RWJ-RU4474

Evacuation Planning and Emergency Management Study Of Robert Wood Johnson University Hospital

FINAL REPORT
November, 2005

Submitted by

Dr. Mohsen Jafari

Center for Advanced Infrastructure & Transportation (CAIT)
Civil & Environmental Engineering Department
Rutgers, the State University of New Jersey
Piscataway, NJ 08854-8014

In cooperation with

State of New Jersey
Department of Health
And Senior Services
&
Robert Wood Johnson University Hospital

Disclaimer Statement

"The contents of this report reflect the views of the author(s) who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of New Jersey Department of Health & Senior Services Or Robert Wood Johnson University Hospital. This report does not constitute a standard, specification, or regulation."

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of New Jersey Department of Health & Senior Services in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
RWJ-RU4474		

4. Title and Subtitle	5. Report Date
Evacuation Planning and Emergency Management Study Of Robert Wood Johnson University Hospital: Evacuation & Surge Capacity	November 2005
	6. Performing Organization Code CAIT/Rutgers
7. Author(s) Dr. Mohsen Jafari	8. Performing Organization Report No. RWJ-RU4474
9. Performing Organization Name and Address Robert Wood Johnson University Hospital One Robert Wood Johnson Place New Brunswick, NJ 08901	10. Work Unit No.
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address Department of Health and Senior Services P. O. Box 360 Trenton, NJ 08625-0360	13. Type of Report and Period Covered Final Report 04/1/2004 - 11/1/2005
	14. Sponsoring Agency Code

15. Supplementary Notes

U.S. Department of Transportation
Research & Innovative Technology Administration (RITA)
400 7th Street, SW
Washington, DC 20590-0001

Center for Advanced Infrastructure & Transportation (CAIT)
Rutgers, The State University
Piscataway, NJ 08854-8014

16. Abstract

The objective of this study was the optimization of evacuation and surge capacity strategies using computer simulation models. This study consisted of modeling and simulating the current evacuation and surge capacity procedures at Robert Wood Johnson University Hospital. In this technical report, we will cover in detail all the process models, simulation models and results of simulation runs for each unit focusing on its evacuation and surge activities. The analysis and interpretation of results and final suggestions and recommendations to improve the corresponding processes will also be provided. This project is intended to simulate and henceforth develop a modeling framework using which a wide spectrum of evacuation and surge capacity scenarios can be virtually built, tested and analyzed. The results and findings from this project can be extrapolated to other hospitals but with a lesser degree of accuracy. The model is also intended to provide a training environment for medical emergency professionals.

17. Key Words	18. Distribution Statement
Evacuation, Surge Capacity, Simulation, Modeling, Systems Planning	

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
		72	

Form DOT F 1700.7 (8-69)

A SIMULATION BASED STUDY OF EVACUATION AND SURGE CAPACITY PROCEDURES AT ROBERT WOOD UNIVERSITY HOSPITAL – PHASE I

FINAL REPORT – PART I: EVACUATION STUDY

November, 2005

SPONSORED BY THE NJ DEPARTMENT OF HEALTH & SENIOR SERVICES AND IN COLLABORATION WITH ROBERT WOOD JOHNSON UNIVERSTY HOSPITAL

Research Team

Rutgers University
M.A. Jafari
K. Seyed
A. Maher
L. Bodnar

Robert Wood Johnson Medical School & UMDNJ
J. Hammond

Robert Wood Johnson University Hospital
D. Campbell

ACKNOWLEDGEMENTS

We would like to extend our gratitude and appreciation to:

Mr. Doug Campbell
Mr. Louis Sasso
Mrs. Kathy Zavotsky
Mrs. Kathy Scipione
Mr. Peter Torres
Mrs. Laura Mansfield
Roberto Chiu and
Katie Meagher
Mrs. Joann Bobal
Mrs. Becky Ramos
Mrs. MaryAnn Brooks

We would also like to thank all the nurses and personnel of the units and departments in RWJUH that kindly helped us throughout this project.

Finally, we would like to thank the New Jersey Department of Health and Senior Services for sponsoring and funding this project.

Table of Contents

INTRODUCTION

In 2003, a group of graduate students from Rutgers University developed a simulation model of the evacuation of the Medical Intensive Care Unit (MICU) and Cardiac Care (CCU) unit of the third floor of Robert Wood Johnson University Hospital (RWJUH). This simulation was used to assess various evacuation strategies in the event of a fire or smoke condition located on the 3rd floor.

Given the floor layout of the two units, the availability of resources and staff, and the evacuation procedures that would be followed, the results from running the simulations were disquieting. It would take the staff a total of over two hours to evacuate thirty patients from MICU and CCU to the courtyard, Robert Wood Johnson University Hospital's designated "safe location". Even after running multiple models based on the manipulation of different variables such as the number of nurses available and patient to nurse ratios on the third floor and at the safe location, the simulation illustrated that evacuation times below thirty-five minutes were not feasible.

The results obtained from the simulation model far exceeded the expected evacuation times predicted by hospital personnel from the MICU and CCU units.

A New Study – Phase I

The ability to optimize the evacuation strategies of the MICU and CCU units using the simulation model led to this investigation of four other units at Robert Wood Johnson University Hospital: the Surgical Intensive Care Unit (SICU West), the Emergency Department, the Adult Unit (Med-Surgical Floor), and the Pediatrics Unit (children under eight years old).

Each of the units that were chosen had distinctive natures and contained variables that posed unique constraints that would affect its evacuation strategy. At the same time, the four units are representative of the spectrum of treatment offered at hospitals nationwide.

This simulation project with Robert Wood Johnson University Hospital consisted of modeling and simulating the current evacuation procedures in the above-mentioned four units. In this technical report, we will cover in detail all the process models, simulation models and results of simulation runs for each unit focusing on their evacuation activities. The analysis and interpretation of results and final suggestions and recommendations to improve the corresponding processes will also be provided.

Process Modeling and Simulation

Today, evacuation planning and emergency management are sophisticated fields of engineering sciences, aimed to save human lives by safe facility design and optimization of rescue operations. Scientists are using the latest achievements in various, fundamental and applied disciplines, such as simulation, process control, applied mathematics, psychology, architecture and physics in the assessment of emergency situations and predicting outcomes.

Simulation is a tool that will prove useful in evacuation and surge capacity process planning and improvement. In simulation, a computer model of a real world system is built and used to study various alternatives or scenarios in operating and controlling the system. Computer simulation is also used for studying design and operation alternatives for new systems or concepts.

Simulation modeling involves a number of steps including problem definition and scope analysis, data collection, building of conceptual and computer models, verification and validation of these models, design of experiments and output analysis, and finally reporting and documentation of results. Simulation modeling can be accomplished using high-level computer programming languages or general-purpose simulation languages. Simulation languages provide graphical user interfaces (GUI’s) as well as computer animation of system operation.

For this study, the Rutgers University team chose ARENA software, a commercially available simulation package to create Robert Wood Johnson’s University Hospital’s evacuation models.

Robert Wood Johnson University Hospital

Robert Wood Johnson University Hospital is the principal hospital of the University of Medicine and Dentistry of New Jersey (UMDNJ) - Robert Wood Johnson Medical School (RWJMS), a member of University Health System of New Jersey and the Robert Wood Johnson Health System and Network.

The hospital is committed to a fourfold mission: patient care, research, education of tomorrow's health professionals and community outreach. The hospital offers a full range of healthcare services, from primary, tertiary and quaternary services to specialty and sub-specialty diagnosis and treatment.

As one of the nation's leading academic health centers, Robert Wood Johnson University Hospital treats the most severely ill patients referred from community hospitals around the state and from around the country.

General Information:

- 572 inpatient beds
- More than 200,000 patients treated annually, with 28,013 admitted in 2004 (excluding newborns)
- 1,100 physicians and surgeons in every specialty are affiliated with the hospital
- Founded in 1884[1]

Overview of Building Codes and Fire Standards

The New Jersey Department of Health and Senior Services have established some standards for fire and emergency preparedness. Section 8:43G-24.13, "Fire and emergency preparedness," is part of the NJDHSS N.J.A.C Title 8, Chapter43, Hospital Licensing Standards. Section 8:43G-24.13 identifies fire and emergency criteria to be met by New Jersey hospitals. First, hospitals must act in accordance with the 1985 edition of the National Fire Protection Association "Life Safety Code" (N.F.P.A. 101).

All hospital employees, medical and non-medical, must be trained annually to respond to an event of fire and in the use of fire-fighting equipment. Instructions addressing emergency protocols should be printed and distributed to all hospital employees, medical and non-medical. Units must display written diagrams of evacuation procedures and the locations of fire exits, alarm boxes, and fire extinguishers. Exits, stairways, doors, and hallways should be kept free of blockage.

Fire drills should be conducted at least twelve times per year, with at least one drill on each shift and one drill on a weekend. Fire extinguishers must receive a visual examination monthly in addition to full inspections annually and must be labeled with the date of last inspection. Fire detectors, alarm systems, and suppression systems must all be tested and documented at least twice [1]a year. It is advised that all hospitals should have an alternate emergency power supply. Emergency power generators must be able to sustain power for at least twenty-four hours. [2]

EVACUATION

Emergency situations could happen internally or externally. In case of an internal event such as a fire or contamination initiated from a laboratory, the hospital emergency management staff may decide to evacuate parts of the hospital, which are affected or located in the vicinity of the event. This may apply to the whole hospital if the entire system is in danger.

Since hospital patients are by definition compromised in some way, and are in many cases, (ICU and CCU) confined to beds and dependant on life support, real-time, live evacuation drills are not feasible. However, it is crucial to know in advance how an evacuation would run and what factors are important in the process. This information can be used to empower staff through education, discussion, and practice.

Evacuation planning employs proactive approach to problem solution by modeling the hazard occurrence process via various kinds of simulation techniques and develops recommendations for improvement of evacuation procedures: building plan redesigning, creating additional shelter areas, evacuation training, etc.

Successful evacuation strategies are dependent upon the fire protection features built into the health-care facility, the compartmental design of the hospital, and above all, the proper training of staff regarding response to a fire incident. Patients whose conditions may prevent them from evacuating without aid are reliant upon the staff and emergency response personnel of the health-care facility. Patients must be removed from the area of immediate danger while still receiving the proper care.

The ultimate goal of any evacuation planning effort is to maximally reduce the number of casualties in case of possible hazards and emergency events. Being capable of promptly initiating an evacuation, ensuring that occupants take appropriate actions during the evacuation, and being able to account for people after an evacuation are preparedness steps that may make the difference between life and death.

Protocol

In the event of an internal disaster such as a fire, evacuation plans for the hospital describe how and where to relocate patients from an area of danger to a designated safe location. The magnitude of the fire, the ability of hospital and emergency personnel to contain and control the fire, and the movement of smoke dictates the course of evacuation. All health-care staff members are trained to respond to a fire in their unit using the "RACE" protocol. The acronym "RACE" illustrates the steps to be taken upon discovery of a fire:

- **R**emove patients, visitors, and staff from immediate danger.
- **A**ctivate the nearest alarm pull station. Notify the switchboard operator on extension 2222.
- **C**onfine the fire by closing doors and windows.
- **E**vacuate patients, visitors and staff in general area. **E**xtinguish the fire if it can be done safely.

The activation of an alarm either through a pull station or a smoke detector prompts the switchboard operator to announce on the overhead page system "Code Red" and the location of the fire. All pull stations and smoke detectors are numbered; activation of either a station or a detector identifies its respective number, allowing for the fast and efficient detection of a fire location. The announcement of "Code Red" initiates the mobilization of a fire response team to the location of the fire.

The team is composed of personnel from the following departments: Safety and Security, Engineering, Housekeeping supervisor(s), Nursing supervisor(s), and Respiratory Therapy. The team receives a response call via a two-way radio or the overhead announcement from the operator. All fire response team personnel are instructed to bring extinguishers with them to the location of the fire. At the scene of the fire, the Security Supervisor coordinates the activities of the fire response team until the arrival of the New Brunswick Fire chief or designee.

There are three categories of fire: Class A, Class B, and Class C. Class "A" fires are caused by combustible materials such as wood, paper, cloth, etc. Flammable liquids such as gasoline, grease and paints are typical agents of Class "B" fires. Class "C" fires are characterized as electrical equipment fires that can occur to x-ray machines, monitors, etc. Although water may be used to extinguish Class "A" fires, water must not be used for Class "B" and Class "C" fires. Extinguishers are classified as ABC extinguishers and can be used to handle all the categories of fire. The use of ABC extinguishers, rather than separate extinguishers to handle each class, facilitates a faster and more efficient response by the fire response team to the afflicted area.

There are several phases of an evacuation. The first phase is the room of origin. Hospital staff members must be trained to evacuate as quickly as possible the room directly involved in the fire incident. One of the most rapid methods of evacuation is to remove patients in their beds to the corridor area. For non-ambulatory patients, this process is more involved due to the generally more critical conditions of these patients and often requires greater time for their preparation and movement. In the event of a fire, the door to the room of the fire origin must be immediately closed and wet linens should be placed at the base of the door to prevent toxic levels of smoke from spreading to surrounding areas. The next phase of evacuation occurs if the fire cannot be contained to the room of origin. Staff members should remove patients horizontally to a safe area beyond fire doors on the same floor. Typically, ambulatory patients should be the first to be moved. Hospital personnel should be trained to instruct ambulatory patients to line up in the corridor and follow a designated employee to the safe area. Non-ambulatory patients are the next to be moved. Wheeled or non-wheeled stretchers, wheelchairs, blanket carriers, and in the case of Intensive Care Units, patient beds, all require the assistance of hospital personnel for the removal of non-ambulatory patients to safe areas. The nursing staff members are responsible for accounting for all persons and patient records. Records must accompany patients as they are transported to safe locations to ensure the continuity of proper medical treatment.

For units located above the ground floor, vertical evacuation is the next phase. Vertical evacuations can be conducted via elevators or stairs. The use of elevators can be controlled with a security key, making it possible to designate elevator use to the evacuating floor. Vertical stair evacuations of some non-ambulatory patients can be achieved with the help of the fire department and EMS using stair-chairs. However, for patients that cannot sit up, the stair-chairs cannot be used to evacuate these non-ambulatory patients. Thus, bed-ridden, non-ambulatory patients are dependent on elevators for vertical evacuation. For this reason, a failure in the functioning of elevators during an evacuation poses a serious threat to the safety of non-ambulatory patients.

All hospital units have two means of egress. Evacuation routes are planned in relation to the locations of the nearest exits to the unit. If both the primary and secondary evacuation routes are obstructed by either fire or other condition that may harm patients, hospital personnel should be trained to “shelter in place.” Implementation of “shelter in place” involves following the steps of the RACE protocol, although evacuation may not be possible, and remain in place until the arrival of the fire response team, the New Brunswick Fire Department or other emergency personnel. The above overview is part of the many guidelines that were utilized in the creation of the simulation models for RWJUH.

RWJUH Facility Design

The design of Robert Wood Johnson University Hospital reflects the “unit” concept based on the division of the facility to restrict the propagation of fire and smoke. Each room or unit is viewed as a “box.” Together, all the “boxes” form the hospital building. Six sides make up a unit: four walls, a ceiling, and a floor. Within the unit, doors, windows, HVAC vents, electrical conduits and piping are all openings that may act as potential pathways for the spread of heat and smoke to adjacent units.

Fire rated doors and ceiling tiles and fire rated caulk (which must surround all wall openings) act as temporary barriers between facility partitions. Although not permanent barricades, fire rated assemblies can delay and limit the horizontal and vertical spread of heat and smoke to unaffected areas of the facility.

The number one reason for fire at Robert Wood Johnson University Hospital is popcorn left too long in a microwave. In areas that include teen or family lounges, which offer the use of microwaves to visitors, the chances for fire are greater. Other vulnerable areas to fire are the lab, the Emergency Department, the Radiology Department, sub-basements that house electrical wiring, and parking decks.

Process Modeling of Assigned Units

Extensive interviews with head nurses and nurses of the corresponding units, yielded information about rules and procedures for evacuation. In order to create the model of current evacuation protocol, each one of the assigned units, was studied to understand the layout, its available facilities and exit routes as well as the current evacuation procedure at hand.

A questionnaire was prepared for each unit and was presented to the head nurse of that unit. The questions generally covered the steps that need to be followed to evacuate the patients from that unit to a safe location, available or assigned safe locations, staffing and schedule of staff, different types of patients at the floor, different type of helpers available to fro help in case of emergency, available facilities and exit routes such as elevators and stairs, and so on. The questionnaires used in these interviews, are attached in Appendix I.

The head nurses provided the project team tours through the corresponding units to further illustrate the evacuation paths that they may follow during an emergency situation. These routes were noted and compared to the CAD drawings of floor maps.

This information was summarized and became the basis for a flowchart. The flowchart or "process model" for each unit was established using Visio software. Each flowchart shows the sequence of steps and their connectivity for the current evacuation process at each corresponding unit.

After the problem was defined in a simulation-modeling project, the next step was to understand the system and the underlying processes. In this case, knowledge of current evacuation procedures was necessary in order to model the system appropriately. For this to be accomplished, thorough interviews were conducted with the vice president of risk management, head nurses and nurses of the units that were involved in this study. The concept used by Evacuation Process Simulation approach is to analyze possible hazard scenarios for the given facility/unit of the hospital and develop procedures for safe transfer of people from the affected area into safe areas. Available simulation software packages were used to simulate the current procedures and to run alternative and improved scenarios.

Med-Surgical Unit

Unit Overview

The *Med-Surgical Unit* is a general care unit that accommodates adults after they are transferred from other critical care units and are in a more stable condition. There are 30 beds in this unit: nine rooms with 2 beds; one room with 4 beds and a nursing station of its own (named *cluster* room); and eight rooms with one bed. There is one nurse always monitoring the cluster room patients, as they may need more supervision. There is a four-to-one patient-to-nurse ratio for the cluster room patients. For the rest of the unit this ratio increases to six-to-one. In terms of staffing and personnel, this unit has seven nurses and a nursing director (head nurse) during the day shift and six nurses and one head nurse during the evening and night shifts, three critical care technicians (CCT) and one unit clerk.

As shown in the flowchart below, there is a hierarchy of personnel based on which they are used during the evacuation process. There are typically three types of patients within this unit. About sixty-five percent of them are considered ambulatory and in case of an emergency they would be able to walk without help. They will be gathered and guided by a nurse or technician, whoever is available, and moved two floors down and either stay there or move to another location, based on the circumstances. The remaining thirty-five percent are divided between *minimal assistance* and *maximal assistance* patients. The former ones could be moved out using wheelchairs because they do not have any devices attached to them, and the latter ones need to be transferred on their beds because they are attached to IV poles or they may not be able to walk or able to sit on a chair. The patients in the cluster room also are considered maximal assistance and they are under continuous surveillance. When creating the simulation for this floors evacuation, all of these particular needs of these different patients will have to be addressed.

Med-Surgical Floor (Adult Unit) Assumptions

Staffing:

- Nurses, Technicians, Unit Clerk
- Extra nurses, volunteers, medical and nursing students may arrive after a certain amount of time.

4 Types of patients (Max. 30):

1. Ambulatory: move on their own in groups using stairs
2. Minimally assisted: moved on a wheelchair with one helper
3. Maximally assisted and cluster: moved on their beds with two helpers and they may need oxygen.
4. The last 3 types use elevators.

Med-Surgical Floor (Adult Unit) – Input variables

The following nominal values are provided by Robert Wood Johnson University Hospital:

– # Ambulatory patients	(9)
– # Minimum Assist	(6)
– # Max_assist	(8)
– # Cluster	(4)
– # Nurses	(8)
– # CCT	(3)
– # Non-medical	(1)
– # Extra nurse	(5 after 10 min.)
– # Volunteers	(5 after 5 min.)
– # Nursing_students	(5 after 10 min.)
– # Medical_students	(0)
– Safe_Distance	(Distance from safe location)
– Speeds for different types of patients	

Med-Surgical Input Variables Defined

While creating these models, the Rutgers team needed to address these different types of patients and the different types of challenges they present during an evacuation. Although ambulatory patients can walk on their own during an evacuation, at least one clinical technician is needed to guide the patients to the safe location. Minimal assistance patients, on the other hand, must be transported by wheelchairs (or any other rolling chairs available) and moved by a family member (if available) or at least one non-medical personnel. It must be considered that although family members may assist their own family patient, they may not assist other patients. The estimated time to prepare a minimal assistance patient is two to three minutes[1]. This time does not include any movement out of the unit. A maximal assistance patient, similar to a minimal assistance patient, would be transported by a wheelchair yet needs at least two persons to transport him/her to the safe location. The time to prepare a maximal assistance to evacuate would be two to three minutes[1]. A maximal assistance patient from the cluster room needs at least one nurse and at least on non-medical personnel to move him/her during an evacuation. Remaining maximal assistance patients need at least one clinical technician and one, non-medical personnel (per patient) to transport them during an evacuation. Some maximal assistance patients may need oxygen tanks to accompany them during transportation.

The acquisition of oxygen tanks presents another constraint during evacuation. In the instance where the unit is caring for twelve maximal assistance patients, all of which require oxygen, the time to obtain twelve oxygen tanks could take up to thirty minutes[1]. There are two possible strategies that could be used to execute the evacuation of maximal assistance patients that are dependent on oxygen. In the first strategy, if nurses are waiting for the arrival of all the tanks, the unit staff would evacuate the patients that are most dependent on oxygen after all other; less oxygen dependent, maximal assistance patients have been evacuated. In the second strategy, nurses may move the maximal assistance patients that require oxygen as the tanks arrive. In this case, the patients that are most dependent on oxygen would be evacuated before all other, less oxygen dependent, maximal assistance patients. Once oxygen tanks have been requested, any patient left in the unit that is waiting for the arrival of a tank would be evacuated if the oxygen does not arrive within ten minutes. All of these scenarios were included in the programming of the RWJUH simulation models.

Med-Surgical Evacuation Flowchart

Med-Surge is located on the fifth floor of one the buildings of the hospital complex, the *Tower Building* and is the only unit on that floor. This unit does not horizontally connect to other facilities or buildings, thereby limiting means of egress and making the efficient vertical evacuation

[1] Time estimate given by the Nursing Director of the Adult Unit

of patients so critical. In case of emergency, vertical evacuation is performed first. The hospital staff will take the patients by elevators to the lowest level allowed. The patients are then moved horizontally across the hospital to the designated safe location. There are 2 sets of fire doors that can contain fire when closed and divide the floor in half. The unit utilizes six elevators of the Tower Building for transportation to and from the unit.

The ambulatory patients would be evacuated using the stairs in order to leave the elevators free for the other two types. During an evacuation, they would be gathered and guided by a nurse or technician, whoever is available. They are then moved two floors down and would either stay there or move to another location, based on the circumstances. The other non-ambulatory patients will be moved via elevators to the designated safe location. RWJUH has designated the atrium as its "safe location" for our simulation modeling however, this "safe location" could be any location that the emergency control officer assigns. Once at the safe location, the unit manager or head nurse would try to maintain the standard patient to nurse ratio. At minimum, one nurse must be with cluster room patients and another nurse with the remaining maximal assistance patients during an evacuation. One nurse or CCT is assigned to ambulatory patients and one nurse is needed to care the minimal assistance patients.

There are certain rules that need to be followed as much as possible during an emergency evacuation. On the other hand, there are several constraints that affect the evacuation strategies of this unit. The Tower Building is amongst the oldest buildings of RWJUH and does not feature a sprinkler system. Thus, a fast and efficient method of evacuating Adult Unit patients becomes even more crucial to securing patient and staff safety.

Figure 1 shows the flowchart made for *Med-Surgical Floor* (internally known as *Adults Unit* or *5 tower*). As it shows, the evacuation process starts when there is an emergency situation and the staff is required by a higher-level authority to evacuate the unit and transfer all the patients and staff, to the safe location.

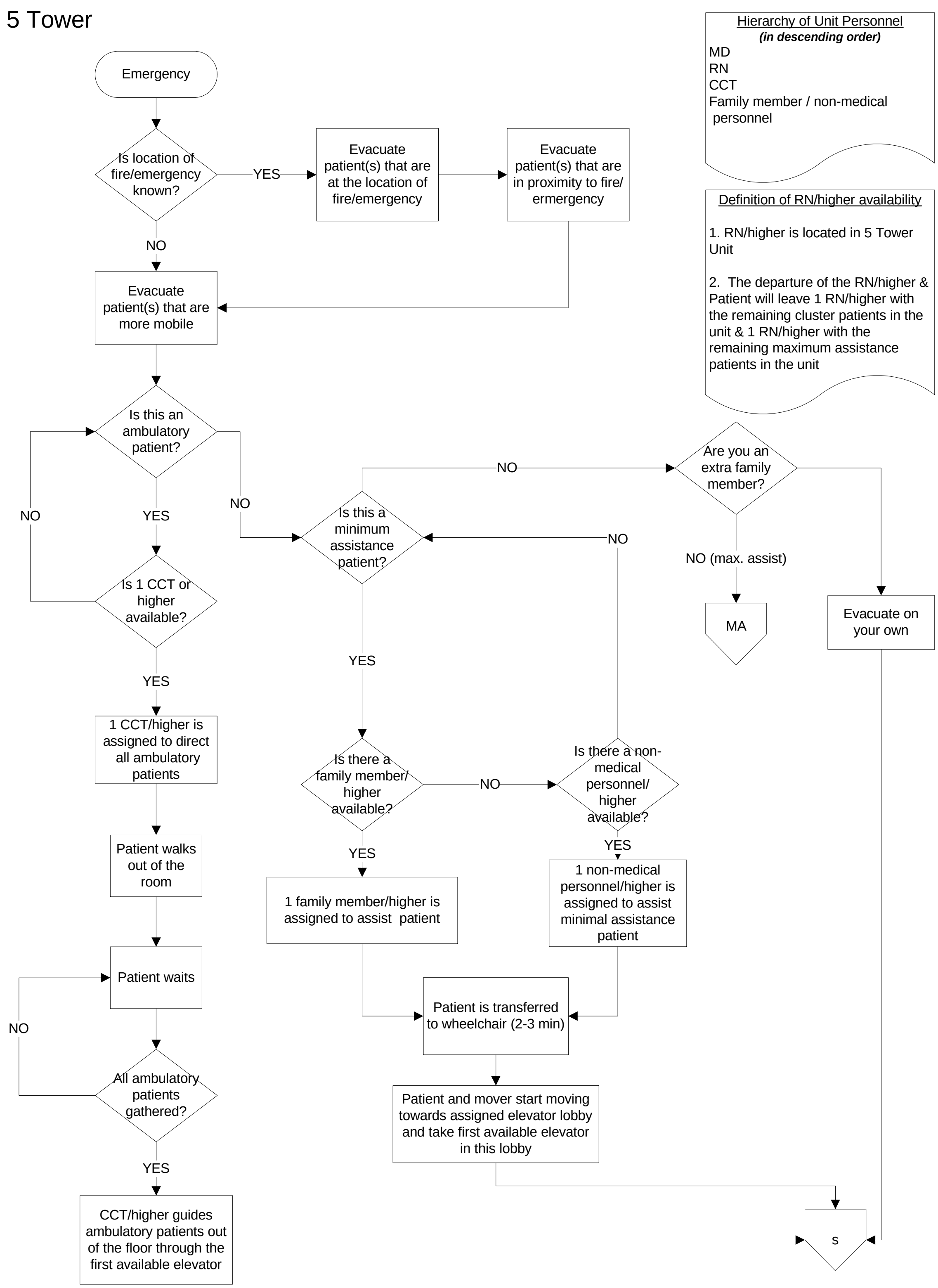

Figure 1:Process Flowchart for Evacuation Procedure for Adults Unit (5 Tower)

5 Tower

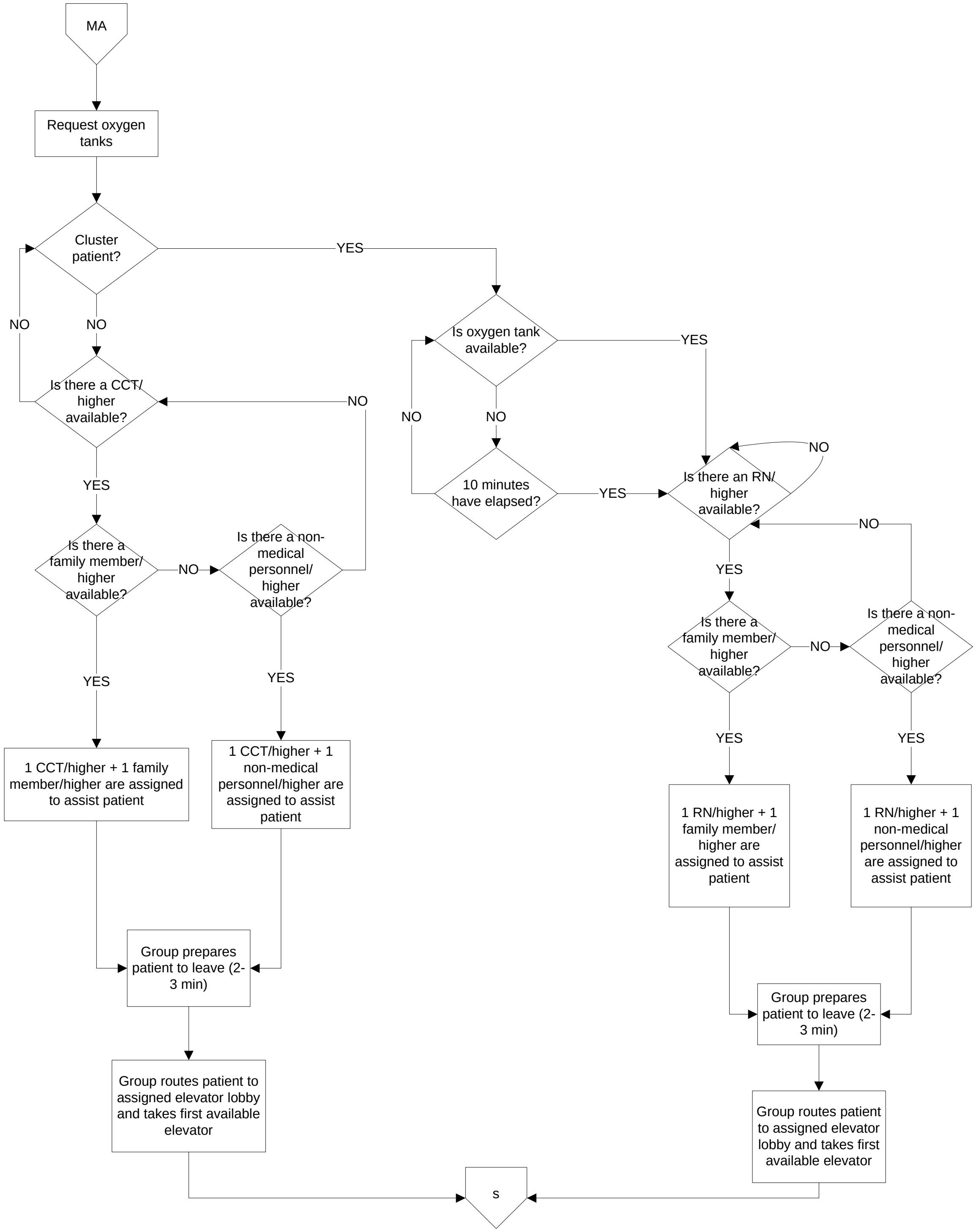

Figure 1: continued.

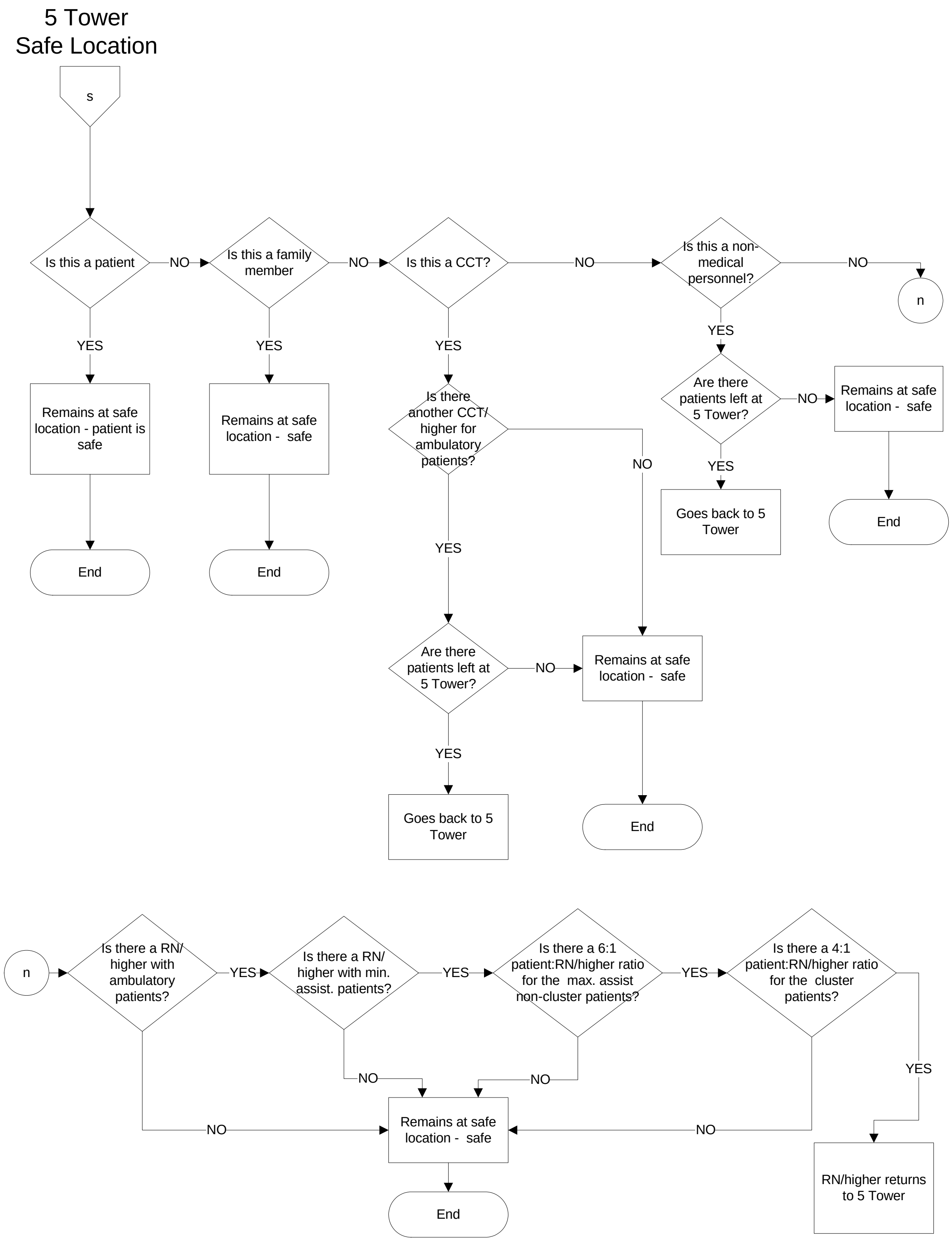

Figure 1: continued.

Adult Unit (5 Tower) Simulation Experiment and Synopsis of Results

The table below illustrates evacuation times as a function of number of extra nurses arriving at different times.

Table 1: Effect of Extra Nurses on Evacuation Times (5 Tower)

	Time of Availability (min)				
Extra Nurses	0	5	10	15	20
0	72.87	72.87	72.87	72.87	72.87
5	48.58	48.58	47.89	52.81	55.75
10	43.47	43.47	42.68	43.06	46.75
15	34.76	34.76	35.45	40.07	43.68

The table below illustrates evacuation times as a function of number of nurses and volunteers. The Rutgers team has concluded that the evacuation time cannot be decreased beyond 35 minutes regardless of number of nurses and volunteers.

Table 2: Effect of Number of Nurses & Volunteers on Evacuation Times (5 Tower)

	Volunteers			
Nurses	0	5	10	15
8	72.871406	62.51699	60.04883	60.04883
10	60.578868	49.08797	48.32655	48.32655
12	49.015158	46.58942	46.11457	46.11457
13	48.576498	44.85867	42.75501	42.75501
15	46.092162	38.04737	35.44688	35.44688
17	44.802783	34.75036	35.44688	35.44688
20	37.624406	34.83114	34.77493	35.19944
22	34.764669	34.83114	34.77493	35.19944
24	34.764669	34.83114	34.77493	35.19944

Note: Additional Staff arrive after 5 minutes

Based on the above and several other simulation experiments that the Rutgers team has conducted, it is shown that the number and availability of nurses are the two most significant factors in the evacuation time. Hence, we provide the following synopsis of results:

- The number of nurses seems to be the most significant factor towards evacuation time.
- The availability (in terms of time) of nurses influences the response time.
- Elevators are not bottlenecks (if all six are working properly).

Pediatrics Unit (Little Peds)

Pediatrics Unit Overview

Located on the second floor of the 1958 building, the "*Little Peds*" unit is occupied by children up to the age of eleven. This unit is U-shaped and can accommodate fourteen medical and surgical infants, toddlers, and school aged children. Ten rooms are private patient rooms and can have either one bed or one crib, depending on the age of the patient. Two rooms are double patient rooms with either two beds or two cribs, once again, based on the age of patients. On average, the unit cares for five infants, six toddlers, and three school-aged during a given time. Patients in this unit may need oxygen, IVs, feeding tubes and dialysis. The staffing of the unit includes four nurses, one clinical technician, one unit clerk, two to three child life specialists, and three residents. The unit does not maintain a patient to nurse ratio. Family members are often present with most patients.

Pediatrics Assumptions

Unit Breakdown:	14 total Patients 10 single-bed rooms 2 double-bed rooms
On average:	5 infants 6 toddlers 3 school age children

If available, family members can assist in the evacuation of infants and toddlers. Groups of 4 children can be evacuated in one crib. Volunteers may arrive after a certain amount of time to assist with an evacuation. In this scenario, once medical staff leaves this unit, they do not return from the safe location.

Pediatrics – Input Variables

The following nominal values are provided by Robert Wood Johnson University Hospital:

– Number of RNs	(4)
–Number of CCTs	(1)
–Number of Residents	(3)
–Number of Unit Clerks	(1)
–Number of Child life Specialists	(2)
–Number of Volunteers	(2)
–Number of Oxygen tanks	(2)
–Number of Wheelchairs	(5)
–Speed inside the unite (ft/sec)	(1.76)
–Speed outside the unite (ft/sec)	(4.62)
–Total patient	(14)
–Percent of family member	(0.75)

Pediatrics Input Variables Defined

With the offset of an alarm, the unit staff would convene at the nursing station to assign roles to unit personnel in order to carry out this unit's evacuation. The estimated time to convene and designate responsibilities to unit staff is ten to fifteen minutes[1].

The time to prepare each infant for evacuation is three to five minutes[2]. The estimation does not include any movement out of the unit. Toddlers may be evacuated in the same manner, although toddlers and infants may not be placed in cribs together. Again, at least one medical personnel or one child life specialist must move toddlers. The time to prepare each toddler for evacuation is three to five minutes and does not include migration from the unit[1]. Of the school-aged patients, some are able to walk, some must be moved in wheelchairs or reclining chairs (determined by availability), while others must be moved on a bed. Those that can walk require at least one non-medical personnel per child to guide them to the safe location. The time to prepare each patient to evacuate is three to five minutes and does not include movement out of the unit[3]. Those that need a wheelchair or reclining chair need at least one non-medical personnel to assist them and move them to the safe location. The time to prepare the patient for evacuation is again three to five minutes[1]. Unlike the other school-aged patients, those that must be moved in a bed require at least two non-medical personnel to assist them and move them to the safe location. The preparation time, not including migration from the unit, is once again three to five minutes[1].

Pediatrics Evacuation Flowchart

There are two sets of elevators, which can be used by the unit staff. Three elevators make up the first set and are located in the center of the unit. Pushing a button to open the automatic glass doors can access the entrance to the elevators from this unit. It must be noted that entrance to the unit from the elevators requires card-swipe access. The four elevators that service the 1958 Building, located directly outside the unit, make up the second set. The unit was not physically part of the Children's Hospital at the time it was being surveyed, but will eventually relocate to that new section of the hospital. The unit is adjacent to the OB (infant/newborn) unit, which is adjacent to the adolescent unit.

[1] Time estimate given by the Nursing Director of the Pediatrics Unit
[2] Time estimate given by the Nursing Director of the Pediatrics Unit.
[3] Time estimate given by the Nursing Director of the Pediatrics Unit

The teen lounge and hallways of the adolescent unit may be used to place relocated “Little Peds” patients. The Children’s Hospital, however, is located on the ground floor, thereby making the use of elevators or stairs necessary during an evacuation. Infants and toddlers carried by their family members as well as mobile school-aged patients would be utilizing the staircase. Family members may assist their own family patients but not the other patients. Elevators that lead to the Children’s Hospital include the three elevators located in the center of the unit, the four elevators of the 1958 Building and even the four elevators of the Tower Building adjacently located to the 1958 Building.

In the proposed model of evacuation procedure of the pediatrics unit, the staff would attempt to execute the evacuation of the different types of patient in parallel. This means that there is no priority among patients during an evacuation. However, if the unit finds such an evacuation procedure impossible (i.e. not enough resources), mobile patients would be gathered and evacuated first, followed by infants and toddlers. If the location of the emergency event is within a patient room, the patient within the room would be evacuated first, followed by patients in proximity to the room of danger.

Once personnel have left the unit, they do not return from the “safe location”. As with the other three units, this unit also faces its own constraints to consider during evacuation. Other than oxygen, all equipment can be unhooked and left behind in the event of an emergency. Any type of patient (infant, toddler, or school aged child) could require oxygen. However, those that need oxygen must wait for the supply tanks to arrive. Once additional oxygen tanks have been requested, if oxygen does not arrive by the time that all other patients have been evacuated from the unit, all oxygen dependent patients left in the unit will be evacuated without the oxygen tanks. Their own family members if available may carry out infants. Another method of evacuating infant patients is to move one infant crib into the hallway and to relocate additional infants into the central crib. One crib may hold up to four infants at one time. At least one medical personnel or one child life specialist must move infants.

Little Peds unit does not have a predefined area to relocate patients to during an evacuation. Possible “safe locations” are the adolescent unit and the Children’s Hospital (perhaps the lobby). One must pass through the OB unit in order to arrive at the adolescent unit. Advantageously, the adolescent unit is located on the same floor, so the use of elevators is not needed.

Besides the constraints that result from the needs of different patient types, the areas of and means of egress to possible “safe locations” present additional challenges. For example, in order to arrive to the adolescent unit, one must pass through the OB unit. The doors to the OB unit however cannot be opened for the “Little Peds” unit without swipe-card access. Thus, in the event of an emergency evacuation, these doors must be unlocked and remain unlocked in order to provide a continual means of egress out of the “Little Peds” unit. If the central elevators are to be used in an evacuation, there must be a manner to secure the automatic glass doors open in order to expedite the evacuation process. Figure 2 illustrates the evacuation process.

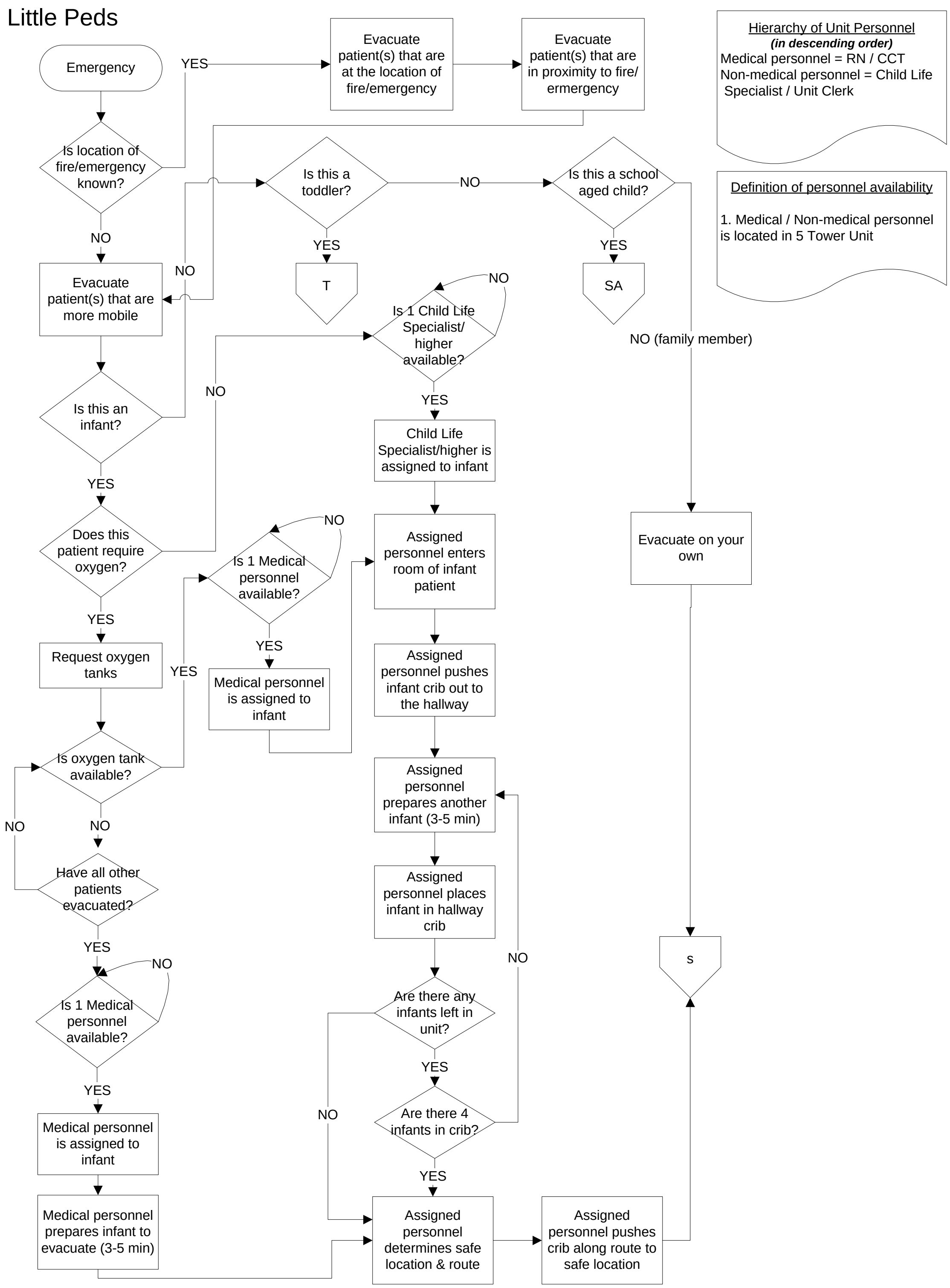

Figure 2: Process Flowchart for Evacuation Procedure in *Little Peds* Unit

Little Peds

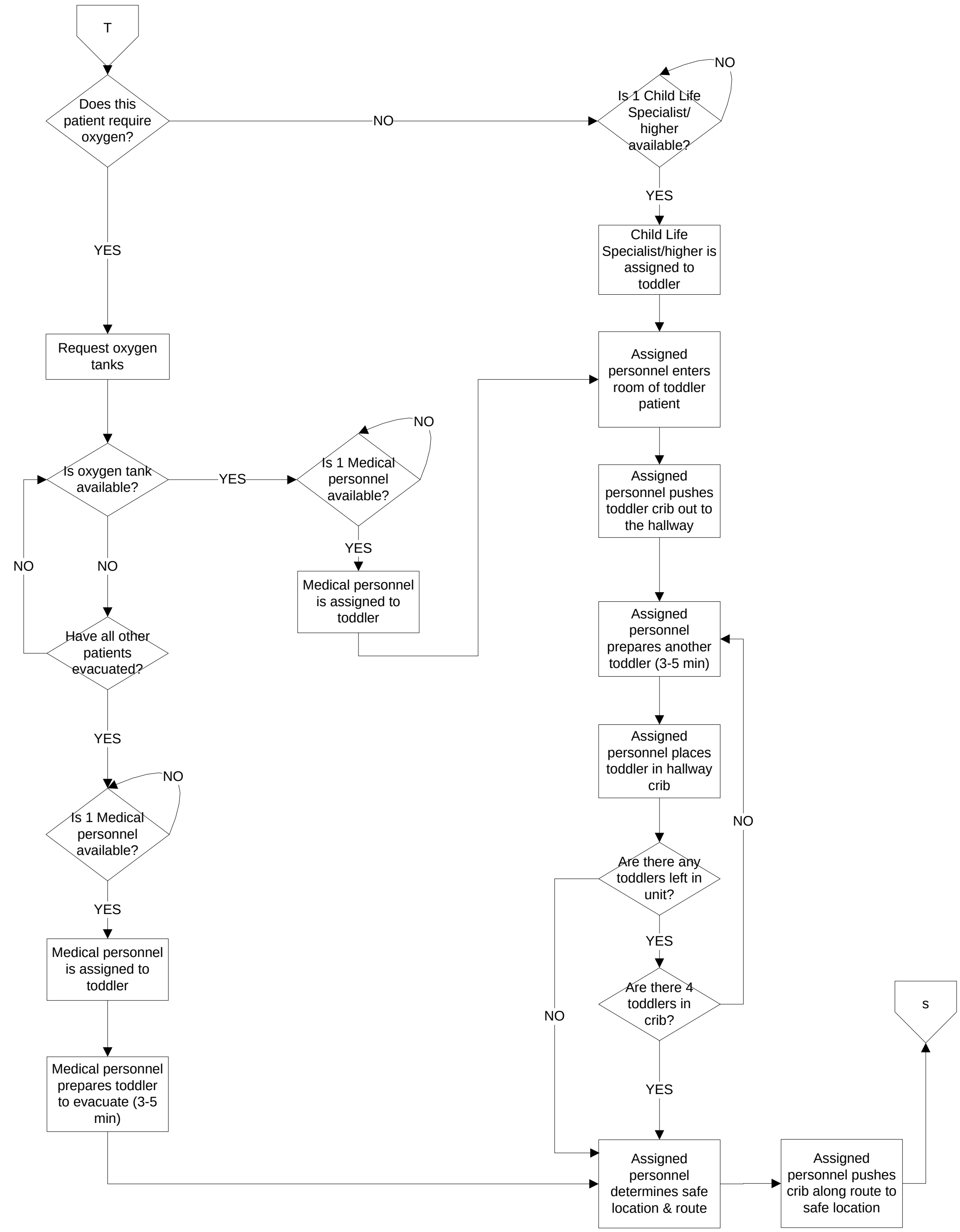

Figure 2: Continued

Little Peds

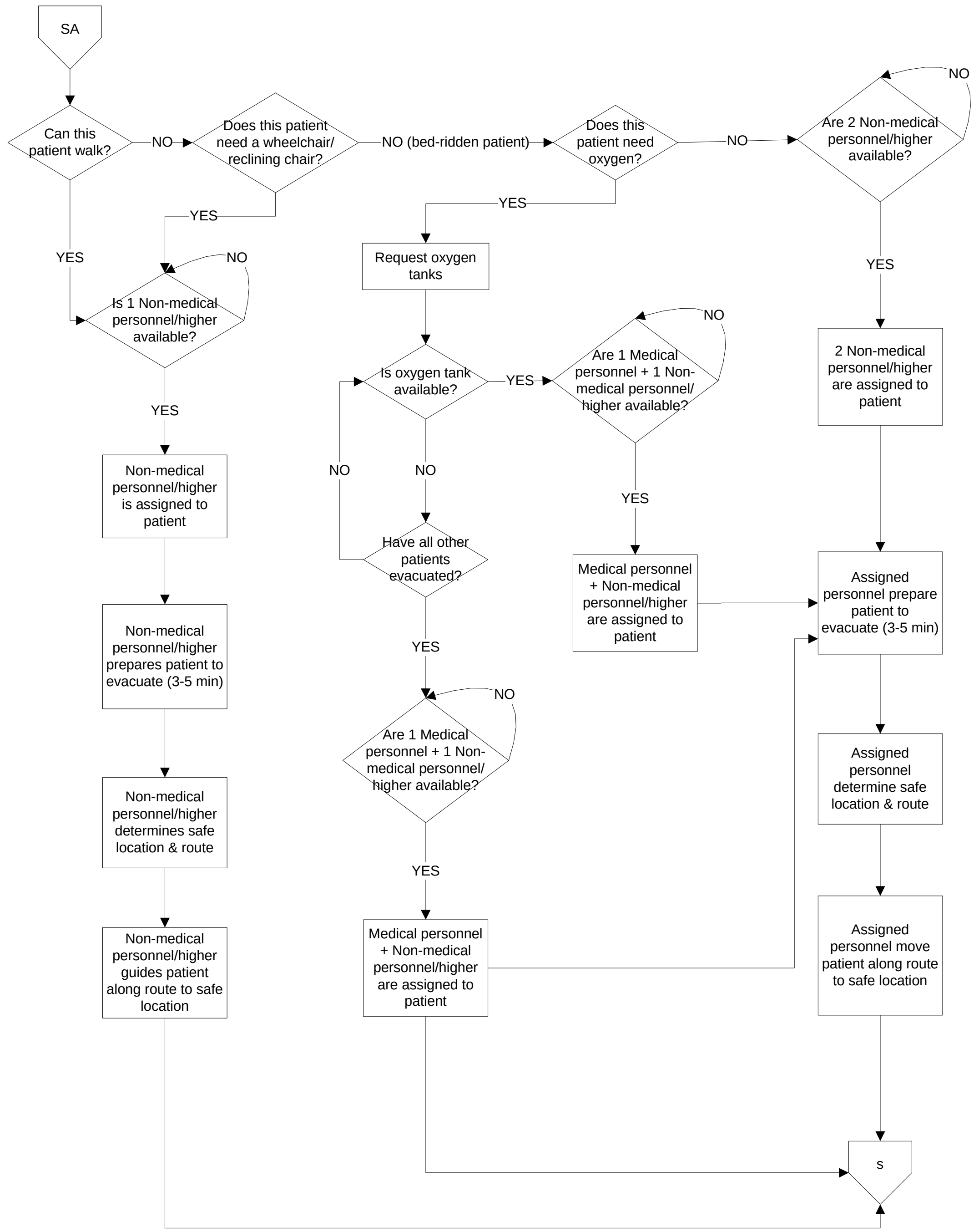

Fig. 2) Continued

Safe Location
Little Peds

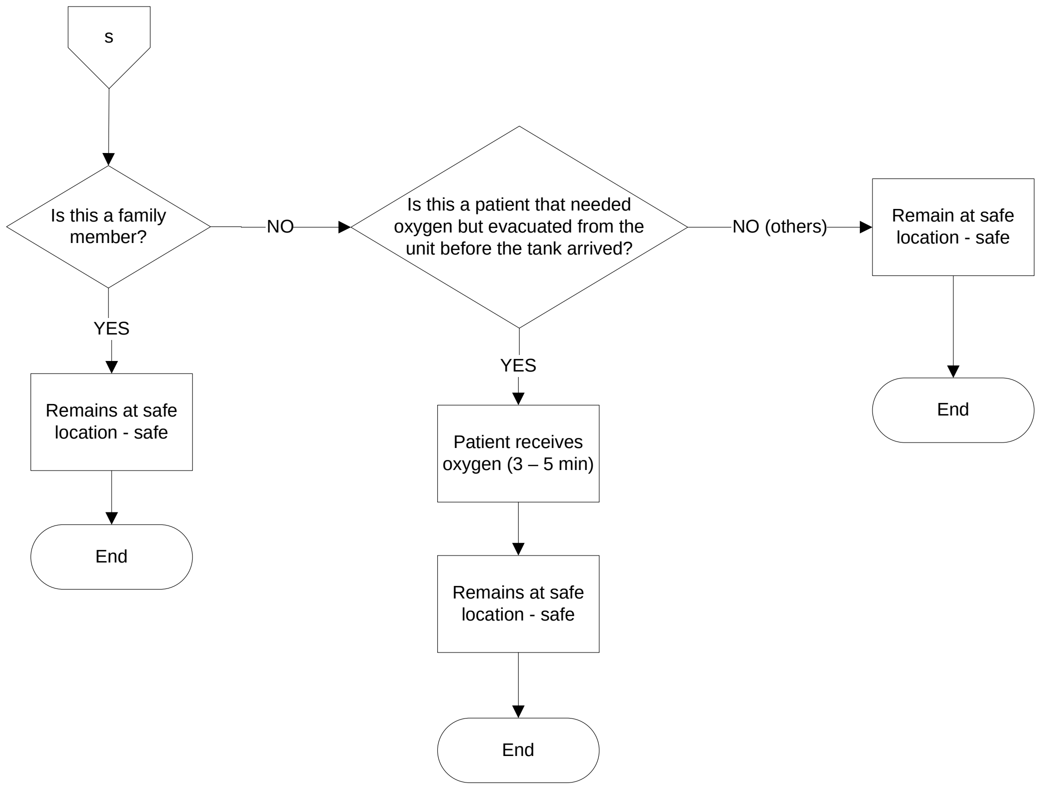

Fig. 2) Continued

Pediatrics Simulation Experiment and Synopsis of results

If an evacuation was to be carried out using both the elevators and stairs, a division of the unit may result. For instance, patients evacuated through the elevators of the 1958 Building and patients evacuated through the stairs located in the unit, are not led to the same locations. Overall, the Pediatrics unit is limited in possible “safe locations” and must travel a distance to arrive at “safe” areas apart from the unit.

The following synopsis of results can be made:

1. The # of volunteers and their arrival time does not significantly influence the response time, since there are enough staff members to move out all the patients.
2. The evacuation time significantly depends on the number of patients who need oxygen.
3. As the percentage of patients requiring oxygen tanks increases from 25% to 70% the evacuation time for 14 patients increases from 42.56 to 63.02 minutes, respectively.

4. The higher the percentage of family members, the lower the evacuation time would be.

5. When the total # of patients increases from 6 to 14, the evacuation time increases from 22.19 to 46.56 minutes.

Table 3: The Effect of Volunteers on Evacuation Times in Little Peds

# of volunteers	Arrival of volunteers	#of oxygen tanks	# of Wheelchairs	total patients	% family members	% school age patients who need wheelchairs	% patients who need oxygen	Time
2	10	2	5	6	0.75	0.5	0.25	22:19
2	10	2	5	8	0.75	0.5	0.25	27:19
2	10	2	5	10	0.75	0.5	0.25	33:52
2	10	2	5	12	0.75	0.5	0.25	38:17
2	10	2	5	14	0.75	0.5	0.25	46:56

Surgical Intensive Care Unit (SICU-West)

SICU-West Overview

In many ways, the SICU West parallels the MICU and CCU units examined by the 2003 Rutgers group. The SICU West is one of three sub-units that make up the Surgical Intensive Care Unit (SICU) and cares for trauma, post-surgical, and neurosurgical patients. The unit is located on the ground floor, eliminating the need for elevators during an evacuation. SICU West is U-shaped with a central nurse station and can accommodate up to ten patients.

The patients are non-ambulatory and rely on several biomedical devices that must be moved with them in the instance of an emergency evacuation. IV poles, portable monitors, portable ventilators (which are limited in number and have limited battery capacities), and patient charts are just some examples of the mechanisms that must accompany patients.

Staffing for SICU West includes six registered nurses, one nursing director, one technician, and one secretary, one respiratory therapist and one to two residents. The nursing director may sometimes be included in the count of six registered nurses and the respiratory therapist and residents may not always be stationed at the unit. Thus, there may be anywhere from eight to twelve personnel available during a given time for the unit's evacuation. The patient to nurse ratio is often two to one, although it could be reduced to a one to one ratio based on patient acuity.

SICU West Assumptions

Staffing: Doctors, Nurses, Technicians, Unit Clerk, Respiratory Therapist

Patients, 2 types:

Stable: may or may not need oxygen (probabilistic)
Unstable: always need oxygen

Other resources:

Portable monitors
Oxygen tanks

Head nurse is the last one to go out.
Stable patients do not need RT.
Monitors should be provided at the safe location.
Portable monitors are carried back to the unit to be used again.
There are enough oxygen regulators available.
Request will be sent if there is no oxygen tank available.
At least two nurses are required to stay at the safe location.

SICU West – Input Variables

The following nominal values are provided by Robert Wood Johnson University Hospital:

- Oxygen tanks (4)
- Portable monitors (3)
- Nurses (6)
- Technicians (1)
- Respiratory therapists (1)

- Patients (10)
- Secretary (1 fixed)
- Doctors (2)

SICU West - Input Variables Defined

In this case, first the model was run for different values of input variables, assuming that the unit could have more respiratory therapists available. This may not be a highly valid assumption as most of the time there is only one RT available who shares his time between this unit and other units. But this will give us an idea of how the evacuation time may be affected by the number of available respiratory therapists. After observing the effect of changes in the value of input variables on the response time, the important variables are identified and applied to a second version of the model. In this case, the model was run assuming that there are two RTs such that one of them stays at the unit and the other one stays at the safe location. This way, none of them needs to travel back and forth with the patients between unit and the safe location.

SICU West - Evacuation Flowchart

Figure 3 shows the process flowchart of the evacuation procedure in the western part of the surgical intensive care unit. The SICU West does not have predefined locations for which to relocate to during an evacuation. The unit should relocate horizontally in the event of an evacuation. Possible areas that may serve as "safe locations" include the courtyard and the Children's Hospital. The amount of time to migrate to the courtyard may be two to three minutes while the time to travel to the Children's Hospital may be ten minutes[1]. The route of egress though the back exit of the SICU West which leads to the SICU Core may not be practical, for the SICU Core houses its own critical care patients. For this reason, the front (main) entrance of the SICU West may be the most effective exit to use during an evacuation (assuming that the entrance itself is not blockaded). In the event that the SICU West must be evacuated, less critical patients are to be evacuated first. If a fire occurs within a patient room, that patient is evacuated first, followed by patients in proximity to the room of danger, then less critical patients, and lastly the most critical patients.

There are several constraints for the SICU West that must be considered during an evacuation. For our purposes, eighty to ninety percent of SICU West patients may be considered bed-ridden during an evacuation, while wheelchairs may transport the remaining twenty to ten

[1] Time estimates given by the Head Nurse of the SICU West

percent of patients. Furthermore, patients may be classified as either “stable” or “unstable.” Moreover, “stable” patients either may or may not require oxygen during an evacuation. The estimated time to prepare a “stable” patient to evacuate is five to six minutes[1]. This does not include any movement out of the unit; the estimation includes simply the time that all personnel are present in the patient’s room to the time the patient is ready to be moved. The patients must be moved in their beds along with their necessary biomedical devices. For this reason, three personnel are needed for the evacuation of one “stable” patient. Of these, one must be a nurse, preferably a respiratory therapist, while the remaining two must be at least clinical technicians. Once at the safe location, one nurse must remain with the patient to re-stabilize him/her; the time to re-stabilize a patient is three to five minutes. “Unstable” patients require oxygen during transportation and may need ten to twelve minutes to prepare for evacuation[1]. This estimate does not include the time needed to request oxygen tanks and the waiting period of their acquisition. Once again, the estimated time of ten to twelve minutes does not include any movement out of the unit. These patients require three personnel to prepare them for evacuation, one of which must be a respiratory therapist, a nurse, and at least one additional clinical technician. At the safe location, one respiratory therapist and one nurse must remain with the patient to re-stabilize him/her; the time to re-stabilize a patient is ten to twelve minutes[1].

The nurse that accompanies the first patient to the safe location, regardless of the type of patient, must not be left to care for the patient alone. Thus, two personnel (only one of which must be a nurse) must be present at the safe location with the first evacuated SICU West patient. After the evacuation of the first patient at the safe location, a patient to nurse ratio of two to one would try to be maintained for “stable” patients, while a patient to nurse ratio of one to one would try to be maintained for “unstable” patients. The availability of power at the safe location (for the SICU West the designated location is the courtyard) is another constraint for the evacuation of the unit. On average, each patient would need one to two power strips to sustain their necessary life support equipment. The SICU West does not have twenty power strips on hand in the unit in case of an emergency evacuation. Furthermore, existing electrical outlets in the courtyard are limited and there are no red emergency outlets available in the area. Additional limitations to the courtyard include no running water and sinks, no trashcans for the disposal of clean waste and medical waste, and a lack of infection and sanitary control within the vicinity. From these observations, it is evident that shortages in staffing and resources would arise during an evacuation of the SICU West.

[1] Time estimates given by the Head Nurse of the SICU West

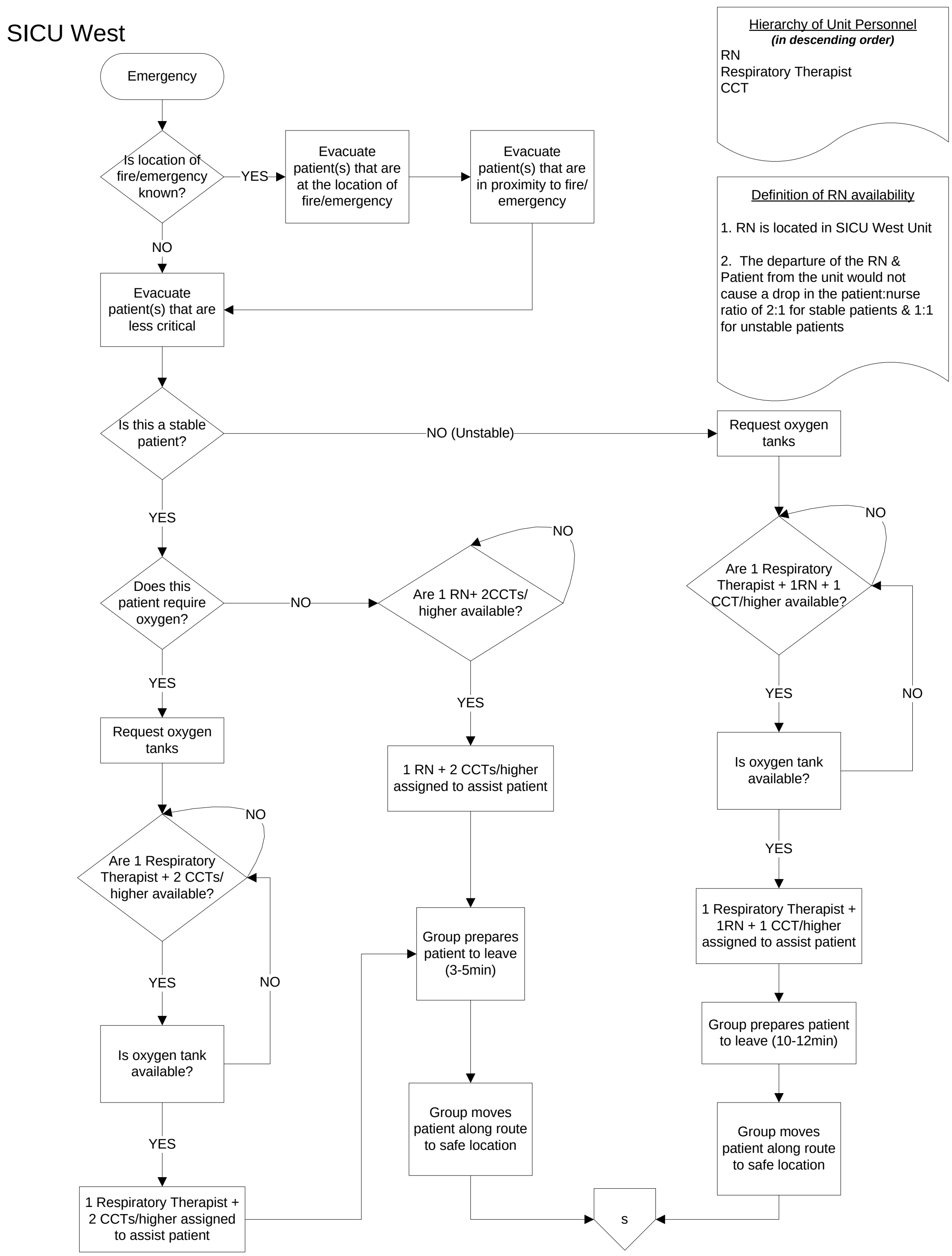

Figure 3: Process Flowchart of Evacuation Process in SICU-West

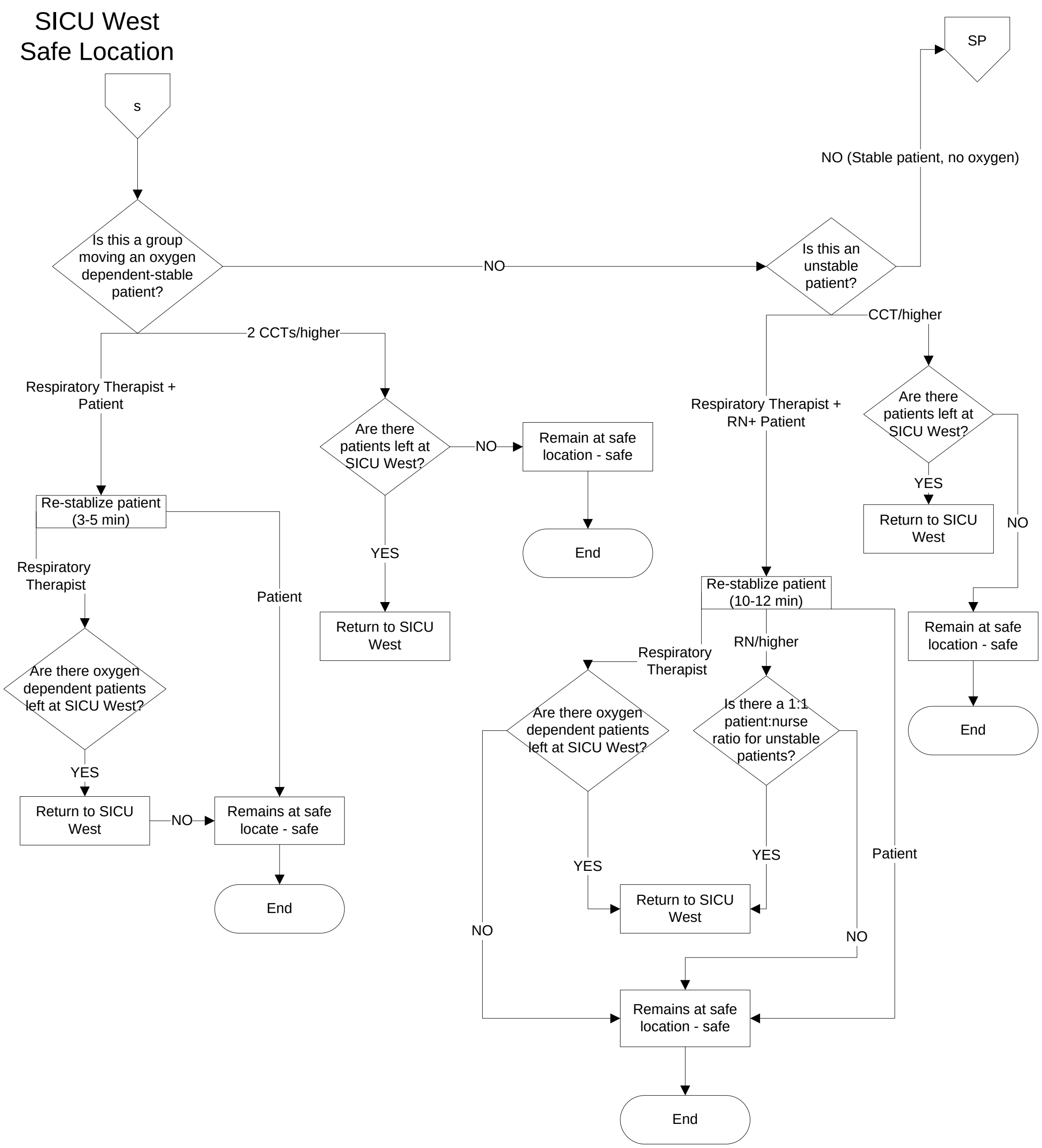

Figure 3: Continued

SICU West
Safe Location

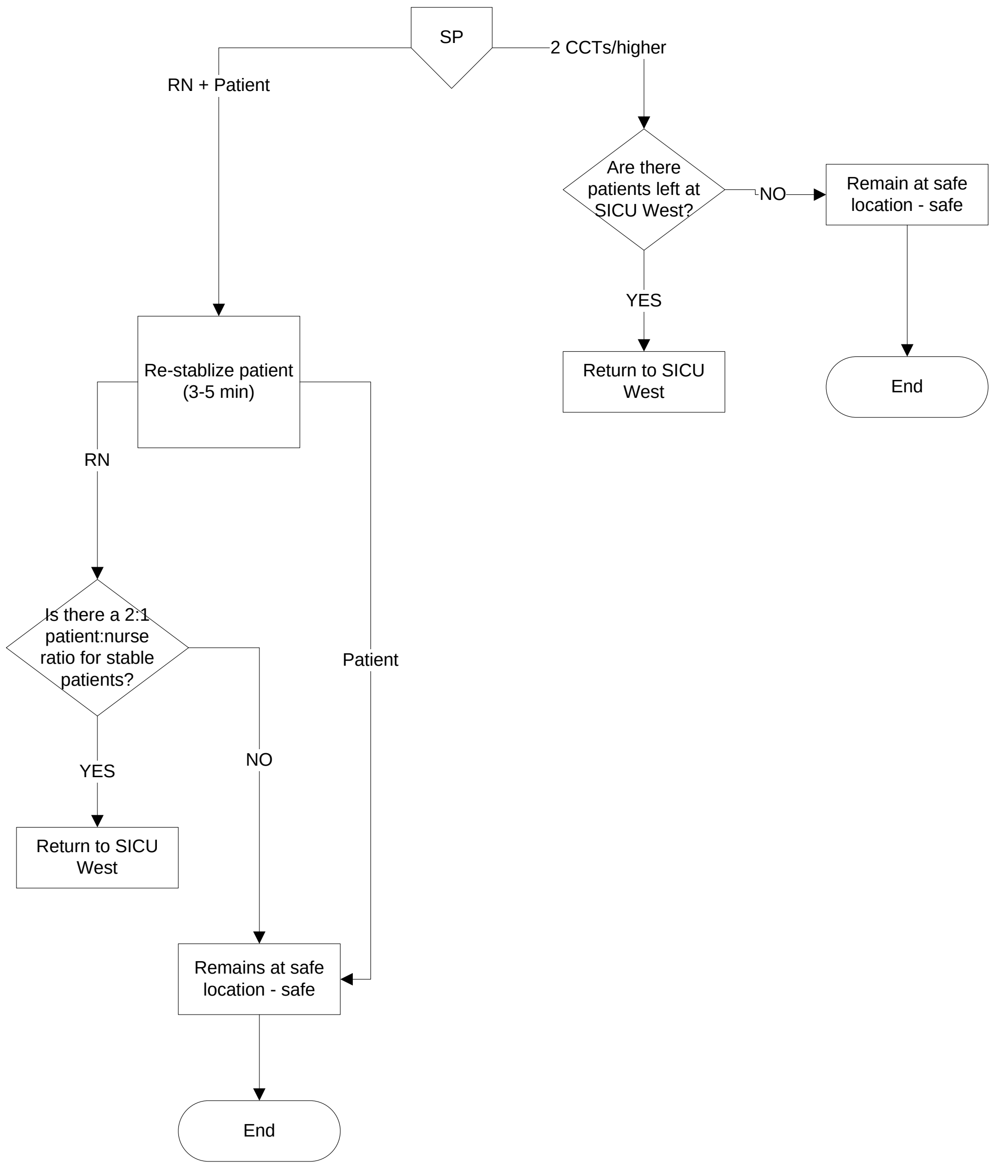

Figure 3: Continued

SICU West – Simulation of Experiment and Synopsis of Results

The table shown below is the worst-case scenario. This is the current situation of the SICU west unit. It takes about 139 minutes to evacuate the unit given the values of other input variables. In this particular case, the respiratory therapist (RT) is traveling with the patients. If the floor were staffed with 4 RT(s), the evacuation time would reduce to 65 minutes.

We see that if there is only one RT, increasing the number of technicians from 1 to 9, will reduce the evacuation time to 119 minutes, which is still not acceptable. Therefore, we observe that the number of available therapists has a great impact on the evacuation time and hence, this is the most important input variable. The number of available portable monitors is another important input variable. These monitors are moved with the patients and are returned to the unit after the patient has been delivered to the nurses at the safe location.

#oxygen tanks	#monitors	#nurses	#techs	#therapists	#patients	time(min)	Input
4	3	6	1	1	10	138.92	worst-case scenario (base)
4	3	6	1	4	10	65.81	Adding more RTs
4	3	6	9	1	10	119.	Adding more technicians(movers)
6	5	8	9	6	10	35.35	Best case scenario (in case they can have more RTs). Having more RTs is a less likely scenario then having more nurses or technicians.
10	4	8	8	1	10	39	More nurses, 2 RTs one staying at the unit the other at the safe location.
10	3	6	1	1	10	61.72	Less portable monitors, 2 RTs
10	4	6	8	1	10	40.56	Regular staffing, 2 RTs
4	3	6	1	1	10	65.41	Less Oxygen tanks, 2 RTs

Table 4: Selected Results of SICU West Runs

The second half of table 4 shows the selected results for the improved model. In this case, we assume that there is always one therapist staying at the unit. The best scenario happens when we have 10 oxygen tanks, 8 nurses, 8 technicians, and 4 portable monitors, which takes 39 minutes to evacuate 10 patients. If there are fewer monitors, the time increases to 61 minutes. If there were also fewer oxygen tanks, the evacuation time would be about 65 minutes. The number of movers and nurses are also important factors affecting the total evacuation time.

The following synopsis of results can be made:

- The base case result is 138.92 min.
- It seems that the # of RT's available at the unit, is the most significant factor.
- Adding more RT's will reduce the evacuation time.

    - With 4 RT’s the evacuation time reduces to 65.58 min.
    - Other variables do not effect the evacuation time considerably.
    - If only one RT available, adding more technicians (movers) will reduce the time to 119.08 min. (still high!).
    - Best-case scenario: 35.35 min. with 6 oxygen tanks, 5 portable monitors, 8 nurses, and 9 technicians, 6 RT’s.

The unit response can be considerably improved if one RT was positioned at the safe location. The following synopsis of results of the “Improved Model” can be made:

- If one RT could be present all time at the safe location, then the one at the unit need not to move with the patient.
- Dramatic reduction in the evacuation time:
    - 65.41 min. with 4 oxygen tanks, 3 portable monitors, 6 nurses, 1 technician, 1 RT (staying)

The Best case:

- 39 min. with 10 oxygen tanks, 4 portable monitors, 8 nurses, 8 technicians, 1 RT

By providing 1 RT at the safe location and using more resources, the evacuation time is reduced significantly.

Emergency Department (ED)

Overview

The Emergency Department is made up of three facilities: the North building, the Acute Services Building and the Core Pavilion. Up to two hundred patients can be serviced in the ED daily, sixty percent of which are ambulatory. Generally all patients begin in the triage room of the North building, unless a patient is brought to the ED by way of an ambulance. After examination by a triage nurse, patients are either discharged or admitted to one of three other areas within the ED: non-urgent care, urgent care, or emergent care (which includes the shock/trauma unit). Non-urgent patients are typically considered as ambulatory. There are eight available treatment areas within non-urgent care, though each area may accommodate more than one patient. The maximum capacity of the non-urgent care area is fifteen patients.

ED Assumptions

Staffing:

Medical:	Doctors, Registered Nurses, Nursing Administrators, Head Nurses, and Physician Assistants
Movers:	technicians, family members, unit clerks

Extra nurses, volunteers, medical and nursing students and escorts may arrive after a certain amount of time.

Areas (types of patients):

1. Triage (ambulatory)
2. Non-urgent (ambulatory)
3. Urgent (80% ambulatory – 20% need one helper)
4. Emergent/Shock –Trauma (20% ambulatory – 56% need one helper, 24% need two helpers)

- Staffing is based on a schedule for different time slots during the day and the day of the week.
- The safe location is assumed to be the physical therapy unit.
- Two elevators and stairs are used.
- All ambulatory patients use the stairs and the others use the elevators.

ED Input Variables

The following nominal values are provided by Robert Wood Johnson University Hospital:

- Number of medical staff and the movers will be determined automatically based on the staffing schedule.
- Day and event time
- # triage (2)
- # non-urgent (15)
- # urgent (40)
- # emergent (50)
- Extra nurses1 (5 after 10 minutes)
- Options for extra nurses 2 and 3
- # of volunteers (5 after 5 minutes)
- Nursing students (0)
- Medical students (0)
- # escorts (0)
- Safe distance from safe location)
- Speeds of different types of patients

ED Input Variables Defined

Urgent care patients are typically ambulatory. Eighty percent of these patients may be able to move on their own, while the remaining twenty percent may need the assistance of one non-medical personnel or the use of a stretcher to relocate them to the safe location. The urgent care unit includes seventeen treatment areas, though the unit can accommodate up to forty patients. The emergent care unit treats patients that are in critical condition, only twenty percent of which are ambulatory. Thirty percent of the eighty percent that are non-ambulatory are often on stretchers and require one nurse plus an additional ancillary person for their evacuation. The estimated time to prepare to evacuate a patient on a stretcher is two to five minutes[1]. Twenty treatment areas are located within emergent care, though the unit can accommodate forty to fifty patients. The urgent and emergent care areas maintain a two to one nurse to patient ratio.

Like the SICU West, the Emergency Department also faces constraints, though different, that affect its evacuation strategies. First, the number of visitors within each unit of the ED may effect an evacuation. In the triage and non-urgent care areas, visitors are not permitted. In contrast, the urgent area allows one visitor per patient while the emergent area allows a maximum of two visitors per patient. Another point to consider during an evacuation is that patients will need assistance once moved to the safe location. One nurse is sufficient to care for triage area patients and another nurse for non-urgent area patients. Two nurses are necessary to care for urgent care patients. At the safe location, the nurse to patient ratio of two to one must be maintained for emergent care patients.

The location of fire also affects the course of ED evacuation. If the location is known, evacuations of those closest to the fire are carried out first. If the location is not known, the ambulatory and less critical patients are evacuated first followed by those that require assistance.

Staffing of the Emergency Department varies according to patient acuity and time of day based on the following schedule:

Medical Staff:

TIME OF DAY	**# Of Registered Nurses (RN's)**
7 am – 11 am	10
11 am – 3 pm	14
3 pm – 3 am	16
3 am – 7 pm	10
TIME OF DAY	**# of Nursing Administrators (NA's)**
9 am – 5 pm	3
TIME OF DAY	**# of Head Nurses (HN's)**
7 am – 3 pm	2
3 pm- 11 pm	2
11 pm- 7 am	1
TIME OF DAY	**# of Medical Doctors/Physicians Assistants**
7 am – 7 pm	2 PA's

[1] Time estimate given by the Clinical Nurse Specialist of the ED

7 pm – 7 am	1 PA
7 am – 8 am	1 MD
7 am – 5 pm	3 MD's
5 pm – 9 pm	3 MD's
9 pm – 1 am	2 MD's
1 am – 7 am	1 MD

Non-medical Staff:

TIME OF DAY	Critical Care Tech. (CCT)	Unit Clerk (UC)
7 am – 3 pm	3	1
3 pm – 11pm	3	1
11 pm- 7 am	3	1

Table 5: Emergency Department (ED) Staffing Schedule

Nurses are scheduled throughout the ED based on patient volume and time of day. Thus, the availability of hospital personnel during evacuation is dependent upon these factors.

ED Evacuation Flowchart

Figure 4 shows the process flowchart of the evacuation activities at the emergency department of Robert Wood Johnson University Hospital.

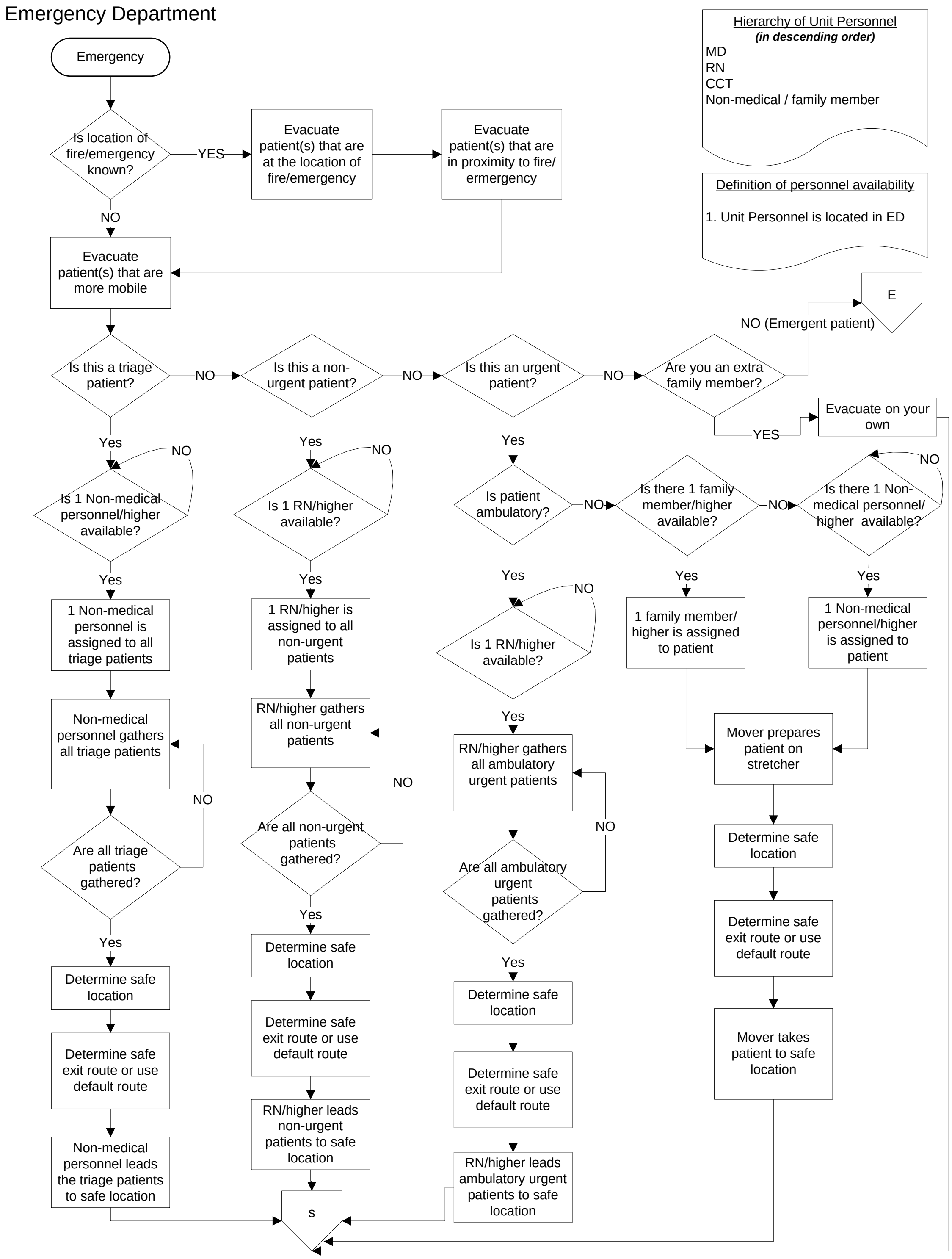

Figure 4: Process Flowchart for Evacuation Procedures for E.D.

Emergency Department

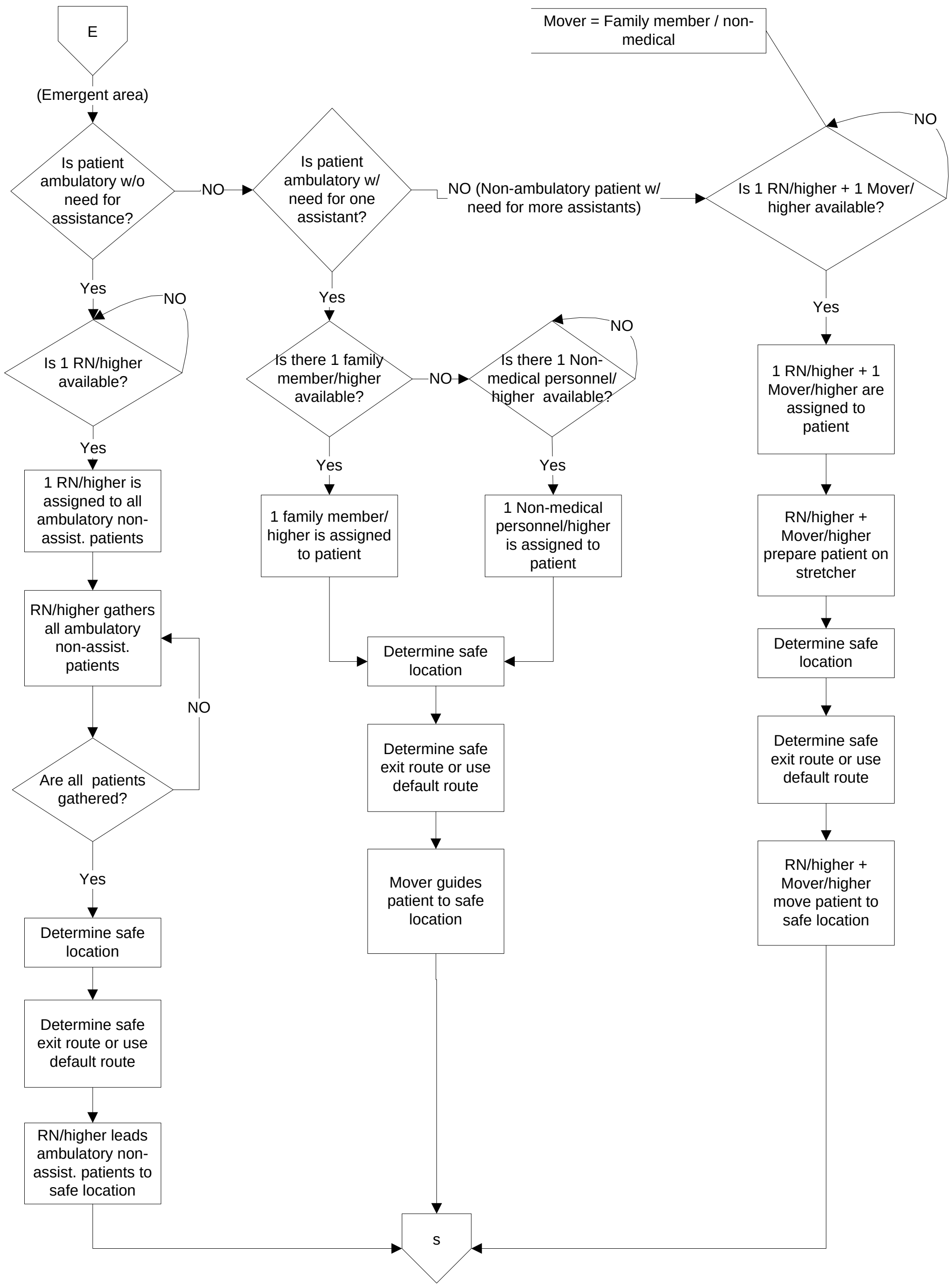

Fig. 4: Continued

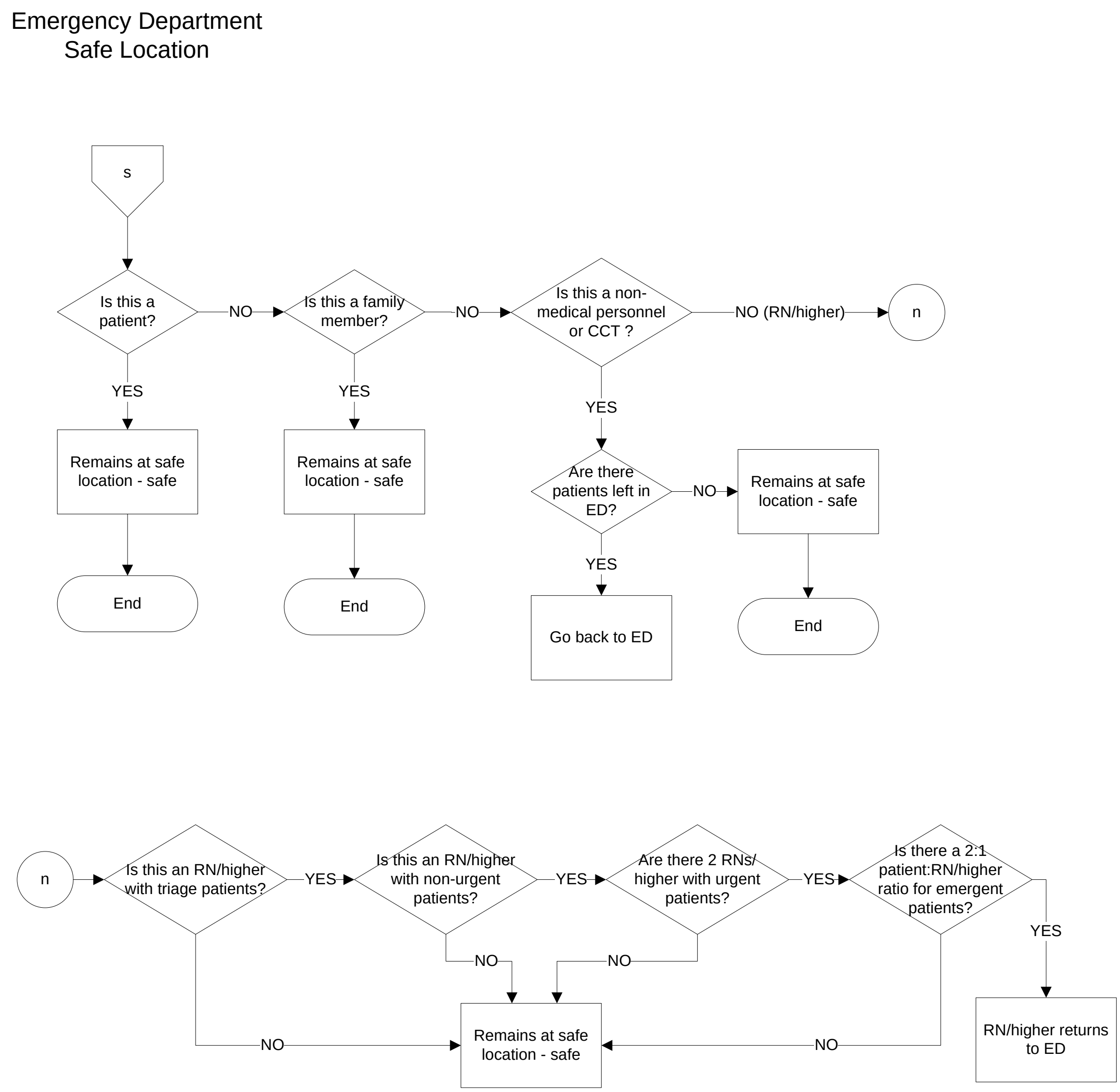

Fig. 4: Continued

ED -- Simulation Experiment and Synopsis of Results

The table below illustrates the evacuation times as a function of number of patients, level of medical staffing, and availability of extra nurses.

Evacuation Time (min)						
# of patients	# of medical staff + no extra help			# of medical staff + 15 extra nurses after 5 minutes		
Avg. (107)	45.76	35.82	32.55	31.82	30.73	30.4
High (177)	73.45	55.75	50.92	51.15	48.87	47.74

Table 6: The Effect of Extra Nurses on Evacuation Times in ED

Three levels of staffing are considered, low, medium and high. This is based on the time of the day and the staff schedule used in emergency department. The results are shown for the average and high number of patients present at unit at time “zero”.

In the case that there are no extra nurses to help, we see that the total evacuation time decreases with an increase in the number of staff for each level of patient count. Also true is that the evacuation time increases as more patients are present. A 65% increase in patient count, causes on average 5.7% increase in the evacuation time. On the other hand, using 15 extra nurses that arrive after 5 minutes of the beginning of evacuation, we see that the total evacuation time decreases comparing to the previous case. This shows that using extra nurses (or extra helpers in general) would help decrease the total evacuation time in both patient counts.

On the other hand, we also see that in the cases of medium and high staffing level there is not a significant change in the time as compared to the previous case (zero extras). For example, compared to the case of having no extra nurses available with an average number of patients, there is a 29% decrease in the evacuation time when staffing increase from low to high level. For the case that 15 extra nurses arrive, this percentage reduces to about 4.5%. Adding more helpers may reduce the evacuation time but at the same time it may increase the level of congestion in the system especially knowing that there are long queues in front of the elevators. Therefore, there should be an optimized balance between the current staff and the additional helpers.

The results for the ED evacuation times are also shown graphically in figures 5 and 6.

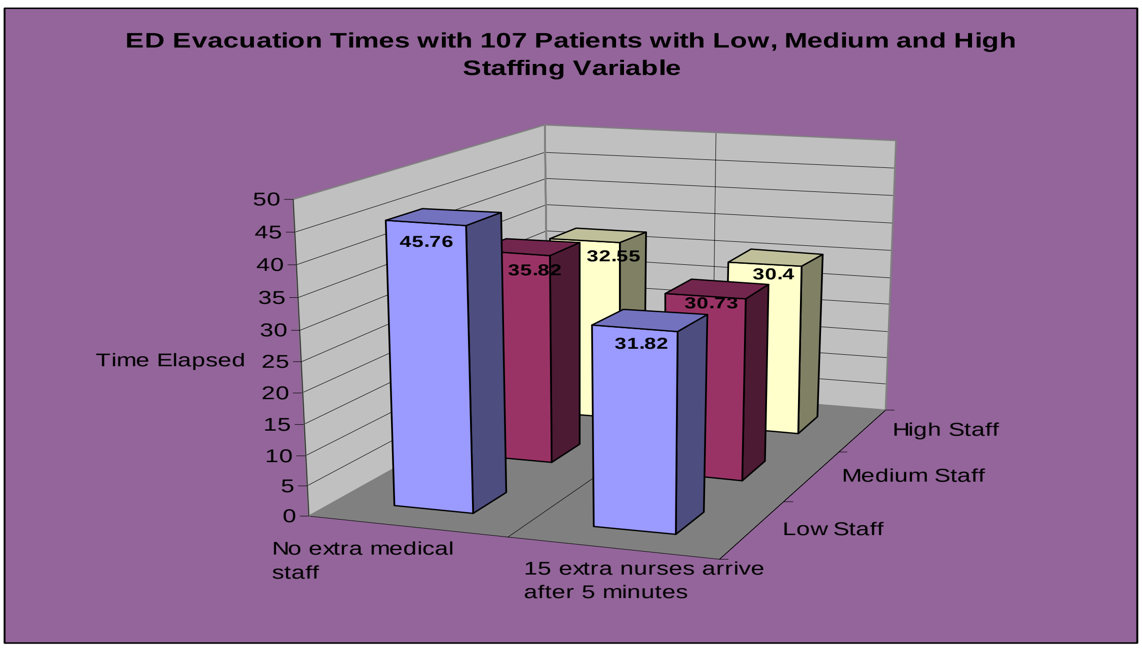

Figure 5: The Effect of Staffing Levels on Evacuation Times in the ED

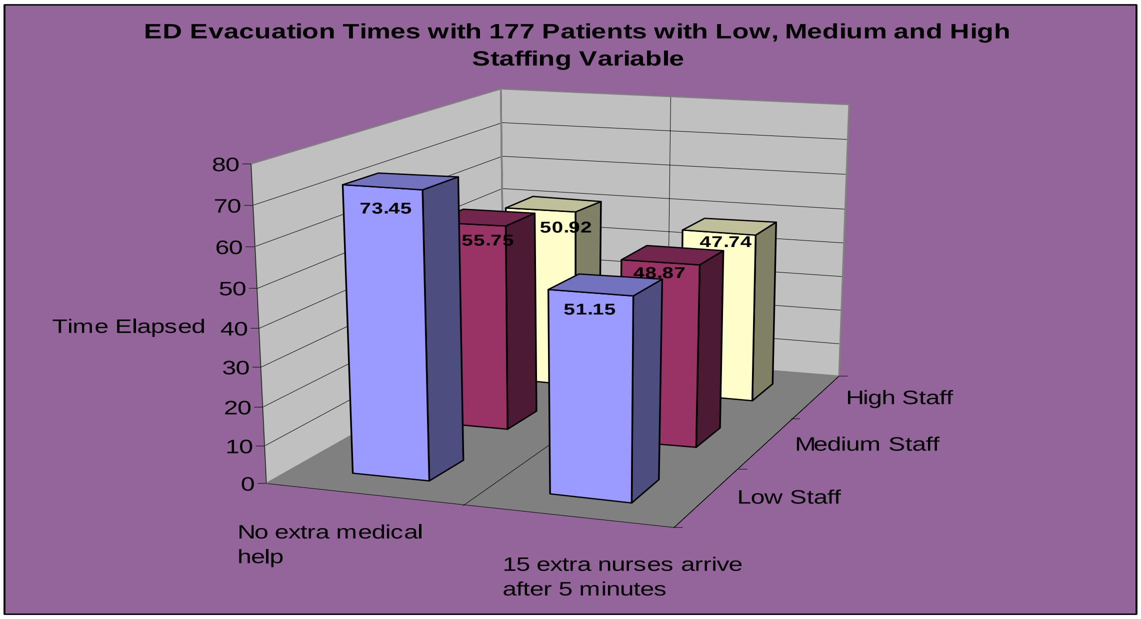

Figure 6: The Effect of Staffing Levels on Evacuation Times in the ED

The following synopsis of results can be made:

1. For the scenarios considered here, the elevators are the bottlenecks. There is always a queue in front of the elevators regardless of the number of staffing or extra helpers.

2. Regardless of the number of patients the following conclusions can be drawn:

   a. Having additional medical staff helps reduce the evacuation time.

   b. Adding extra nurses reduces the time even further.

CONCLUSION AND RECOMMENDATIONS

Based on our modeling and simulation studies during Phase I of this project, the following recommendations could be made:

- These preliminary models show the possibility of conducting “virtual drills” in cases that real drills cannot be done according to the time and budget limitations. This becomes more important for units like ED and ICU that deal with severe cases on a daily basis and may not be able to train their staff through running drills in short intervals. Therefore, the simulation modeling could also be used as a training tool for the hospital risk management to increase the readiness of their staff by exposing them to some extreme conditions that could happen during a real disaster but are hard to mimic in a real drill. The application of this system is highly recommended in that regard.

- Based on the results of simulations throughout this study, we realized that an increase in the amount of some resources might not always decrease the evacuation time. The major goal of an evacuation operation is to safely remove the patients and unit staff off the floor and transfer them to a designated safe location. This should be done efficiently in a short amount of time. Increasing or decreasing the amount of medical staff and movers who play the main role in evacuating the patients to the safe location, will help the unit director find the best and worst cases and make suggestions to higher management accordingly. (Adults unit). In that case, we noticed that increasing the number of nurses and volunteers (if available) is not helpful in terms of reducing the evacuation time. As a matter of fact, the response time reached a plateau and did not change any further with changes in the value of input variables.
- In the case of SICU (ICU in general) unit, despite the fact that the Rutgers team was assigned to model and simulate only part of the unit (its west wing), the experiments showed significant outcomes. In units such as the ICU that accommodate and treat patients with more acute and severe conditions than other units of a hospital or a similar health care facility, there is equipment that needs to be moved with the patient by a nurse or a helper. On the other hand, based on the severity of the patient's condition, they may need to have a respiratory therapist available during the evacuation. The results show that the availability of vital equipment such as portable monitors and ventilators together with the respiratory therapist is of great importance in emergency situations. Based on the results, with the current configuration, it may take more than two hours to evacuate 10 patients, which is the maximum capacity of the unit. In this case, the respiratory therapist needs to move back and forth between the unit and safe location. The portable monitors also need to be carried back to the unit when the current patient is left at the safe location. These activities add significantly to the response time and put the patients' life at risk. Therefore, the addition of at least one more respiratory therapist to the evacuation crew in case of an emergency is highly recommended. Supporting results show that in this scenario, the evacuation time reduces significantly. One therapist could be located at the safe location and the other one preparing the patients at the unit.
- In case of the emergency department, the simulation shows that using the suggested pathway to the safe location causes long queues in front of the elevators regardless of the number of staff and extra helpers. Elevators become bottlenecks in the system. This will reduce the efficiency of the operations and add more to the evacuation time. It is recommended to use an alternative path to the safe location in addition to the current one. This helps to divide the population of non-ambulatory patients (who need to be carried by

elevators to the level of safe location) between several paths. As mentioned earlier, an optimized balance between the number of scheduled staff and extra helpers may alleviate this problem. Adding more helpers of any kind regardless of the constraints on the floor (in addition to the level of scheduled staff present) may have a reverse effect on the evacuation time.

- The designated safe location needs to be prepared before or as the patients arrive. Equipment and medications need to be available at the safe location upon patients' arrival. Computers, ventilators, portable monitors, beds and stretchers, medication carts, and IV poles are among the most important items that are needed at the safe location. There is also the need for sufficient amount of electric outlets and/or power generators to provide electricity in case of an emergency. This is especially important for non-ambulatory patients and the patients transferred from acute care units like ED and SICU.
- Other than the above-mentioned recommendations, the Rutgers team recommends frequent drills and experiments to improve the response of the system to emergency situations. Because of the cost and the resources necessary to do drills, it may not be feasible to conduct them often. Hospitals can use these simulation toolkits to generate different scenarios (virtual drills) and analyze the response of the system to the events of different nature.

APPENDIX 1: SURGE CAPACITY

Emergency Response Modeling and Evaluation at Robert Wood Johnson University Hospital

FINAL REPORT: PART II

Surge Capacity Preparedness

November, 2005

Emergency Response Modeling and Evaluation at Robert Wood Johnson University Hospital: Surge Capacity Preparedness[1]

Mohsen. A. Jafari, PhD
Kian Seyed
Lisa Bodnar
Department of Industrial & Systems Engineering
Rutgers University
&
Jeffery Hammond, MD, MPH
Robert Wood Johnson University Medical School and UMDNJ

November, 2005

[1] **This project was sponsored and funded by the New Jersey Department of Health and Senior Services.**

Executive Summary

This project is intended to simulate and henceforth develop a modeling framework using which a wide spectrum of surge capacity scenarios can be virtually built, tested and analyzed for the Robert Wood Johnson University Hospital, located in New Brunswick, New Jersey. The model focuses on those processes and resources that involve admission of the arriving patients into the emergency department at the hospital during an incident. The scheduling of resources including medical and non-medical staff is included in the modeling. The tracking of patients, replenishment of resources (e.g., equipments, masks, ventilators, etc.) are not explicitly modeled. The ratio of nurses and doctors to patients both in ED and safe areas (extra capacity) can be implicated from the model. Also, from the model one can calculate how much extra capacity (in terms of beds, equipment) will be needed under a virtually created scenario. Due to the flexibility of the model in terms of defining the arrival patterns to the hospital, one can implicitly simulate scenarios involving bio-attack, chemical-attack or natural disasters. The results and findings from this project can be extrapolated to other hospitals but with a lesser degree of accuracy. The model is also intended to provide a training environment for medical emergency professionals.

PROJECT OBJECTIVE

This project is intended to simulate and henceforth develop a modeling framework using which a wide spectrum of surge capacity scenarios can be virtually built, tested and analyzed for the Robert Wood Johnson University Hospital, located in New Brunswick, New Jersey. The results and findings from this project can be extrapolated to other hospitals but with a lesser degree of accuracy. The model is also intended to provide a training environment for medical emergency professionals.

PROJECT SCOPE

The models and simulations developed under this project mainly focus on those processes and resources that involve admission of the arriving patients into the emergency department at the hospital during an incident. The scheduling of resources including medical and non-medical staff is included in the modeling. The tracking of patients, replenishment of resources (e.g., equipments, masks, ventilators, etc.) are not explicitly modeled. The ratio of nurses and doctors to patients both in ED and safe areas (extra capacity) can be implicated from the model. Also, from the model one can calculate how much extra capacity (in terms of beds, equipment) will be needed under a virtually created scenario.

Emergency preparedness and how a given hospital must respond to a major incident should be addressed in conjunction with the normal operation of that hospital. Clearly, when such an incident happens, there are already patients in the hospital, subsequently, normal operations should continue. Also, replenishment policies for major equipment and resources, scheduling and allocation of medical and non-medical staff can not be optimized unless discussed and analyzed within the framework of hospital's normal operation. Therefore, the overall economics of emergency preparedness and how it impacts day-to-day operation of a hospital should be part of any comprehensive surge capacity analysis. Our simulation and models at this time, do not explicitly address these issues. However, many of these issues can be implicitly addressed by the results obtained from the model. For instance, knowing the total number of patients admitted to ED or safe locations, and knowing their conditions, the hospital operations management could compute the number of medical staff that will be needed. Also, from the overflows, planners can easily compute extra capacity needed in that hospital or anywhere else in the community. The model is flexible in defining the arrival patterns to the hospital, thus capable of implicitly simulating scenarios involving bio-attack, chemical-attack or natural disasters.

PROJECT BACKGROUND

During phase I of this project, a preliminary model for surge capacity activities in Robert Wood Johnson University Hospital (RWJUH hereafter) was built mainly based on the rules and guidelines of *Yellow Alert protocol*. This protocol is followed in emergency situations where an unexpected massive influx of patients into the emergency department occurs. According to this protocol, the Med Central (Emergency Medical Service at RWJH) is notified. The hospital operator, security department, and any other respective communication unit within the hospital also receive the initial notification. The medical communicator then determines the location and extent of the incident, number of casualties, and any other relevant information. At this time, the Administrator on Duty (AOD) implements the "Yellow Alert". There are a number of operational steps that must be followed, once the alert plan is put in place, including coordination of the alert plan by the Emergency Operations Center and the coordination of personnel pool and equipment by the Escort Dispatch office.

Generally speaking, the root cause of an emergency incident may trigger different types of responses and steps to be followed. This is a clear indication of how complex surge capacity modeling and analysis is. The Phase I model we developed was a preliminary one with considerably simple approach, involving basic steps in patient admission to the Emergency Department (ED hereafter). Since, partial or full evacuation of existing patients in ED may be required during a surge capacity incident; our models also included the evacuation model of ED which was also developed during Phase I.

In Phase II we extended modeling of surge capacity by further focusing on specific incidents that cause massive influx of patients to the hospital. Here the arrival pattern of the patients varies from one type of incident to another. For example, the arrival pattern during a chemical attack/incident could be different than the one in a biological attack. The time that takes for the staff at the registrar and triage nurses, to detect the incident through observation of the patient arrival pattern, and communication of this information to the rest of the hospital also depends on the root cause of the incident. For example in case of a biological attack, it may take more time for the ED staff to detect the incident than a chemical attack. Therefore we see that the awareness of staff is very important in detecting and responding to the emergency events. In some cases, it is possible for the hospital to be informed by other authorities at the local or state level, like emergency services, hazmat teams and so on beforehand. This should give sufficient time to respond.

For disaster planning, we believe that we must plan for a situation where the hospital does not have sufficient information on the disaster or its type beforehand. This is certainly the worst case, and all the cases where there is sometime for pre-planning are subset of this case. In what follows, we will continue with the system description, simulation model description, output analysis and results and discussions.

SYSTEM DESCRIPTION

Figure 1 below shows the process flowchart of the surge capacity simulation model which is built based on the Yellow Alert protocol. The incident can be due to release of some chemical, biological or radiological agent, resulting in arrival of patients with possible contamination. The incident can also be due to some natural events where the patient arriving at the hospital are not necessarily contaminated with any agent, but are injured and require immediate medical attention. As shown in the model, there are two major activities undertaken by ED staff after the Yellow Alert is activated. According to the ED head nurse, about half of the staff is allocated to prepare the ED for admitting the arriving patients and setting up the triage area in the ambulance bay area together with the decontamination showers (if they are told that the inpatients are contaminated). The other half helps evacuate part of or entire emergency department. In our modeling approach, this decision is made based on the number of arrivals. Depending on the empty capacity of ED at the time of the event and arrival rate of new patients, partial or total evacuation of the ED is triggered. Aside from the fact that the released ED capacity may be needed by the new patients, this also prevents the current ED patients from being contaminated by the new arrivals. The evacuation of patients starts from the emergent area of ED and based on the surge volume, it could also include the urgent, non-urgent and triage areas as well.

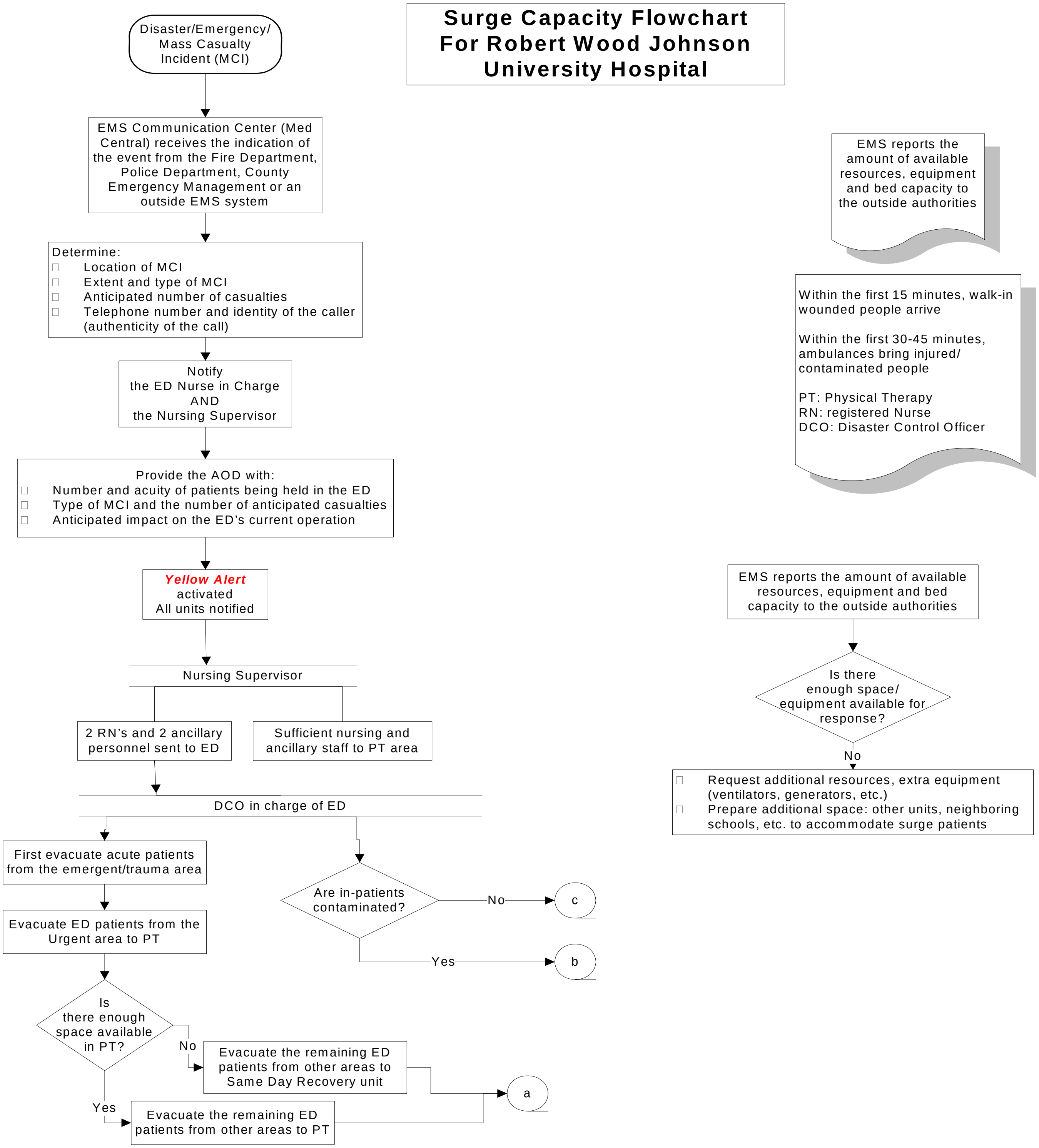

Fig. 1) Surge capacity process flowchart based on the Yellow Alert protocol

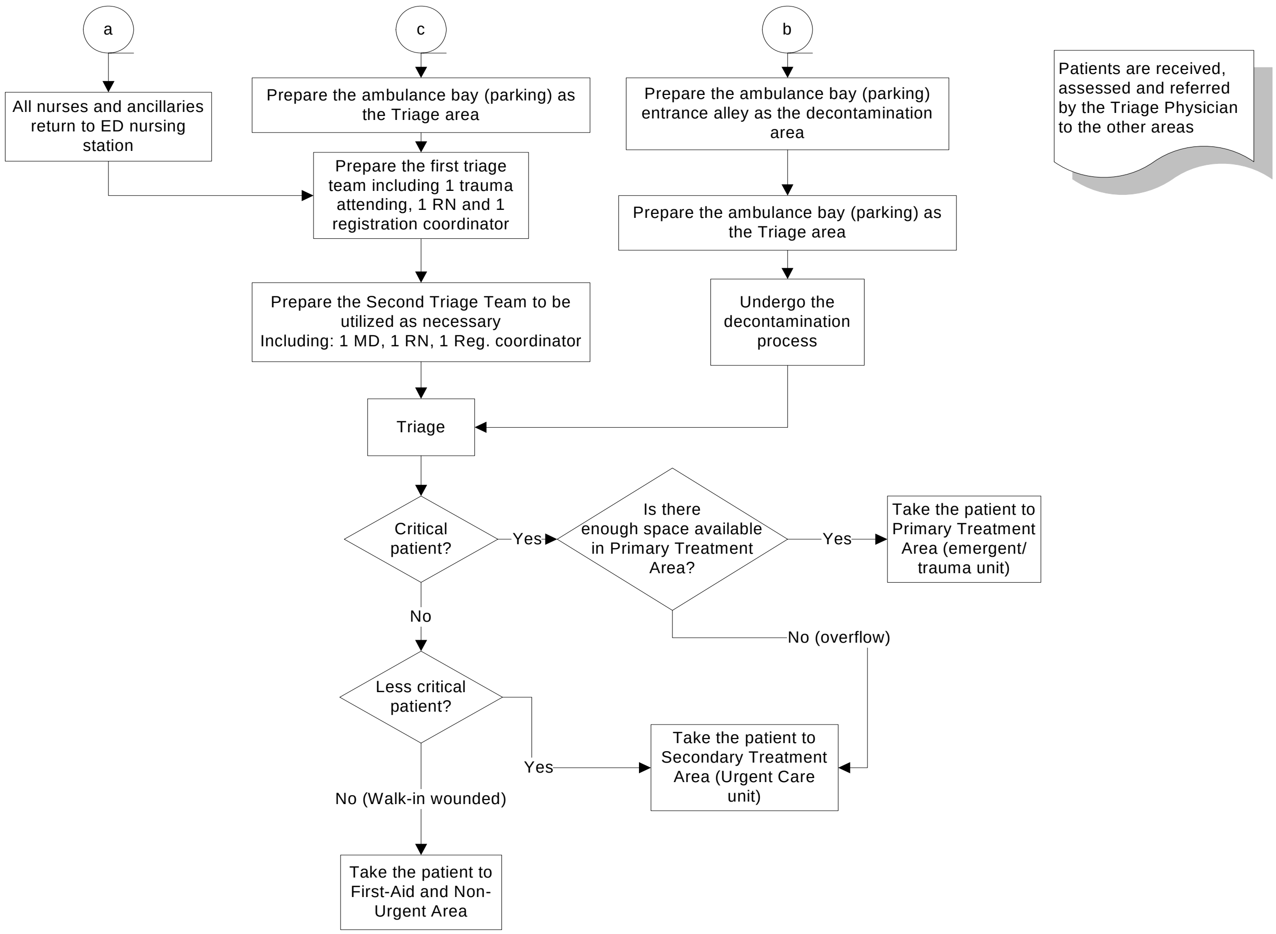

Fig. 1) cont'd

The patients, who occupy ED at the time of incident, are transferred to physical therapy unit, and care is rendered to them by nursing staff assigned by the administration on duty and the nursing supervisor in the area. If the arriving patients are all contaminated, they need to go through a two-stage decontamination process (primary and secondary) each having four (this number can change) showers to be used for decontamination. After decontamination they are ready to be triaged. If the arriving patients are all uncontaminated, they will proceed to the triage stage directly. The triage area set in the ambulance parking bay is the place where patients are assessed (triaged or examined) and referred to different treatment areas. Based on the Yellow Alert plan, there are three major treatment areas that are designated to the inpatients: Primary, Secondary and First Aid, and Non-emergent care. The primary treatment serves critical patients during an ED overflow. Secondary treatment serves for critical patients when the primary treatment area is full to its capacity. First-Aid care is rendered to those who are not critically injured. Additionally, the hospital sets up a DOA, which is used as a mortuary.

At Robert Wood Johnson University Hospital, a safe location is allocated to accommodate the overflow of the emergency room in surge capacity situations as well as in emergency evacuation of sections of the hospital. After the arriving patients are triaged and decontaminated, they are transferred to ED to fill out the available empty beds while the overflow will be transferred to the safe location. Therefore, this location should have all the necessary equipment and medications that patients may need for a short term stay. This includes beds and stretchers, oxygen tanks, IV poles, ventilators, medications of all kinds, computers and printers, portable monitors and so on. Hospital crew in charge need to prepare the safe location equipped with all the necessary accessories before new patients arrive at the safe location. That is why we proposed earlier two main scenarios for a surge capacity preparedness; "*they know*" and "*they don't know*". If hospital staff knows about the emergency event and is informed that there would be a massive influx of injured or worried-well people coming to the ED, then they may have time just enough to start the preparation and evacuation process and get ready to respond and accommodate the patients. This might be true in events like natural disasters where the EMS, Hazmat teams and Police departments are aware of the occurrence of the event and inform the healthcare facilities and emergency departments. On the other hand, there might be situations like chemical and biological attacks through food/water poisoning that may need more time for detection. In this case, which is our core assumption in this project; people affected and contaminated by the incident gradually arrive at hospitals and emergency rooms. The arrival rate in a chemical attack situation may be different than the arrival rate in a radiological or biological attack. Also, the time that may take the staff to detect the cause is different from one event type to another. In the next section, we will introduce our simulation approach and the assumptions we have made.

SIMULATION MODEL DESCRIPTION

Our simulation model takes a case-based approach to the surge capacity preparedness activities. The flexibility of the model allows user to change the arrival rate and simulate different type of disasters and even use real data if available. For example, during the recent TOPOFF drills, the arrival times of the incoming patients were recorded. This information, if and when available, can be used to find a proper arrival distribution/pattern for model. In the absence of real data, the user can use different rates/distributions in the model to create different scenarios. We assume that the hospital staff are not aware of the incident and only find out about it from the arrival patterns and the type of injuries. Again, the model can handle both contaminated and uncontaminated patients.

At time zero, when the patients start arriving at the emergency department, ED is fully or partially filled with patients. The empty capacity of ED is its maximum normal capacity minus the current number of patients plus the number of patients that ED can usually accommodate in addition to its normal capacity. If the size of the patient influx is smaller than this number, then all the new patients can be admitted without a need for evacuation.

After admitting certain number of undetected contaminated patients to the ED, an alert goes off in the model showing that there is a repeating pattern and the staff needs to set up triage and decontamination (decon hereafter) areas. The triage and decon settings are located in the ambulance bay area in front of the emergency department. The decon process has two stages each having four showers to be used for decontamination. After triage, the patients are identified as one of the following three types:

- Walk-in-wounded who are transferred to another unit like same day surgery or are discharged,
- Less critical
- Critical

Less critical and critical patients are admitted to ED based on the available empty capacity. After admitting two times the available capacity, an alert (evac_alert) goes off to trigger the evacuation of part or all of ED. The current patients are transferred to physical therapy unit upon evacuation. After filling the evacuated section of ED, the third alarm (yellow_alert; has nothing to do with the Yellow Alert protocol) goes off that triggers the preparation of designated safe location (court yard at RWJUH). This will trigger also the deployment of certain equipment and medication to the court yard (also called atrium).

In the animation we show the related processes and the sequence of events that happen and some useful statistics about different parts that are involved like physical therapy count, court yard status, ED status, staffing, patient counts, and so on.

In the simulation, there are red alerts that indicate to the user when ED runs out of some of important resources such as oxygen tanks, IV poles, beds and so on. This is checked with a base value that is also user-defined. The upper left-most of the animation shows the layout of the emergency department which consists of four parts: registration and triage, non-urgent, urgent and emergent/shock-trauma areas.

Other General Assumptions

These assumptions are mostly made in the input of the model. Therefore, they could be changed, altered or tailored according to the user's needs. Here are the main assumptions:

- Medical staff on board consists of doctors, head nurses, registered nurses, nursing administrators, and physician assistants, medical and nursing students (if present).
    - It should be noted that the staffing is created based on the schedule that ED follows for its permanent staff. The number of medical and nursing students and other temporary resources of this type such as volunteers is variable that could be defined and changed by user.

- Critical care technicians (CCT's), volunteers, unit clerks, escorts and family members are considered movers (same as non-medical).
- Standard triage set up in the ambulance bay area consists of one MD and one RN (Registered Nurse) to examine the incoming patients.
- The model assumes a probability distribution for the type of arriving patients. For example, Type I (walk-in-wounded) with 40% probability, type II (less_critical) with 40% probability and type III (critical) with 20% probability. There is also a probability distribution for the patient to use ventilator with 5% probability. These numbers can be changed by the user.
- The threshold on the number of contaminated arrivals that triggers the contam_alert is set to be 10. This is an input variable and could be changed by user.
- If all the inpatients are uncontaminated, there will be no need to set up the decon showers. Therefore, there will be no contam_alert and the ambulance bay area will be set up only after the number of arrivals exceeds the capacity of Ed.
- When the alarm that triggers the preparation of safe location (to accommodate the overload of ED) goes off, emergency department is fully loaded.

MODEL VALIDATION

The simulation model described above has been developed based on the exact layout of the emergency department at the RWJUH, and according to the preparation protocol adopted by the hospital. Unfortunately, it is impractical to test the validity of the model, except through some known classical techniques. For instance, output sensitivity analysis, where trends in system response(s) are checked against varying known inputs, is a common validation technique. Checking the animation for a spectrum of model inputs is also another common way of model validation. We have been able to successfully pass these validation tests. The input data of probabilistic nature are presented in the model by a probability distribution where the mean and variance of the distribution were obtained from personal interviews and direct observations. The deterministic input data were collected through personal interviews and direct observations. The TOPOFF3 data and results, when available, can be used for some degree of validation of our model. This validation will not be quite accurate due to the fact that TOPOFF3 was conducted based on the assumption that the hospital has some information on the incident and some level of preparedness had occurred prior to the arrival of patients.

RESULTS AND FINDINGS

There are two application areas for the simulation model developed here. Next we will discuss each in some detail.

Professional Training Tool

The animation provided with the above simulation model provides an environment where medical emergency professionals can view system operation during a surge capacity scenario. Furthermore, the statistical results obtained from running the simulations can provide these professionals with quantitative evaluation of their policies and protocols. For instance, by varying input data, such as arrival pattern, number of medical and/or non-medical staff, one can find out how the system responds. Furthermore, for those input variables which are controllable, such as number of medical staff, or inventory of major equipment resources, the simulation can be used to “optimize” system response(s).

We are planning to organize a statewide half-a-day or day workshop on healthcare emergency preparedness, where we will present this model as a framework for emergency planning. We will also visit a number of hospitals in the state to present the model and our findings. Upon the completion of these activities a technical report will be prepared.

Emergency Planning Tool

The model can be used to create virtual incidents and measure the impact of these incidents on the operation of hospital. In particular, the model can measure, upon an incident, how many patients can be admitted to the hospital, and how many of these patients must wait or be transferred to other hospitals or facilities. The second measure can be indirectly obtained and implied from the amount of overflow calculated by the model. The admitted patients are the ones who go through triage, decontamination (if necessary), and eventually placed either inside ED or in safe location(s) designated for this purpose. At any point in time, which can be seen from simulation snapshots (using animation or by virtue of tallying appropriate statistics) there will be patients waiting at various stages from triage all the way to admission to safe locations. Overflow in safe location(s) include patients who have gone through preliminary stages of admission, but no specific bed has been assigned to them. These patients also constitute overflow that may need to be transferred to another hospital or care facility depending on the severity of their injuries or illness. Depending on the value of the patient overflow within a given period of time, the planners can then decide how to coordinate with other healthcare facilities and providers in order to ensure minimum causalities among these patients.

The model provides alerts and alarms at various points in time where some of the major resources become exhausted. At this time the model does not have provisions for replenishment of these resources. The model also does not specifically track patients after they are admitted to ED or to safe locations. In a later section we will discuss in more detail how the existing model can be extended.

Next, we will provide a number of virtual scenarios, where system responses are analyzed by varying some of major input variables, including arrival patterns. Some of the major input variables are initialized in Table I.

Table I: Major input variables

Initial inventory of required accessories			
		Max ED capacity	
Beds	20		
IV Poles	20	Triage	2
O2 Tanks	40	Non urgent	15
Ventilators	10	Urgent	40
		Emergent	50
Computers	6	Total	107
Printers	3	**Max Atrium capacity: 75**	
Threshold amount for the required accessories			
(Red alarms go off at these levels.			
Beds	10		
IV Poles	10		
O2 Tanks	5		
Ventilators	2		
# escorts	20		

Table II illustrates two similar cases, where only the simulation time has changed from 5 hours to 24 hours. One can think of the first case as the fifth hour snapshot of the second case. It is assumed that patients arrive at a rate of 20 per hour, and that only after the 10^{th} patient there is an alert for emergency. One can think of these two cases resembling a bio-attack or chemical attack scenario, where all the patients are contaminated and require showers prior to admission.

Table II: Some system responses for cases in Table I with arrival rate of 20 per hr

Smulation run for:	5 hours	24 hours
Initial number of present patients	86	86
Initial empty capacity	42	42
contam alert called after (min)	72	72
# Patients arrived	82	396
# Walk in wounded	34	161
# Contaminated	47	235
Admitted into ED	45	90
less critical,critical,need(s) vent	54,25,2	58,31,2
Total decon processes WIP	2	4
# Uncontaminated	0	0
# Registration WIP	1	0
evac alert called after (min)	211	307
TEVAC (min)	8	17
yallow alert called after (min)		591
ED floor count	99	128
evacuated to PT	18	47
Total Atrium count (admitted + overflow)		141
WIP: Work in process or size of the waiting line.		

We can clearly see from the above table that the emergency department and the hospital saturate by sometime between the 5th and 24th hours. We note that our models do not take into account replenishment of major resources. Such replenishment may reduce the waiting lines and bottlenecks.

Figure 2 below shows three cases of arrival patterns for virtual scenarios, where the major inputs are given in Table I. Tables III - V show four snapshots of the emergency response after 12 hours, 24 hours, 36 hours, and 48 hours, for Cases I, II and III, respectively. Again all the arriving patients are contaminated. Case I is a virtual scenario where arrivals are slow at first but then accelerate fast. In Case II, initial arrivals are occurring fast, but they slow down as time passes by. Case III is when arrivals are very slow at the beginning, pick up and accelerate slowly, and finally settles to some constant value. In all cases, arrivals require decontamination. Unfortunately, it is not practical to validate how these arrivals relate to cause of incidents. We can only conjecture at this time that Case I mimics natural disasters where initially injuries come to the hospitals at lower rates, but then they pick up fast. Case II mimics chemical attacks where arrivals start fast, but then slow down considerably. Finally, Case III mimics bio-attack cases where arrivals start with very low rate, pick up slowly, and eventually settle to some constant level.

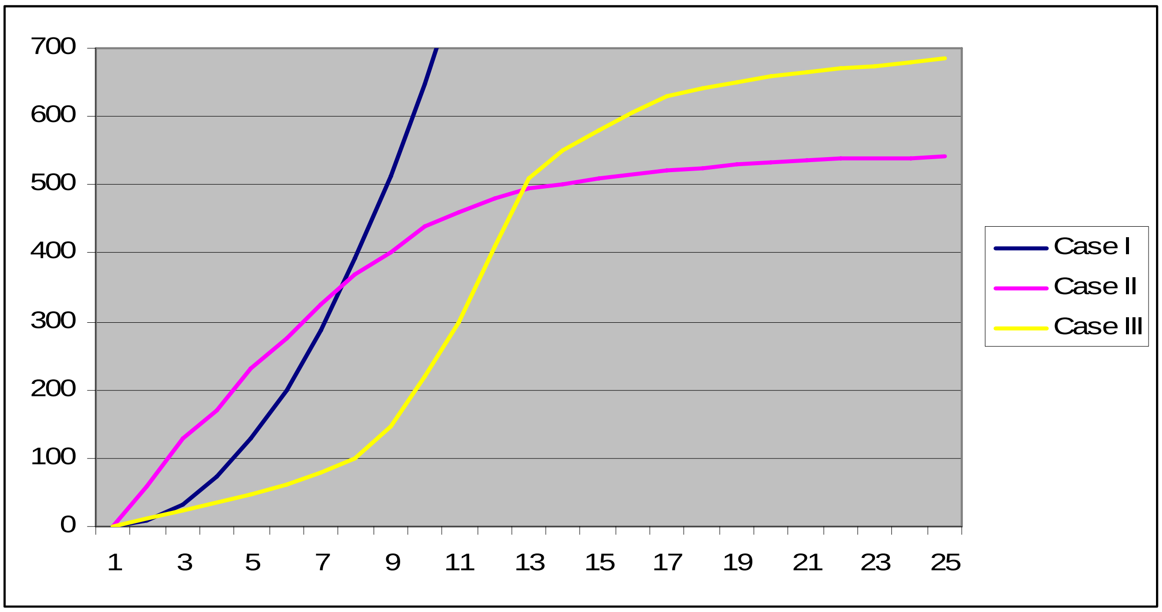

Fig. 2) Arrival patterns for cases I, II and III

Table III: Results for Case I of Figure 2

	after 12 hrs	after 24 hrs	after 36 hrs	after 48 hrs
Initial number of present patients	83			
Initial empty capacity	49			
contam alert called after (hrs)	3			
# Patients arrived	294	1155	2602	4566
# Walk in wounded	126	343	561	783
# Contaminated*	163	519	873	1221
Admitted into ED	93	93	93	93
Total decon processes WIP	24	148	273	392
# Registration WIP	5	293	1168	2563
# Waiting for mask	0	61	290	519
evac alert called after (hrs)	7			
TEVAC (hrs)	0			
yallow alert called after (hrs)	10			
ED floor count	132			
evacuated to PT**	44			
Total atrium count	44	217	217	217
Atrium overflow	0	142	142	142
** PT: Physical Therapy unit				
*All the arriving patients are contaminated.				

Table IV: Results for Case II of Figure 2

	after 12 hrs	after 24 hrs	after 36 hrs	after 48 hrs
Initial number of present patients	83			
Initial empty capacity	49			
contam alert called after (hrs)	1			
# Patients arrived	314	483	523	533
# Walk in wounded	134	207	223	229
# Contaminated*	181	276	300	305
Admitted into ED	93	93	93	93
Total decon processes WIP	2	1.5	1	1
# Registration WIP	0	0	0	0
# Waiting for mask	0	0	0	3
evac alert called after (hrs)	4			
TEVAC (hrs)	0			
yallow alert called after (hrs)	7			
ED floor count	132			
evacuated to PT**	44			
Total atrium count	84	181	206	208
Atrium overflow	19	106	131	133
** PT: Physical Therapy unit				
*All the arriving patients are contaminated.				

As we experienced in Table II, the hospital saturates quite fast depending on the speed by which patients arrive.

Table V: Results for Case III of Figure 2

	after 12 hrs	after 24 hrs	after 36 hrs	after 48 hrs
Initial number of present patients	83			
Initial empty capacity	49			
contam alert called after (hrs)	2			
# Patients arrived	90	530	662.5	696
# Walk in wounded	35	199	262	275
# Contaminated*	56	301	400.5	421
Admitted into ED	53	93	93	93
Total decon processes WIP	3	61	1	0
# Registration WIP	0	30	0	0
# Waiting for mask	0	0	89.5	111
evac alert called after (hrs)	5	7		
TEVAC (hrs)	0	0		
yellow alert called after (hrs)	0	17		
ED floor count	111	132		
evacuated to PT**	25	44		
Total atrium count	0	147	217	217
Atrium overflow	0	72	142	142
** PT: Physical Therapy unit				
*All the arriving patients are contaminated.				

CONCLUSION AND FUTURE WORK

The cases we illustrated above are just few examples to demonstrate the utility of the simulation environment developed here. Generally speaking, this environment provides, through user friendly interfaces, the means of creating virtual emergency incidents and the tools for analyzing hospital response to such incidents. Despite a number of shortcomings that the model has, it is a major step towards understanding the operational behavior of a major hospital to emergency incidents with large influx of patients. The model is flexible in that many of the major input variables can be changed by the user, thus, providing an analytical environment for "what-if" analysis. In particular, changes in arrival patterns can be essential to understand the response of the hospital to patient influxes of different magnitudes and caused by different reasons. For instance, one can identify the sources of bottlenecks. From the above examples, we can see that registration, triage, and decontamination process are potential sources of bottlenecks, which perhaps can be overcome by adding more nurses, showers, etc. In order to better understand the impact of increasing these resources, user can ramp up size of nursing staff at the ED, showers at the decontamination stations, and rerun the model again.

The above model can be extended in a number of ways:

(1) To include replenishment of inventory on major resources - We note that with the current model one can always re-run simulation with high inventory levels on these resources and determine their impact. But in a real life scenario, aside from the initial amount, the inventory of major resources must be dynamically replenished as patients are being handled. One can adopt a policy, like (R,r) policy, where as soon as the inventory level drops under value r, a new order is made to bring the inventory level back to R. Calculation of the two parameters, r and R, depends on many factors, such as cost of resources, lead times for delivery, type of emergency, etc. We strongly believe that in order to make emergency preparedness as an integral part of any hospital operation, such calculations and optimization should be in conjunction with the normal operation of that hospital. One has to show that emergency preparedness, not only, prepares hospitals to do what society expects from them at the time of crisis, but also, it helps them to streamline their own operations during normal times.

(2) The current model does not track the patients after they are admitted. To that end, the model cannot explicitly determine the impact of changes in the number of medical and non-medical staff. Also, the interaction of the new patients with the existing patients, aside from the fact the existing patients are evacuated from ED when necessary, is not explicit in the model.

(3) As can be seen from some of the examples above, the influx volume can be too high for any given hospital to handle. A comprehensive surge capacity should look into a community or a city at a time rather than a single hospital.

Furthermore, issues such as transporting patients from one facility to another and also conversion of hotels or schools into temporary care facilities should be studied explicitly.

(4) Emergency preparedness, especially surge capacity, is not just for terrorism. Epidemics, such as avian flu, may be more demanding on hospital and healthcare resources than any terrorist act or natural disaster. The dynamics of the problem, in terms of quarantining the patients, resources, etc. can be very different that cases that we have looked so far. In such cases, availability of appropriate medicines and treatments can also be a major factor, which should be studied in more general way (either at a community level) than a single hospital.