*Proceedings of the 2006 Winter Simulation Conference*
*L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, eds.*

# A SIMULATION MODEL FOR BIOTERRORISM PREPAREDNESS IN AN EMERGENCY ROOM

Lisa Patvivatsiri

Department of Industrial Engineering
Texas Tech University
Lubbock, TX, 79409-3061, U.S.A.

## ABSTRACT

The use of biological agents as weapons can cause disease and deaths in sufficient numbers that can greatly impact a city or region. Consequently, concerns about the preparedness and efficiency of healthcare systems for bioterrorism events have increased dramatically among hospital managements. This paper presents an innovative and sophisticated computer simulation model of the emergency room (ER) at the hospital featured in this study. The objective was to analyze patient flow throughout the treatment process, assess the utilization of ER resources, evaluate the impact of a hypothetical bioterrorist attack, and determine the appropriate resource and staff levels for such a bioterrorism scenario. The recommended staffing strategy at two bottlenecked areas of the hospital's treatment facility would allow a significant reduction in patients' total time in the ER and an improvement in the utilization of resources. A sensitivity analysis was also performed to investigate the effect of changes in input parameters.

## 1 INTRODUCTION

Among many emergencies and disasters, where public health authorities may be called upon to respond, is the deliberate use of biological agents to cause harm. Biological terrorism can take many forms ranging from the contamination of food with bacteria, to the dissemination of anthrax or plague in a subway station, and the infection of airplane passengers with smallpox. The goal of bioterrorism is to produce fear in the population with a subsequent disruption of society (Koehler 2001). The solution to the problem, of how to look at the level of bioterrorism preparedness, is not an easy task. Until now, there are few textbooks and book chapters that describe this problem.

As a result of the September 11, 2001, attacks and the anthrax letter incidents, concerns about terrorists' use of biological agents have increased dramatically at state and federal levels of government and in the popular press.

Therefore, such public concerns over bioterrorism responses have motivated healthcare management, and many corresponding organizations, to explore new alternatives for increasing efficiency during a sudden crisis. More recently, many papers and articles pertaining to bioterrorism responses have been published to give guidelines for preparedness. In addition, modern operation research, system management, and technology techniques have been applied to the outbreak and bioterrorism response problem. For example, Osterholm's 2001 discussion focused on the Neisseria meningitis, serogroup C outbreak and the responses, which involved a large community-based immunization program. Oh, Zhang, Mode, and Jurgens (2004) also developed an effective response hinged on information technologies, namely defection, isolation, communication, and education. The objective of their research was to study the scenarios where biochemical agents were released in the public transportation system of a major metropolitan city (2004). In addition, Walden and Kaplan (2004) presented a Bayesian approach to the problem of estimating the size and the time of a bioterrorist attack by simulating an anthrax attack, of 100 infected persons, and employing the actual data from the Sverdlovsk outbreak.

In comparison to other techniques, such as mathematical or Markov modeling, simulation modeling allows users to reconstruct a more comprehensive representation of real-world features during disaster response. Simulation has been successfully used to develop aspects of the public health infrastructure in order to respond to bioterrorist threats. This information can also be applied to other incidents that require rapid distribution of medical material among civilian populations. In this paper, we proposed and tested an interactive simulation model, at the hospital featured in this study, to simplify the treatment process in an emergency room (ER). This simulation model can help healthcare management determine a staff and resource level in hypothetical bioterrorist-attack scenarios. This suggested strategy determined the minimum staff and resources required to process high patient volumes without causing long queues in the ER.

**1-4244-0501-7/06/$20.00 ©2006 IEEE**

## 2 PROBLEM FORMULATION

Efficient allocation and utilization of staff resources are important issues facing all emergency room administrations, including those at the healthcare unit in Lubbock, Texas that is the subject of this study. In particular, the problem of providing sufficient staff resources in an emergency room during a widespread bioterrorist attack, such as the deliberate release of the smallpox virus, would be a challenging one. Availability of adequate staff to treat a large number of patients in an emergency room is a critical and potentially rate-limiting factor in planning the public health response to a bioterrorist attack. In addition, while the Department of Health and Human Services requires that every state have detailed plans for bioterrorism response, many states have delayed the production of such plans because of a lack of research on how these strategies should be designed and operated.

To remedy these situations, computer simulations are used to contribute significantly to US, state, and healthcare management efforts that organize the most efficient plan for treating infectious illness resulting from a bioterrorist attack. An innovative and sophisticated computer simulation model of the ER, at the hospital featured in this study, was developed using the Flexsim 2.6 simulation software. In the first step, the model verified the hypothesis that the higher the level of bioterrorism, the more total time each patient spends in the system and the greater the utilization of ER resources. More ER resources, including doctors, treatment nurses, beds, and technicians, are typically required to process high patient volumes. Currently, however, there is no proven theory to support the determination of such staff requirements. Using the computer simulation technique, we were able to identify the staff requirements for the ER treatment process in order to avoid long lines and delays in treatment for a variety of hypothetical bioterrorist attack scenarios. Moreover, our model of healthcare responses to bioterrorism is distinguished from earlier simulations by the following advantages:

- *Validity*: Our model is tailored to the specific hospital, not a generic one, utilizing all of the hospital's actual variables and values associated with this ER operation. Thus, the results obtained from simulation accurately represent the response to the posited bioterrorism scenarios and can be used in such events.
- *Real-Time Processing*: Our model is capable of processing data in real time. As patient flows fluctuate, the program can re-allocate ER resources in a fraction of a second—for example, sending more doctors or nurses to one station or more triage nurses to the triage area would re-allocate resources.
- *User Interface*: Our model is designed in the form of an interactive model that provides a front-end input data sheet allowing the users to tailor all the input data to specific needs without the users even knowing how Flexsim works.
- *Flexibility*: With the user interface, our model gives the users more flexibility to investigate multiple bioterrorism scenarios by varying the patients' arrival rate and the duration of a bioterrorist attack.
- *Ease of use*: By simply observing the results from our model's output sheet, a user can analyze and adjust the number of ER resources in order to setup the preparedness plan.

## 3 EMERGENCY ROOM PROCESS

This research studies the operation of the emergency room (ER) at the subject of this study, a medium-sized hospital whose emergency room provides a service to both trauma and non-trauma patients in the Lubbock, Texas, area. However, this study concentrates on only non-trauma patients. During peak hours, patients arrive at the average rate of thirteen per hour by walking into the emergency room reception. The emergency room is staffed 24 hours each day by doctors, triage nurses, charge nurses, treatment nurses, and technicians. Before explaining the ER process, the following definitions need to be clarified.

- *Pod* – A pod represents a section in the ER. There are a total of 60 beds for patient care divided into three individual areas. Specifically, these sections include Pod A with nineteen beds, Pod B with twelve beds, and Pod C with ten beds. An additional nineteen beds are located in a hallway as supplementary bed supply in case all beds in each pod are occupied.
- *Severe patients* – patients that require emergency treatment and will be assigned to Pod A.
- *Serious injuries patients* – patients that are seriously injured but a short treatment delay can be allowed. These patients are assigned to Pod B.
- *Walking-wounded patients* – patients who have a little cut, bug bites, and similar cases, that do not need urgent action. These patients are assigned to Pod C.
- *Charge nurses* – nurses in charge of a pod who usually perform bed side registration and keep track of the number of patients in each pod. Normally, there is only one charge nurse operating in each Pod area.

The emergency room process begins when a patient arrives in the ER and ends when the patient leaves the ER. Although it is impossible to precisely classify the flow of all ER patients through the system, a general flow process for a typical ER patient is presented in Figure 1. The overall process is divided into four sections: the arrival process, the triage and pod assignment, the treatment process, and the ER departure process. The arrival process differs depending on the type of arrival. The other processes are identical for all patients.

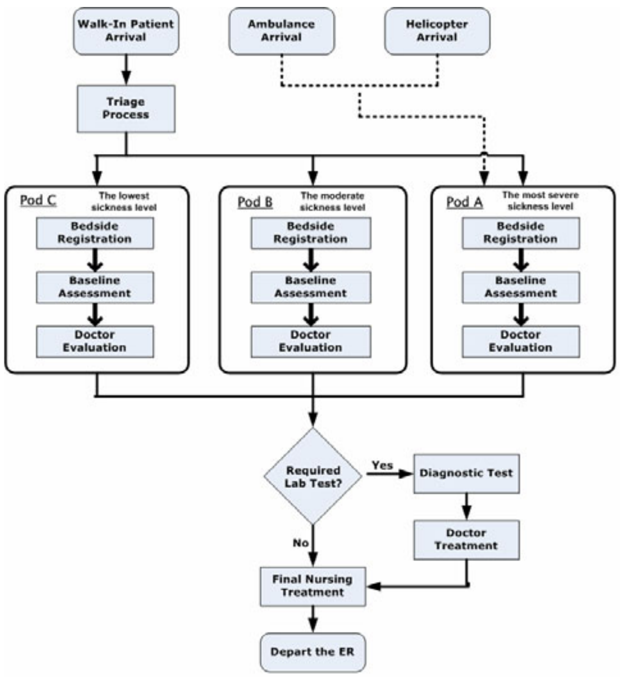


Figure 1: The Flowchart of Patient Care for the Emergency Room

### 3.1 Arrival Process

Typically, a patient enters the ER through one of three ways: walk-in, ambulance, or helicopter. This section gives a brief overview of each activity in the general patient arrival process. The term walk-in patient is used to describe any patient who arrives at the ER using any vehicle that is not an ambulance, rescue vehicle, police car, or helicopter. Once arriving at the ER, walk-in patients need to walk to the registration window, briefly address their problems to the triage nurse, and then wait in the lobby for the next available triage room. The process of patients arriving by ambulance is identical to that of the helicopter patient. After unloading the patients from the vehicle or helicopter, the patients are transferred to Pod A by default.

While the hospital was unable to provide data on the exact arrival time between two consecutive patients, they were able to provide data for the average number of patients who arrive in the ER throughout the day or the week. The hospital has an average of 723 walk-in patients per week, 5 ambulance patients per day, and 1 helicopter patient per week. Therefore, these arrival processes were modeled as time-dependent Poisson processes, with a mean of 13.94 minutes for walk-in patients, 288 minutes for ambulance patients, and 10080 minutes for helicopter patients.

### 3.2 Triage Process and Pod Assignment

As previously described, patients who arrive by ambulance and helicopter are immediately sent to Pod A without going through the triage process. Only walk-in patients have to go into the triage process and pod assignment. Triage nurses measure and record patients' body temperature, blood pressure, and other necessary measurements. Then, the triage nurses take patients' personal information, perform a preliminary check, and create a file for this specific visit. To ensure that patients with more life-threatening or painful conditions receive immediate attention, the triage nurses assess the patients' condition and assigns patients to different pod according to their sickness level. Eventually, with the assistance of a triage room technician, patients are placed on a bed and transferred to their assigned pod. Generally, there are a total of four triage nurses on call throughout the day to handle patients who come to the ER. The service time for this process was modeled with Triangular Distribution, which showed a minimum of 20, or most likely of 23, and a maximum of 25 minutes.

### 3.3 Treatment Process

Treatment process begins once a patient is transferred to these three pod areas. Pod A is a unit that works with the most severe patients. Pod B is used to treat patients with the less urgency, and Pod C deals with patients of a lower level of severity. While Pod A and Pod B are staffed 24 hours a day, seven days a week, Pod C only accepts patients from 11:00AM–11:00PM on weekdays. When Pod C is not in operation, patients who would normally be assigned to Pod C are sent to Pod B for treatment. There is a total of six treatment nurses, four treatment nurses, and two treatment nurses who work in Pod A, B, and C, respectively. In addition, a total of three shared medical doctors (MD) are assigned to work within these three pod areas.

The typical treatment process begins with a bedside registration by the pod charge nurse, and then an initial assessment by the Pod treatment nurse. The patient is then treated by a MD who decides whether the patient requires further testing such as X-rays, blood tests, CAT scans, MRI scans, and others. It is possible that a patient requires multiple types of tests. If a patient needs further testing, the MD orders the test and then pod technician transfers the patient to the facility area. Based on the data provided by the ER management, a total of 86 out of 723 patients are required to have lab tests. Therefore, an average of 12% of the ER patients was used in the model as the proportion of patients having lab tests. Once the MD has received any necessary test results, the MD provides any appropriate treatment and a pod treatment nurse provides a final nursing treatment to the patient. If the patient does not need further testing, the MD provides necessary medical orders for the patient, and then the treatment nurse provides the patients' final nursing treatment. At this point, the treatment process is considered complete.

According to the data of activity service time recorded by the ER administration, these service times were provided in average time without any specific statistical distribution. Since mean service time does not represent the process characteristics for the model well, a meeting was convened with the ER director to fit the service times into a Triangular Distribution, with a minimum, and average, and a maximum time for all activities. The service time for each activity in these three pods is summarized in Table 1.

Table 1: Service Times in Minutes for Each Activity in Three Pod Areas

| **Activities** | **Triangular Distribution (Min, Average, Max)** | | |
|---|---|---|---|
| | **Pod A** | **Pod B** | **Pod C** |
| Bedside Registration | (15,20,25) | (15,20,25) | (15,20,25) |
| Baseline Assessment | (7,12,15) | (7,12,15) | (7,12,15) |
| MD Evaluation | (15,25,40) | (8,15,30) | (5,15,25) |
| Follow-Up MD Treatment | (25,60,150) | (25,45,60) | (15,20,45) |
| Final Nursing Assessment | (30,50,120) | (30,50,90) | (15,30,60) |

### 3.4 Departure Process

Following the follow-up MD treatment and the final nursing treatment, a patient needs to fill out some paper work and leave the ER. A patient is either discharged from the ER or admitted to the hospital depending upon the MD's orders. Once a patient leaves the ER, either by discharge or admittance, it simply means that the patient leaves the system. Therefore, the simulation model in this study does not simulate the way patients leave the ER. It is important to note that, throughout the treatment and testing process, a patient continues to occupy the bed assigned to him or her in the pod treatment unit. Only after completing treatment, therefore, is a patient considered to be releasing an assigned bed.

## 4 SIMULATION MODEL DEVELOPMENT

In this study, the ER process was modeled using Flexsim software, version 2.6. The simulation model followed the patient-flow process described in last section, including all other input data obtained. The goal of the simulation model was to develop an understanding of system performance. The experimental scenarios have been evaluated to determine the hospital's level of preparedness to respond if a bioterrorist attack happens. The key performances measured are the average, total time patients spend in the ER, the patients' waiting time during each treatment activity, and the ER's resource utilization.

### 4.1 Model Assumptions

- The model allows patients to capture a different follow-up MD after returning from required testing.
- Since further testing procedures were done in another department of the hospital, we did not consider testing equipments as a resource and testing procedure as part of the ER process. In the simulation model, diagnostic testing is only a delayed process with Triangular Distribution of a minimum of 94, a maximum of 192, and an average of 156 minutes. Time recordings result from the minimum (94 minutes in the CAT lab), maximum (192 minutes in the operating room or OR), and average service times during all four available tests.
- Testing time represents all the tests required regardless of the number of testing equipment that a patient required.
- MDs and treatment nurses in Pod C continue to provide treatment to patients until the last patient leaves the ER even it goes beyond the Pod C operational hours.
- A patient occupies the assigned bed even though he or she is sent for a testing process. A patient releases the bed only when leaving the ER

### 4.2 Model Description

The software package, Flexsim, was used to develop and simulate the operations of the ER at this hospital. The simulation model followed the patient flow process previously described and included all other input data obtained. An additional sub-model, called Day-Time Check, was created because of the limited operation hours of Pod C, which receives patients between 11:00AM and 11:00PM on only weekdays. This sub-model was developed mainly to simulate the operational hours and differentiate weekdays from the weekend. Upon completion of the triage process, the model checks on the value of variables in this sub-model to determine if Pod C open before assigning patients to the pod. In addition, several sub-models and variables, entitled Dummy, were developed to help with the operational logic of the system and statistical collection. For verification and validation purposes, the model has been animated to provide an overall view of the ER system as the simulation is running. This animation not only helps the modeler to determine whether the model is working correctly (Law and Kelton 2000), but it also allows the decision-maker to view a snapshot of the entire simulation. A snapshot of the animated ER model is shown in Figure 2.The flow process starts on the far left of a screen, which generates the patient arrivals by three transportation modes, and moves forward process-by-process to the far right. The treatment process has been separated into three parallel sections by each Pod area for ease of view. The upper, the central, and the bottom sections of the animation display the flow of patients and the status (busy or idle) of the MDs, the treatment nurses and beds in Pod A, Pod B, and Pod C, respectively.

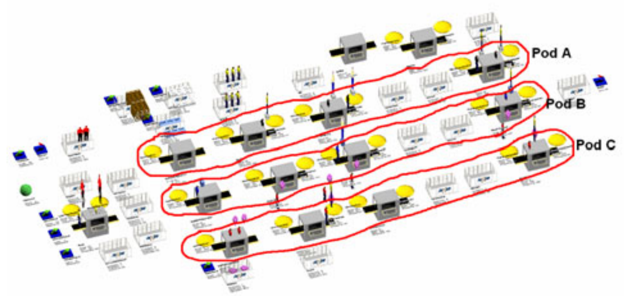


Figure 2: Animation Snapshot of Emergency Room Model

The remarkable characteristic of this ER simulation model is that it has been developed in the form of an interactive model. This interactive model allows users to make changes in all parameters, including the number of MDs, nurses and beds, the patient arrival rate, the service time of each treatment activity, and experimental scenarios. Therefore, the model has a high capability to simulate the ER operation in order to get much closer to the actual system. Consequently, the model is able to provide the healthcare management with more accuracy and flexibility. To make the interactive model, the input data and output result spreadsheets were created on MS Excel 2003. These spreadsheets are linked with the Flexsim simulation model and give the analyzers more visualization and ease in adjusting input data, formulating bioterrorism scenarios, and analyzing output results. By doing this, the users are able to evaluate the preparedness level of the hospital without even knowing how Flexsim works.

### 4.3 Validation and Verification

In order to determine whether or not the simulation model accurately represents the real system, we used several methods for validating the simulation model. Following the first meeting with the ER director, the flow process diagram, as shown in Figure 1, was presented to validate that the model is an accurate representation of the actual system according to the information obtained. Each section of the model logic as well as the service time distributions and arrival time were discussed in detail with the ER director before the construction of the model began. The data collection process was performed by the ER management and included all shifts. All modeling input that was unavailable was estimated by the panel of ER staff members who are knowledgeable about the actual system. Moreover, after ten replications of the simulation model, with seven days warm-up period and one month run length for each run, the simulation results were collected. These results consist of the average time of three periods, including the time between when a patient arrives at the ER until he or she is assigned to a bed (Arrival to Bed), the time when a patient occupies a bed until he or she leaves the ER (Bed to Depart), and the total time a patient stays in ER. These simulation results were compared to those from the actual system provided to ensure that this model accurately represents the system.

While validation refers to the modeling aspect, verification concerns the computer code. Law and Kelton (2000) define verification as the process of determining whether the conceptual simulation model has been correctly translated into a computer program. These following strategies were used to perform model verification in order to ensure that the computer program is operating correctly as expected. The capability of the Flexsim debugger was used to check the model while it runs. If some errors were detected during the run time, a Flexsim compile-error window appeared. The Visual C++ programming was used to locate and fix the error code position. In addition, the animation of the model imitates the behavior of the actual system and helps us verify the model by visualizing its performance. The model was run many times while closely watching the animation which led to the discovery of several errors that were subsequently corrected.

One pseudo-random number stream, for each of the ten replications, was executed under the current hospital resource level. Run lengths and warm-up periods of 30 days and seven days, respectively, were used to allow the system to reach realistic operating conditions before the model collected the appropriate statistics. The model showed that the average total time was 202.42 minutes, which was close to the actual real time of 207.49 minutes. These results were presented to the ER director for evaluation. Eventually, we concluded that these results accurately represent the actual systems and are ready to be applied in a future experiment. The simulation result of the current system is summarized in Table 2 in the next section.

## 5 EXPERIMENTAL SCENARIO ANALYSIS

After the model was validated and verified, we used the model to experiment with the input parameters of the process to determine effects on the system performance measures before a bioterrorism event actually occurs. These measures of performance of interest for the selected decision tracked down the patients' total time in the ER and the ER resource utilizations. The experimental scenario simulated a bioterrorist attack in the Lubbock, Texas area that initiates an outbreak of contagious disease. Although an actual time span of an outbreak might be more than two weeks, an approximation of the first 72 hours is usually considered the critical period, where an enormous number of patients are sent to the hospital. In a bioterrorism attack scenario, we assumed that 432 people are infected with disease during the first three days (72 hours). Thus, we estimated that an additional patient, from the normal three ways of patient arrivals (walk-in, ambulance, and helicopter), is admitted to the ER every ten minutes at a constant rate throughout 72 hours. By running the simulation model with the same type of patients under the same operating conditions and then comparing them to the experimental scenario, any differences observed between both scenarios is due to the impact of the scenario themselves, not to the treated patients.

The average simulation results from ten replications with a seven-day warm-up period, as presented in Table 2, shows that the patients' total time in the ER increases from 202.42 minutes to 495.73 minutes, or an increase of 145%. In addition, the utilization of doctors, as well as beds and treatment nurses in Pod B and Pod C increase over 85%.

The model output portraying both scenarios, in Table 3, shows that the longer total time of patients in the bioterrorist attack scenario results from the longer waiting time in the points of entry into Pod B, Pod C, and the triage area. As shown in Table 2, although there is an extreme increase of the waiting time in the triage area, there is only a slight change in the triage nurse utilization. The reason for this is that under the bioterrorism scenario the treatment in Pod B and Pod C bottlenecks because over 85% of resource utilization occurs in these two pod areas. Thus, adding more triage nurses does not present any improvement in the system.

To process the higher patient volumes during the critical period of 72 hours, we proposed a new strategy of transferring ten surpassing beds from Pod A and twelve surpassing beds from the hallway to Pod B and Pod C, increasing the pods to the maximum capacity of 24 and 20 beds, respectively. To conform to the higher level of transferred beds, two treatment nurses in Pod A would be transferred to Pod C, and an additional five treatment nurses would be assigned to work in Pod B. In addition, two more medical doctors (MDs) would be assigned during this critical period. Therefore, the input parameters of the simulation model were justified. Results from the suggested plan are compared to those of the original bioterrorism scenario in the following summarization.

- The total patient time in the ER is reduced from 495.73 minutes to 188.47 minutes, or a reduction of 62%, under the suggested strategy. Moreover, as shown in Figure 3, this suggested strategy consumes the lowest amount of the patients' total time among these three scenarios.

Table 2: Simulation Results of Two Scenarios

| | **Current system** | **Bio-terrorism** |
|---|---|---|
| **Average Time (min)** | **Time** | **Time** |
| Average Total Time in System | 202.42 | 495.73 |
| **Utilization (%)** | **Rate** | **Rate** |
| 1. Beds in Pod A | 14.47 | 17.21 |
| 2. Beds in Pod B | 57.13 | 88.80 |
| 3. Bed in Pods C | 42.09 | 90.88 |
| 4. Beds in Hallway | 11.74 | 35.84 |
| 5. Doctors | 60.83 | 87.43 |
| 6. Nurses in Pod A | 23.38 | 28.29 |
| 7. Nurses in Pod B | 75.95 | 85.14 |
| 8. Nurses in Pod C | 75.97 | 92.54 |
| 9. Triage Nurses | 39.99 | 49.31 |

Table 3: Waiting Times (Minutes) in Each Treatment Unit of Three Scenarios

| **Resource Facility** | **Current System** | | **Bioterrorism** | | **Suggested** | |
|---|---|---|---|---|---|---|
| | **Avg.** | **Max** | **Avg.** | **Max** | **Avg.** | **Max** |
| **1. Triage Nurse Station** | 0.11 | 16.29 | 224.10 | 671.57 | 0.49 | 26.86 |
| **2. Diagnostic Testing** | 149.67 | 230.78 | 167.89 | 398.32 | 154.65 | 264.71 |
| **3. The facilities in POD A** | | | | | | |
| -- Doctor Evaluation | 26.59 | 39.33 | 26.33 | 38.98 | 26.74 | 39.09 |
| -- Nurse Treatment | 0.00 | 0.00 | 0.80 | 5.63 | 1.91 | 66.52 |
| **4. The facilities in POD B** | | | | | | |
| -- Queue of Entry | 0.14 | 29.44 | 227.74 | 583.94 | 19.49 | 168.00 |
| -- Doctor Evaluation | 17.68 | 29.71 | 17.62 | 29.29 | 17.70 | 29.41 |
| -- Nurse Treatment | 3.13 | 54.69 | 5.29 | 52.11 | 1.33 | 30.14 |
| **5. The facilities in POD C** | | | | | | |
| -- Queue of Entry | 0.15 | 0.13 | 60.03 | 408.42 | 0.53 | 0.96 |
| -- Doctor Evaluation | 14.96 | 24.55 | 15.07 | 24.24 | 15.14 | 24.28 |
| -- Nurse Treatment | 1.81 | 53.80 | 7.55 | 63.10 | 2.18 | 35.95 |

- The suggested strategy reduces the patients' average waiting time for Pod B from 227.74 minutes to only 19.49 minutes and for Pod C from 60.03 minutes to only 0.53 minutes.
- As shown in Figure 4, in the suggested strategy improves the utilization of beds in Pod A from 17.21% to 42.86% and that of treatment nurses in Pod A from 28.29% to 46.61%.
- Since the new strategy reduces the utilization of MDs, beds, and treatment nurses in Pod B and Pod C to a suitable level as shown in Figure 4, we conclude that the additional doctors, beds, and treatment nurses contribute to a significant reduction of excess work load.
- The suggested strategy also reduces the average waiting time in triage queue from 224.10 minutes to 0.49 minutes without adding more triage nurses within this area.

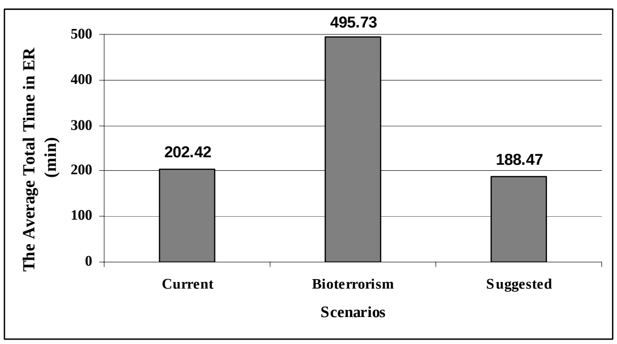


Figure 3: Average Total Time of Patients in the ER for Each Scenario

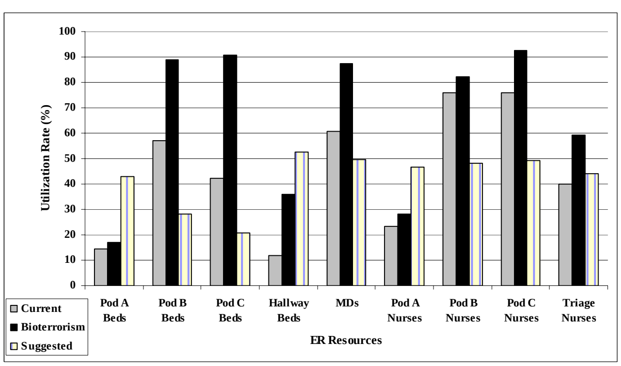


Figure 4: The Utilization of ER Resources for Three Scenarios

Since there were some conditions of uncertainty associated with input parameters, a sensitivity analysis was performed on the simulation results of the suggested strategy scenario. The objective of this analysis was to minimize the risk in making a decision. The following four parameters were selected for this study: inter-arrival time of bioterrorism patients, duration of bioterrorism attack, number of MDs, and number of treatment nurses in Pod B during the first 72 hours of the bioterrorist attack. The initial values of each parameter consist of the input data used in the suggested strategy scenario. To perform sensitivity analysis, these initial values were deviated one at a time, and the simulation model was completed with ten replications and a seven-day warm-up period to observe the effect on the patients' total time in the ER. The results of the sensitivity analysis are presented in Figure 5.

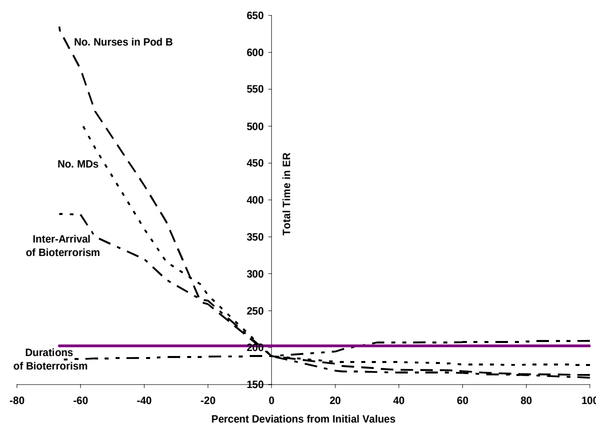


Figure 5: The Results of the Sensitivity Analysis

The sensitivity analysis shows that an excess number of MDs and treatment nurses does not significantly improve the system performance. On the other hand, having insufficient staff is the underlying cause of an increase in the total patient time in the ER. As shown in Figure 5, the patients' total time will be higher than 270 minutes, an increase of 50%, if the number of MDs, treatment nurses, and inter-arrival of bioterrorism patients are reduced by at least 20% of the initial values. However, the duration of bioterrorist attack has a small effect on the system performance. In other words, we now assume that the average patients' total time of 202.42 minutes, which is the result from the current system, is an acceptable level. Therefore, the system performance in the suggested strategy will be acceptable as long as either the duration of bioterrorism does not increase by more than 30% of the initial value or all of those three parameters do not decrease by more than approximately 5% of the initial values.

## 6 CONCLUSIONS AND FUTURE WORK

An innovative simulation model of the ER at the hospital featured in this study was developed, validated, and verified to aid in decision-making about the resource and staff utilization under the hypothetical bioterrorist attack scenario. The performance measures of interest include the average total time in system of patients and the utilization of ER resources. This scenario assumed that an additional patient from the normal three ways of patient arrival (walk-in, ambulance, and helicopter) was admitted to the ER every ten minutes at a constant rate throughout 72 hours. The output results from the current system suggested that the point of entry to Pod B and Pod C are the bottlenecks. The suggested strategy was proposed by transferring the surpassing beds from Pod A and the hallway to Pod B and Pod C and adding treatment nurses, as well as doctors to these bottleneck areas. The suggested strategy not only improved the patient's total time in the ER by 62%, but it also increased the utilization of the resources in Pod A by approximately 20%. The sensitivity analysis also suggested that while the longer duration of bioterrorist attack does not have a significant effect on the system performance, the higher arrival rate of the bioterrorism patients and the smaller numbers of the MDs and treatment nurses are the underlying cause of an increase in the patient's total time in the ER. One of the characteristics of the model is that it is highly flexible. The model is easily customized by allowing users to adjust the input parameters via the user interface form without forcing the users to access the simulation software or language at any time. In addition, the simulation results are presented in the output form that displays all performance measures of interest.

Since this study has a number of assumptions relating to the simulation model, we plan future work to relax all of these assumptions in order to more reflect the real-world situations during bioterrorist threats. For example, the bioterrorism patients' arrival rate should not be a specific, constant rate over a 72-hour period, but we will alter the rate by the hour or even by minute. The number of ER staff will be changed during the day as a result of worker shifts or work breaks. Another issue of consideration is an insufficient amount of medical equipment, medical supplies, or drugs.

## ACKNOWLEDGMENTS

The author would like to thank Dr. Elliot J. Montes for inspiring an initial attraction to this research. In addition, the author is indebted to Ms. Ean-Harn Ng for helping collect the data.

## REFERENCES

Koehler, J. 2001. Communicable Disease Control, Epidemiology & Immunization Section, Public Health – Seattle & King County. *Surveillance and Preparedness for Agents of Biological Terrorism (presentation).*

Law, A.M., and W.D. Kelton. 2000. *Simulation Modeling and Analysis*, 3 rd ed., McGraw-Hill Book Company, New York.

Oh, P.Y., R. Zhang, C. Mode, and S. Jurgens. 2004. *Information Technologies for Civilian Bioterrorism Response. Drexel University*. Online, Available at <http://prism2.mem.drexel.edu/~paul/papers/finalOhCimercCcct2003.pdf>. Accessibility verified October.

Osterholm, M.T. 2001. How to Vaccinate 30,000 People in Three Days: Realities of Outbreak Management. *Public Health Reports*, March-April.

Systems Modeling Corporation. 1994. *Arena User's Guide*, Sewickley, Pennsylvania.

Walden, J., and E.H. Kaplan. 2004. Estimating Time and Size of Bioterror Attack. *Emerging Infectious Diseases*, Vol. 10, No. 7, pp. 1202-1205.

## AUTHOR BIOGRAPHY

**LISA PATVIVATSIRI** receives a doctoral degree in the Department of Industrial Engineering at Texas Tech University. She has a BS degree in Industrial Engineering from Chulalongkorn University in Thailand and a Master's degree in Industrial and Systems Engineering from Virginia Polytechnic Institute and State University (Virginia Tech). Her research interests include simulation modeling, particularly in the healthcare field.