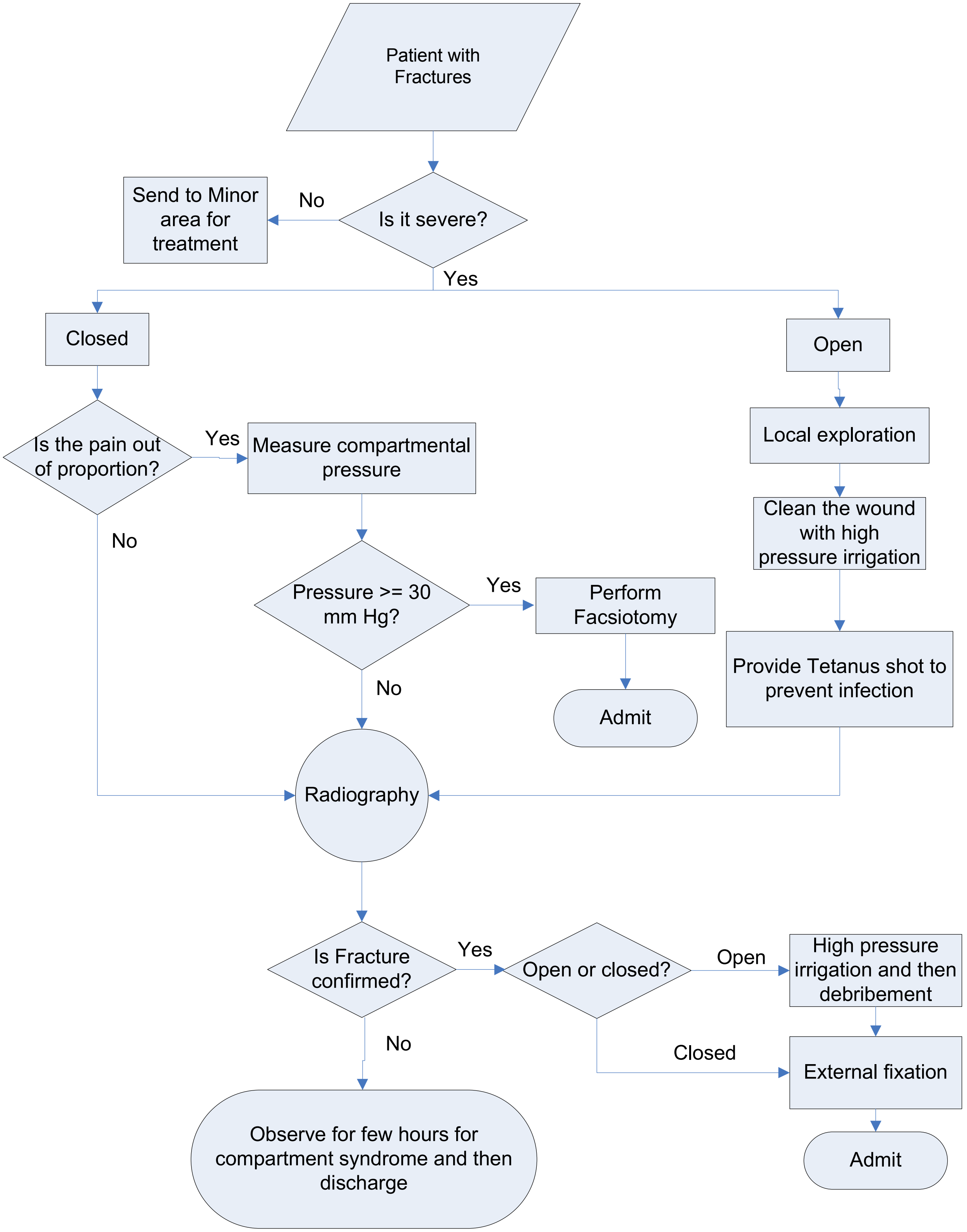


Figure 6-C. Treatment flow chart for orthopedic (Type 7)

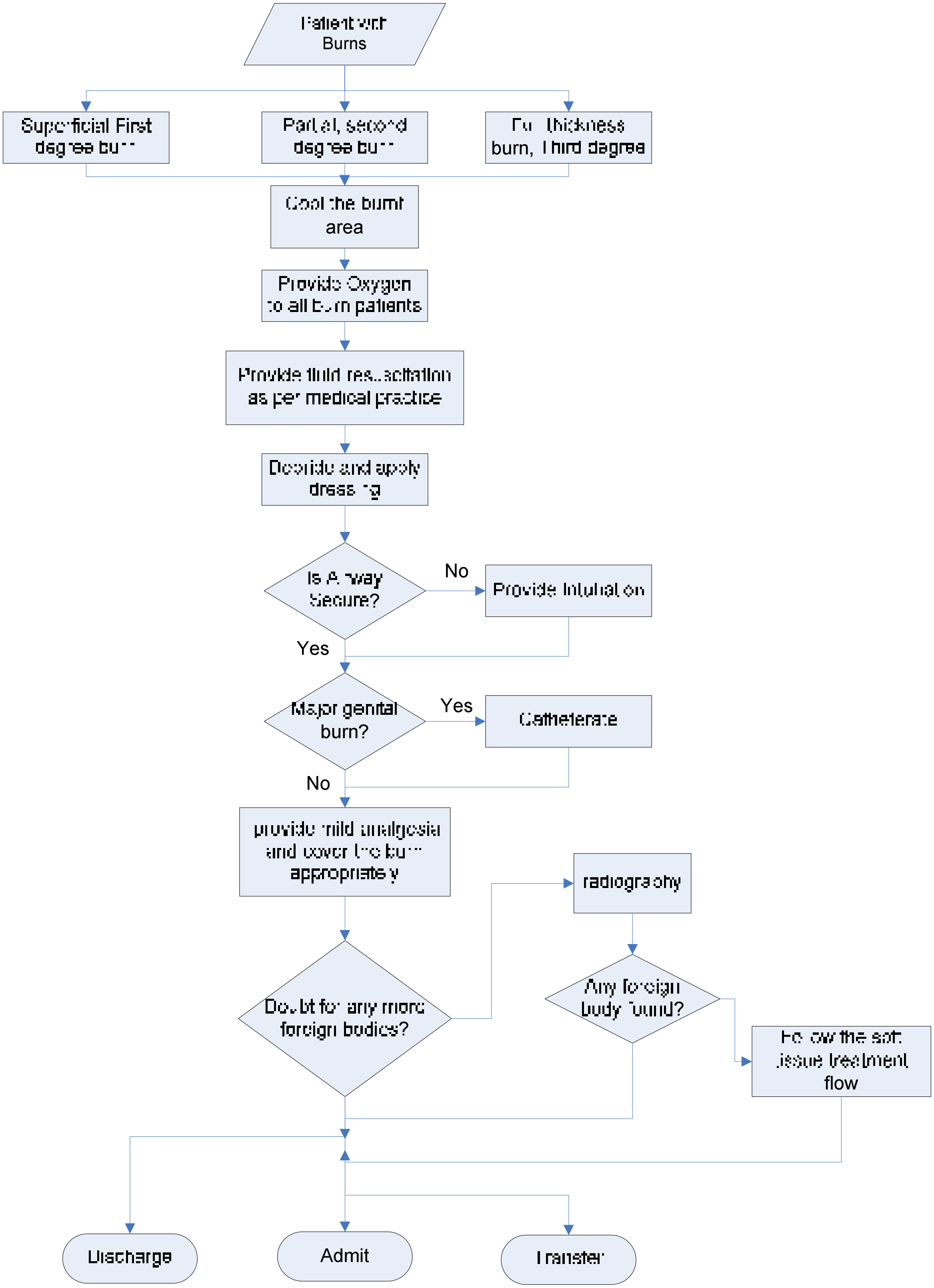


Figure 7-C. Treatment flow chart for Burn (Type 8)

Note: There was no flow chart develop for patients with penetrating eye injury. However, the patient routing and treatment for patients suffering from this type of blast injury was based upon the information provided by Center of Disease Control and Prevention on medical management of penetrating eye blast injuries. http://www.bt.cdc.gov/masscasualties/Blastinjury-eye.asp (accessed on 09/12/08)

Appendix D - Arrival distribution shapes for all the combinations used in the model

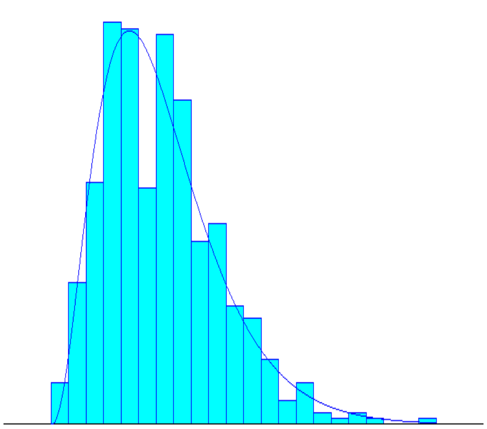


Figure 1-D. Shape of gamma density (3, 4)

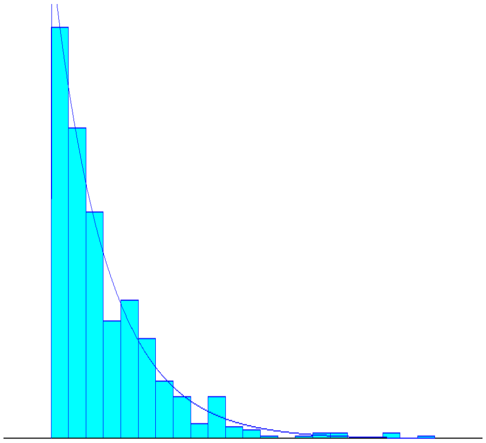


Figure 2-D. Shape of gamma density (3, 1)

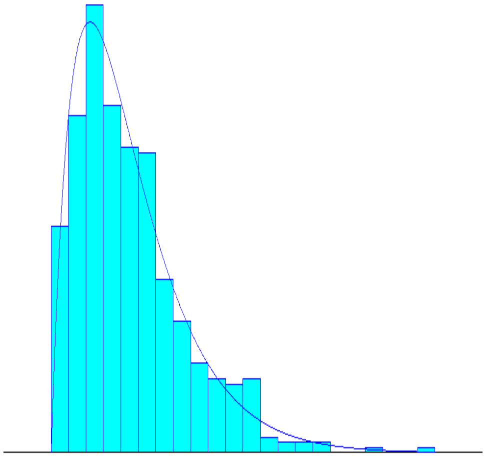


Figure 3-D. Shape of gamma density (3, 2)

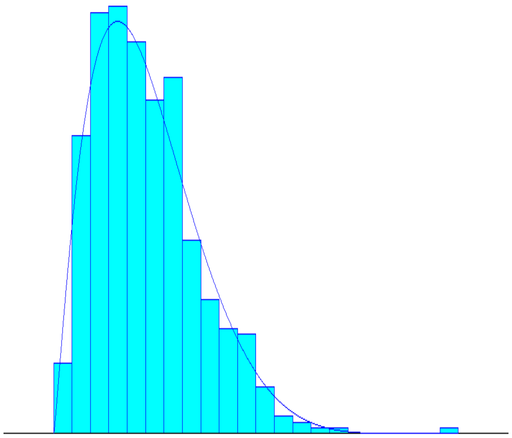


Figure 4-D. Shape of gamma density (3, 3)

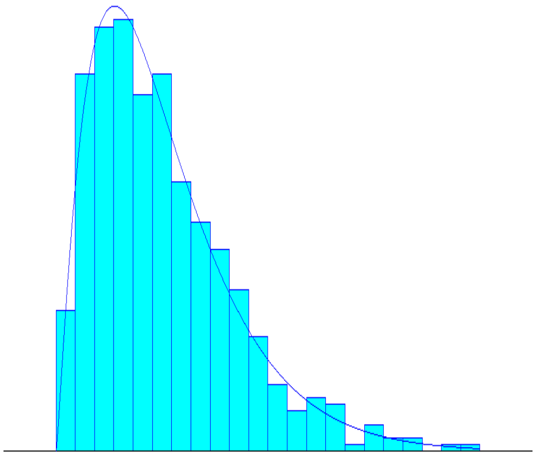


Figure 5-D. Shape of gamma density (4, 2)

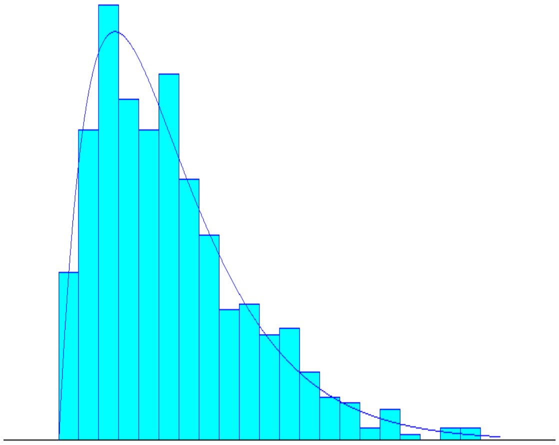


Figure 6-D. Shape of gamma density (2, 2)

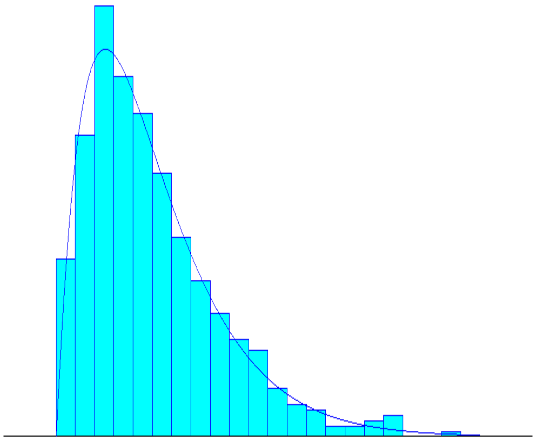


Figure 7-D. Shape of gamma density (1, 2)

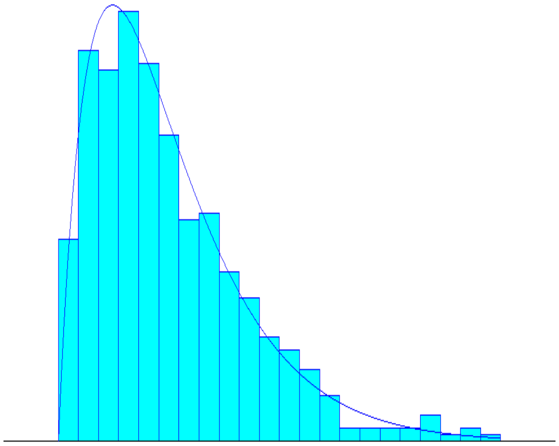
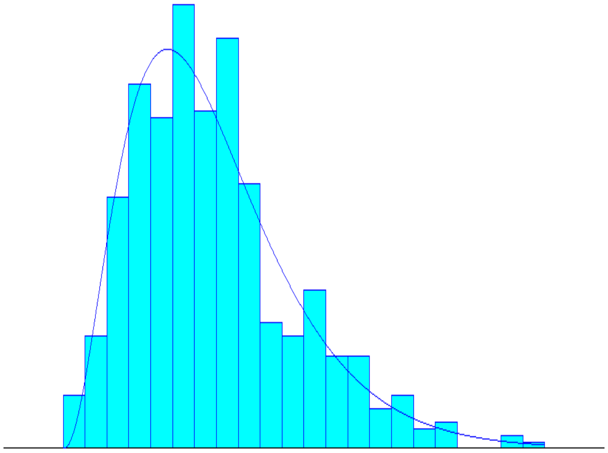


Figure 8-D. Shape of gamma density (0.5, 2)



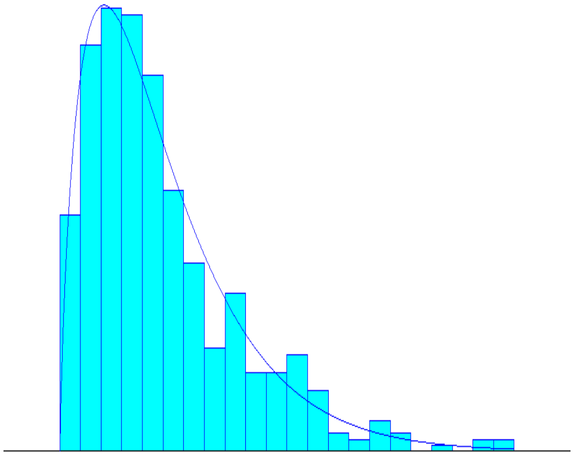
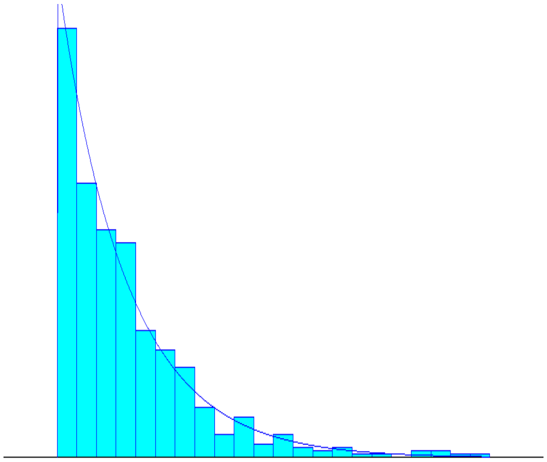


Figure 9-D. Shape of gamma density (2, 4)

Figure 10-D. Shape of gamma density (2, 3)



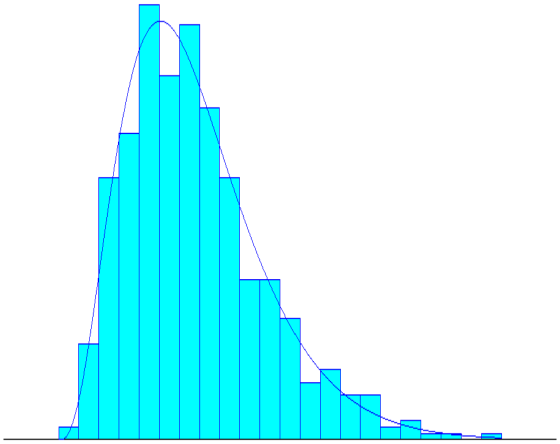


Figure 11-D. Shape of gamma density (2, 1)

Figure 12-D. Shape of gamma density (1, 4)

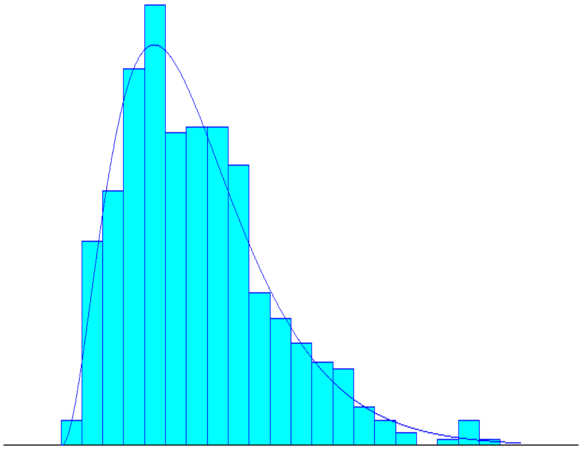


Figure 13-D. Shape of gamma density (1, 3)

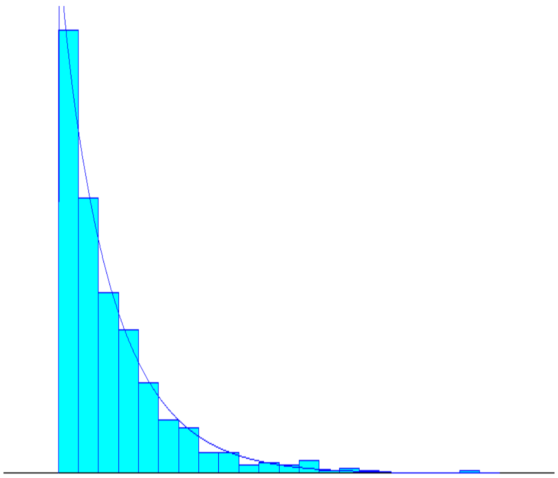


Figure 14-D. Shape of gamma density (1, 1)

Appendix E - Simulation results of base models across scenarios for 12 hrs, 18 hrs and 24 hrs

Table E 1. Simulation results for 12 hrs simulation run time across all the scenarios

Arrival distribution	3,4	3,3	3,2	3,1	4,2	2,2	1,2	0.5,2	2,4	2,3	2,1	1,4	1,3	1,1
Number of disaster victim	83	103	143	274	118	207	384	1492	112	149	383	202	267	749
Number of non disaster victim	69	67	67	67	65	67	66	132	67	68	66	67	68	66
everyday patients diverted	0	0	0	0	0	0	0	**15**	0	0	0	0	0	13
Time until seem severity 1	3.64	3.55	3.5	3.59	3.59	3.56	3.51	3.6	3.61	3.53	3.61	3.56	3.56	3.64
Nurse utilization OPD	22.08	22.54	22.51	23.16	22.83	21.66	22.36	21.71	22.69	22.46	21.41	21.36	21.02	21.2
Time until seen severity 2	4.98	5.01	4.99	5.27	5	5.03	5.59	13.1	4.99	5.01	5.94	5.02	5.07	18.24
LWBS	0	0	0	**1**	0	0	**4**	**318**	0	0	8	0	0	153
ED bed utilization	14.08	16.53	21.55	38.37	17.83	29.63	53.81	91.66	17.45	22.23	54.44	29.1	38.14	91.75
EP1 utilization	52.06	53.69	56.09	70.28	54.86	62.6	84.2	98.91	55.86	58	85.15	63.15	70.93	97.64
EP2 utilization	17.07	20.24	27.39	48.34	22.35	37.82	66.59	96.13	21.58	28.34	65.98	36.66	48.45	94.73
N1 utilization	18.81	22.55	28.92	50.5	24.01	39.83	68.75	96.76	23.79	29.39	68.11	37.85	50.57	95.72
N2 utilization	18.89	22.13	28.81	49.72	23.72	38.19	68	96.86	23.05	29.6	67.37	38.43	49.11	96.14
N3 utilization	19.41	21.55	29.89	50.13	23.89	39.18	67.66	96.81	23.03	29.78	67.98	39.73	48.8	95.94
N4 utilization	18.71	22.11	28.65	48.87	23.17	39.84	66.75	96.74	22.98	28.85	67.23	37.94	49.61	95.77
N5 utilization	17.95	22.57	28.42	48.76	23.15	38.65	67.25	96.65	22.88	29.14	67.1	39.23	49.16	95.47
N6 utilization	17.96	21.04	28.27	49.21	23.04	38.61	67.22	96.56	22.02	28.01	67.22	37.67	49.92	94.92
N7 utilization	18.17	22.1	28.11	49.25	22.94	38.37	66.08	96.52	22.75	29.01	66.08	38.14	50.13	95.32
N8 utilization	17.78	20.45	27.7	48.25	23	38.7	66.96	96.43	22.25	28.66	65.59	36.94	48.84	95.67
N9 utilization	18.06	21.07	27.01	48.22	23.16	36.65	66.65	96.52	22.65	28.42	66.56	36.75	48.77	95.05
N10 utilization	17.29	21.26	26.47	47.65	22.51	38.08	66.13	96.28	21.52	29.46	65.97	36.61	47.46	95.31
Time until seen severity 3	11.15	10.87	11.39	15.86	10.46	13.67	21.08	78.09	10.52	12.45	22.31	14.78	15.27	70.88
critical expire	0	0	0	**3**	0	**2**	**7**	**56**	0	1	7	1	3	27
Shock room utilization	11.66	13.58	17.13	28.21	13.99	23.48	35.49	47.37	14.7	18.35	36.08	25.34	28.98	46.83
Trauma surgeon utilization	25.42	29.24	37.22	61.41	30.5	50.77	76.54	97.36	32.11	39.89	78.13	55.09	63.02	95.76
Trauma nurse utilization	23.32	27.16	34.27	56.42	27.99	46.96	70.99	94.74	29.4	36.71	72.15	50.71	57.97	93.67
Nurse in trauma area utilization	23.32	27.16	34.27	56.42	27.99	46.96	70.99	94.74	29.4	36.71	72.15	50.71	57.97	93.67
Triage team utilization	5.28	5.94	7.08	11.84	6.33	9.35	15.44	28.02	6.19	7.43	15.61	9.08	11.55	28
CT scan utilization	10.47	10.52	14.56	23.58	11.91	18.39	28.67	39.21	12.54	15.21	29.37	21.09	25.05	36.64
X ray utilization	92.71	94.14	95.91	96.89	95.6	96.52	96.88	98.57	95.47	96.16	96.97	96.43	96.59	97.24
OR utilization	24.5	25.41	25.47	27.59	24.96	27.6	29.87	12.39	24.27	27.55	30.82	29.91	29.63	9.57
MEAN	12	9	6	3	8	4	2	1	8	6	2	4	3	1
VARIANCE	36	27	18	9	32	8	2	0.5	16	12	4	4	3	1

Table E 2. Simulation results for 18 hrs simulation run time across all the scenarios

Arrival distribution	**3,4**	**3,3**	**3,2**	**3,1**	**4,2**	**2,2**	**1,2**	**0.5,2**	**2,4**	**2,3**	**2,1**	**1,4**	**1,3**	**1,1**
Number of disaster victim	121	154	213	407	175	310	579	1116	167	218	576	306	400	1126
Number of non disaster victim	104	99	100	100	98	102	100	99	99	102	100	100	101	97
everyday patients diverted	0	0	0	0	0	0	**1**	**13**	0	0	1	0	0	15
Time until seen severity 1	3.63	3.55	3.52	3.58	3.58	3.54	3.52	3.6	3.59	3.54	3.62	3.55	3.56	3.62
Nurse utilization OPD	21.47	22.58	22.37	23.35	23.69	21.25	21.93	21.91	22.18	22.5	21.73	20.85	21.44	20.92
Time until seen severity 2	5	5.01	5	5.25	5.01	5.03	5.6	14.35	5	5	5.9	5.03	5.06	15.6
LWBS	0	0	0	2	0	0	7	229	0	0	12	0	0	243
ED bed utilization	14.08	16.38	21.46	38.29	17.61	30.24	54.36	91.99	17.44	21.94	54.79	29.88	38.17	91.12
EP1 utilization	53.39	54.67	57.4	71.84	55.62	64.13	85.45	98.54	56.49	58.72	86.1	63.6	71.32	98.43
EP2 utilization	17.55	20.53	27.97	48.26	22.24	38.85	67.96	95.97	21.89	27.47	66.73	38.13	48.87	95.18
N1 utilization	18.62	21.98	28.31	49.75	23.18	39.69	68.77	96.95	23.79	28.79	68.18	38.6	50.03	95.76
N2 utilization	18.58	21.95	28.9	49.54	23.16	38.75	68.55	97.13	23.14	28.64	67.54	38.96	49.54	95.89
N3 utilization	19.11	21.21	29.43	49.36	23.55	39.66	68.07	96.95	22.94	29.51	68.43	39.74	48.86	95.93
N4 utilization	18.82	21.38	28.34	48.6	23.21	40.74	67.56	96.71	22.96	28.73	67.78	39.31	49.61	95.62
N5 utilization	18.21	22	27.9	48.87	23.12	39.32	67.92	96.58	22.34	28.64	67.61	40.59	49.59	95.42
N6 utilization	18.08	20.88	28.11	49.26	22.7	39.73	67.85	96.53	21.9	28.33	67.44	38.52	49.97	95.11
N7 utilization	18.27	21.92	27.77	49.13	22.65	39.35	66.92	96.65	22.51	28.56	66.72	39.36	49.35	95.19
N8 utilization	17.88	20.49	27.54	48.65	22.71	39.5	67.47	96.38	22.55	28.32	66.79	38.41	49.26	95.48
N9 utilization	17.83	21.02	26.92	48.51	22.96	37.57	67.57	96.52	22.71	28.55	67.02	38.26	48.94	95.25
N10 utilization	17.41	21.38	26.87	47.95	22.42	39.54	67.11	96.21	21.81	28.95	66.69	38.18	48.51	95.29
Time until seen severity 3	11.13	10.95	11.64	17.8	10.43	14.39	21.91	70.79	10.83	12.84	22.93	14.57	15.87	81.42
critical expire	0	0	**1**	**6**	0	**3**	**11**	**41**	0	1	12	2	5	43
Shock room utilization	11.4	13.71	17.47	29.45	14.42	24.57	36.24	47.01	14.89	18.97	36.9	24.95	28.95	47.28
Trauma surgeon utilization	24.8	29.7	38.12	63.99	31.38	53.27	78.46	96.49	32.71	41.35	79.74	54.41	63.06	97.03
Trauma nurse utilization	22.81	27.43	34.94	58.9	28.84	49.14	72.5	94.03	29.77	37.94	73.93	49.9	57.9	94.56
Nurse in trauma area utilization	22.81	27.43	34.94	58.9	28.84	49.14	72.5	94.03	29.77	37.94	73.93	49.9	57.9	94.56
Triage team utilization	5.21	5.99	7.16	11.75	6.27	9.51	15.64	27.86	6.16	7.32	15.71	9.13	11.71	28.02
CT scan utilization	9.64	11.01	15.03	24.1	11.97	19.57	29.61	39.41	13.38	15.67	29.77	21.83	24.88	38.11
X ray utilization	95.12	96.09	97.27	97.93	97.07	97.68	97.92	98.09	96.98	97.44	97.98	97.62	97.72	98.16
OR utilization	26.51	27.4	28.29	30.49	26.69	30.48	33.04	11.62	26.13	29.68	32.26	31.63	31.77	11.48
MEAN	12	9	6	3	8	4	2	1	8	6	2	4	3	1
VARIANCE	36	27	18	9	32	8	2	0.5	16	12	4	4	3	1

Table E 3. Simulation results for 24 hrs simulation run time across all the scenarios

Arrival distribution	3,4	3,3	3,2	3,1	4,2	2,2	1,2	0.5,2	2,4	2,3	2,1	1,4	1,3	1,1
Number of disaster victim	162	206	285	542	232	410	769	1492	224	287	764	406	532	1511
Number of non disaster victim	137	131	132	133	131	134	130	132	131	134	131	134	134	130
everyday patients diverted	0	0	0	0	0	0	**1**	**15**	0	0	1	0	0	17
Time until seen severity 1	3.59	3.56	3.51	3.57	3.56	3.56	3.53	3.6	3.57	3.59	3.63	3.57	3.55	3.65
Nurse utilization OPD	21.81	22.23	21.91	22.83	23.14	21.58	21.95	21.71	22.34	22.21	22.06	21.27	21.87	21.01
Time until seen severity 2	4.99	5	5	5.25	4.99	5.03	5.58	13.1	5	5	5.88	5.02	5.06	14.38
LWBS	0	0	0	**2**	0	0	**10**	**318**	0	0	18	0	0	338
ED bed utilization	13.99	16.34	21.6	38.61	17.58	30.03	54.55	91.66	17.47	21.86	54.3	29.93	38.18	90.99
EP1 utilization	53.85	55.13	57.96	72.21	56.38	63.94	85.75	98.91	56.65	58.91	86.4	63.88	71.79	98.82
EP2 utilization	17.39	20.79	28.09	48.67	22.72	38.37	68.03	96.13	22	27.57	66.14	37.95	49.18	95.38
N1 utilization	18.22	21.76	28.13	50.09	23.85	39.35	68.92	96.76	23.46	28.75	67.44	39.03	49.91	95.92
N2 utilization	18.25	21.5	28.9	49.95	23.34	38.74	68.89	96.86	23.07	28.67	67.39	39.23	49.64	95.87
N3 utilization	18.82	21	29.27	50.15	23.46	39.81	68.29	96.81	22.87	29.23	67.8	39.24	49.13	95.88
N4 utilization	18.53	21.37	28.39	48.8	23.45	40.17	67.9	96.74	22.94	28.84	67.12	39.37	49.79	95.77
N5 utilization	18.39	21.67	28.14	49.56	23.55	39.47	68.22	96.65	22.46	28.35	67.18	40.33	49.91	95.51
N6 utilization	18.16	21.17	28.34	49.25	23.08	39.26	68.34	96.56	22.09	28.33	66.72	39	50.05	95.38
N7 utilization	18.44	21.78	27.96	49.86	22.85	39.38	67.31	96.52	22.87	28.48	66.04	39.32	48.79	95.36
N8 utilization	17.81	20.57	27.92	49.31	22.9	39.31	68	96.43	22.53	28.46	66.51	38.68	48.99	95.61
N9 utilization	17.85	21.11	27.41	48.35	23.63	37.48	67.68	96.52	22.72	28.4	66.99	38.67	48.77	95.38
N10 utilization	17.42	21.37	27.35	48.88	22.92	39.16	67.39	96.28	22.35	28.6	66.11	38.23	48.71	95.37
Time until seen severity 3	11.28	10.89	12.13	17.76	10.55	14.15	22.2	78.09	11.04	12.7	23.26	14.39	15.68	94.43
critical expire	0	0	**1**	**8**	0	**4**	**15**	**56**	0	1	15	3	6	58
Shock room utilization	11.31	20.79	17.63	29.52	14.25	23.92	36.26	47.37	15.3	18.76	36.45	24.63	28.92	47.74
Trauma surgeon utilization	24.69	30.44	38.46	64.26	31.13	51.96	78.8	97.36	33.47	40.79	79.09	53.72	62.92	97.78
Trauma nurse utilization	22.62	28.07	35.27	59.05	28.52	47.84	72.53	94.74	30.61	37.51	72.89	49.26	57.84	95.48
Nurse in trauma area utilization	22.62	28.07	35.27	59.05	28.52	47.84	72.53	94.74	30.61	37.51	72.89	49.26	57.84	95.48
Triage team utilization	5.22	5.74	7.13	11.68	6.24	9.55	15.54	28.02	6.17	7.25	15.67	9.11	11.66	28.43
CT scan utilization	10.02	11.3	15.13	24.83	12.03	19.66	30.13	39.21	13.23	15.09	30.4	21.29	24.56	38.66
X ray utilization	96.34	97.07	97.96	98.44	97.8	98.25	98.44	98.57	97.73	98.07	98.49	98.22	98.29	98.62
OR utilization	27.41	29.44	28.66	31.41	27.44	31.19	33.52	12.39	27.82	30.6	33.72	31.76	31.74	12.93
MEAN	12	9	6	3	8	4	2	1	8	6	2	4	3	1
VARIANCE	36	27	18	9	32	8	2	0.5	16	12	4	4	3	1

Appendix F - Simulation results of experiment 2 for distribution (1,2) for 12 hours, 18 hours and 24 hours

Table F 1. Simulation results for base model of 12 hrs vs. optimal model of 6 hrs ran for 12 hrs

	Arrival distribution	Base model of 12 hrs	Optimum model of 6 hrs ran for 12 hrs	% changed
	Number of disaster victim	384	391	
	Number of non disaster victim	66	66	
	everyday patients diverted	0	0	
	Time until seen severity 1 (minutes)	3.51	12.38	252.70
	Nurse utilization OPD	22.36	66.09	195.57
	Time until seen severity 2 (minutes)	5.59	5.20	-6.977
	LWBS	4	3	
Utilization of resources in treatment unit for severity level 2 patients	ED bed utilization	53.81	50.04	-7.00
	EP1 utilization %	84.20	75.71	-10.08
	EP2 utilization %	66.59	57.37	-13.85
	N1 utilization %	68.75	57.30	-16.65
	N2 utilization %	68.00	59.25	-12.86
	N3 utilization %	67.66	59.38	-12.24
	N4 utilization %	66.75	59.69	-10.58
	N5 utilization %	67.25	59.22	-11.94
	N6 utilization %	67.22	58.64	-12.76
	N7 utilization %	66.08	57.16	-13.50
	N8 utilization %	66.96	59.12	-11.71
	N9 utilization %	66.65	59.01	-11.34
	N10 utilization %	66.13	57.75	-12.67
	N 11 utilization %		59.19	
	N12 utilization %		57.73	
	Time until seen severity type 3 (minutes)	21.08	10.68	-49.33
	Critical expire	7	2	
Utilization of resources in treatment unit for severity level 3 patients	Shock room utilization %	35.49	45.11	-27.11
	Trauma surgeon utilization %	76.54	48.88	-36.14
	Trauma nurse utilization %	70.99	45.11	-36.45
	Nurse in trauma area utilization %	70.99	45.11	-36.45

Table F 2. Simulation results for experiment 2 (12 hours)

	Base Model (12 hrs)	**Optimal model of 6 hrs ran 12 hrs**	**Percent Change**	**T-test Results from ARENA Output Analyzer**
Time until first seen (severity level 2) in minutes	5.59	5.20	-6.97	Means are significantly different at 0.05 alpha level.
Time until first seen (severity level 3) in minutes	21.19	10.13	-52.19	Means are significantly different at 0.05 alpha level.

Table F 3. Simulation results for base model of 18 hrs vs. optimal model of 12 hrs ran for 18 hrs

	Arrival distribution	Base model of 18 hrs	Optimum model of 12 hrs ran for 18 hrs	% changed
	Number of disaster victim	579	576	
	Number of non disaster victim	100	100	
	Everyday patients diverted	1	0	
	Time until seen severity 2 (minutes)	5.60	5.13	-8.39
	LWBS	7	1	
Utilization of resources in treatment unit for severity level 2 patients	**ED bed utilization**	54.36	42.24	-22.30
	EP1 utilization %	85.45	73.33	-14.19
	EP2 utilization %	67.96	53.75	-21.17
	N1 utilization %	68.77	55.15	-19.81
	N2 utilization %	68.55	55.33	-19.29
	N3 utilization %	68.07	55.98	-17.76
	N4 utilization %	67.56	54.67	-19.08
	N5 utilization %	67.92	55.25	-18.65
	N6 utilization %	67.85	55.13	-18.75
	N7 utilization %	66.92	54.69	-18.28
	N8 utilization %	67.47	54.35	-19.45
	N9 utilization %	67.57	55.39	-18.03
	N10 utilization %	67.11	54.59	-18.66
	N 11 utilization %		53.69	
	N12 utilization %		55.06	
	Time until seen severity type 3 (minutes)	21.91	9.62	-56.09
	Critical expire	11	0	
Utilization of resources in treatment unit for severity level 3 patients	**Shock room utilization %**	36.24	29.91	-17.47
	Trauma surgeon utilization %	78.46	32.53	-58.54
	Trauma nurse utilization %	72.5	29.91	-58.45
	Nurse in trauma area utilization %	72.5	29.91	-58.45

Table F 4. Simulation results for experiment 2 (18 hours)

	Base Model (18 hrs)	**Optimal model of 12 hrs ran 18 hrs**	**Percent Change**	**T-test Results from ARENA Output Analyzer**
Time until first seen (severity level 2) in minutes	5.60	5.13	-8.39	Means are significantly different at 0.05 alpha level.
Time until first seen (severity level 3) in minutes	21.91	9.62	-56.09	Means are significantly different at 0.05 alpha level.

Table F 5. Simulation results for base model of 24 hrs vs. optimal model of 18 hrs ran for 24 hrs

	Arrival distribution	Base model for 24 hrs	Optimum model of 18 hrs ran for 24 hrs	% changed
	Number of disaster victim	769	762	
	Number of non disaster victim	130	133	
	Everyday patients diverted	1	0	
	Time until seen severity 2 (minutes)	5.58	5.15	-7.71
	LWBS	10	0	
Utilization of resources in treatment unit for severity level 2 patients	ED bed utilization	54.55	40.20	-26.31
	EP1 utilization %	85.75	73.63	-14.13
	EP2 utilization %	68.03	53.92	-20.74
	N1 utilization %	68.92	55.27	-19.81
	N2 utilization %	68.89	55.36	-19.64
	N3 utilization %	68.29	55.74	-18.38
	N4 utilization %	67.90	54.69	-19.46
	N5 utilization %	68.22	54.89	-19.54
	N6 utilization %	68.34	54.91	-19.65
	N7 utilization %	67.31	55.27	-17.89
	N8 utilization %	68.00	54.34	-20.08
	N9 utilization %	67.68	55.38	-18.17
	N10 utilization %	67.39	54.63	-18.93
	N 11 utilization %		53.91	
	N12 utilization %		55.05	
	Time until seen severity type 3 (minutes)	22.20	9.59	-56.80
	Critical expire	15	0	
Utilization of resources in treatment unit for severity level 3 patients	Shock room utilization %	36.26	29.58	-18.42
	Trauma surgeon utilization %	78.80	32.27	-59.04
	Trauma nurse utilization %	72.53	29.58	-59.21
	Nurse in trauma area utilization %	72.53	29.58	-59.21

Table F 6. Simulation results for experiment 2 (24 hours)

	Base Model (24 hrs)	**Optimal model of 18 hrs ran 24 hrs**	**Percent Change**	**T-test Results from ARENA Output Analyzer**
Time until first seen (severity level 2) in minutes	5.58	5.15	-7.71	Means are significantly different at 0.05 alpha level.
Time until first seen (severity level 3) in minutes	22.0	9.59	-56.08	Means are significantly different at 0.05 alpha level.