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OPERATIONAL ANALYSIS FRAMEWORK FOR EMERGENCY OPERATIONS CENTER PREPAREDNESS TRAINING

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ABSTRACT

As the U.S. Department of Homeland Security works to create an integrated emergency response system, it is evident that computer-based solutions can support this process. Individual commercial simulation packages and databases can provide a partial solution, but are not easily integrated to provide a comprehensive analysis of the events. To achieve model and domain knowledge integration, an analysis framework is developed to allow a broad range of simulation systems to share information, including inputs, models, and results. This analysis framework facilitates the combination of standalone scenarios into one master scenario where the overall chain-of-events can be analyzed and optimized. This paper describes a framework used in the simulation of an anthrax incident. The simulation modeled State, City, and Department of Health EOC processes executed under the Incident Command System (ICS). Hospital and distribution center models were integrated to add the effects and impact of the general population into the scenario.

1 INTRODUCTION

The National Strategy for Homeland Security and the Homeland Security Act of 2002 initiated a process to organize resources associated with the security agencies of the United States against terrorist attacks. As the nation's numerous local city/county, state, regional, and national agencies reorganize, it has become increasingly apparent that significant efforts are required for these organizations to develop, implement, and test the operating procedures that determine how agencies will respond, manage, and recover from catastrophic incidents. Few, if any, opportunities exist where an agency's response plan and standard operating procedures can be tested. This is particularly true when an incident crosses local, regional, or national boundaries requiring communication and coordinated activities between agencies. The Department of Homeland Security's Science and Technology Directorate is tasked with researching and organizing the scientific, engineering and technological resources and leveraging these into technological tools to help protect the homeland (USDHS 2004). For these reasons, computer-based operational analysis techniques are key in providing efficient and cost-effective decision support for emergency preparedness strategy planning and assessment.

The Incident Command System (ICS) is a model designed to provide fundamental coordination among agencies in an emergency, crisis management, and disaster recovery. The ICS specification served as the framework for the homeland security (HLS) operational analysis modeling effort. In disasters involving multiple emergency operations centers or agencies, ICS provides a framework for an organizational structure and guidelines for standard operating procedures designed to ensure that disaster priorities and resource demands can be met.

1.1 Purpose of Operational Analysis in HLS

Operational Analysis models come in a variety of categories, but generally speaking, can be classified in three basic groups:

- Discrete-event simulation is a simulation that changes state as events occur in the simulation.
- Continuous simulation is a simulation in which state varies continuously based on changes in time.
- Combined discrete-event and continuous simulation – a combination of the two types.

Modeling and simulation (M&S) helps us predict the outcome of decisions, visualize, analyze, and optimize before committing capital and resources.

For the homeland security efforts described in this paper, discrete event simulation models are utilized to analyze and refine standard operating procedures and results of events and decisions by:

- Verifying interoperability between entities,
- identifying gaps and bottlenecks in existing plans,
- enhancing resource utilization and plan functionality, and
- rapidly exploring options to improve/refine plans.

These efforts also address the integration challenges of system integration, data translation and model development as described by Jain and McLean (2003), such as:

- Interoperability between emergency response modeling and simulation applications is currently extremely limited.
- The cost of transferring data between emergency response simulation software applications is often very high.
- The simulation model development process is labor-intensive.

2 OPERATIONAL ANALYSIS FRAMEWORK

Discrete simulation modeling tools provide capabilities to develop and execute models for the analysis of operational processes and system performance. This by itself is a valuable capability, but many of these tools are complex and require special training and technical expertise.

A goal of this simulation effort was to provide to planners and subject matter experts a toolset used to capture, analyze, and execute what-if scenarios with the goal of identifying and improving potential short comings of their operating plans against various emergency incidents. It was deemed necessary to integrate the tools into a modeling and simulation framework in order to isolate the user from the tools complexity and present a common operating environment. The framework allows the users to modify initial and real-time input parameters, execute the models, control the simulation, and view/capture results. The results can be used for process improvements, initial conditions or parameters for follow-on training activities such as a functional or simulation based training exercise. Figure 1 illustrates the operational analysis framework.

The User Community interacts with the tools by way of a Presentation Layer which in turn is interfaced with a Workflow Engine. Separating the presentation from the underlying tool set and tool specific data formats, allow us to achieve a common and consistent user interface. This approach is fairly well known in the commercial enterprise client-server software domain. In addition, the workflow engine introduces flexibility to control the interactions and sequences of actions based on results and user response. The workflow engine helps isolate the tool specific interfaces, which will later facilitate the substitution for different tools should it be necessary. The framework is designed to run with other simulations via runtime web services and simulation standards like HLA/RTI and DIS.

Relational Databases are used to store and manage the data. The data may come from different sources as requirements data, previous analysis data, current statistical data, and data from previously run forecasting tools. This allows for existing or new input data from different agencies to be collected and considered during the simulation. XML/XSLT and SQL stored procedure technologies

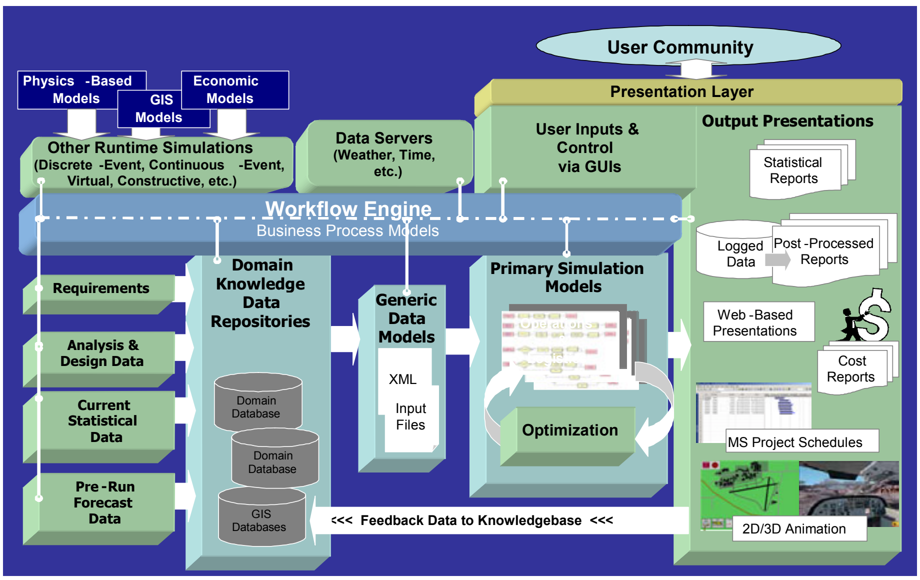

Figure 1: Homeland Security Operational Analysis Framework

are leveraged to parse and format the collected input data as required by specific modeling tools. Via these methods only the data necessary to run the simulation is transferred to the emergency response simulation.

The *Presentation Outputs* can take many forms such as: statistical reports, logged data, cost data, schedules, and 2D/3D animations. Web-based presentations can be generated using to-HTML utilities. It is important to note that the framework includes feedback of result data back to the knowledgebase for data collection and parameters for reports and future runs.

2.1 The Conceptual Scenario Architecture

Figure 2 illustrates the conceptual architecture of the HLS operational analysis scenario which is partitioned into emergency scene models and the emergency operations center models. The Emergency Operations Center (EOC) models simulate the activities and communications performed by the various agencies involved at the local city, department of health and state level.

The emergency scene consists of a collection of models that represent the environment outside of the EOC. The emergency scene contains models which simulate the population, based on census data, to seek healthcare based on exposure to the disease. The healthcare treatment hospital and distribution center models treat the population seeking treatment, both those infected with the disease and the worried well. Worried well patients are not actually affected by the disease, but believe they have symptoms which make them believe they are infected.

3 DESCRIPTION OF THE TEST SCENARIO

A hypothetical scenario for a fictional anthrax incident which involves multiple local city, state, and department of health and safety agencies was used to provide design guidance and parameters for the models.

A terrorist group arranges for an anthrax contamination of the registration materials for veteran's group convention in Dallas, Texas. The staff and attendees who arrived in tour busses are unaware of the exposure and they depart from the convention after the event.

The extent of contamination of the travelers is undefined, but each of the convention goers had ample opportunity to inhale some quantity of anthrax spore. The possibility of contamination of the buses, the Dallas hotel, the hotel service personnel, the bus drivers, and the secondary places of residency of each of the tour groups will be considerations for the emergency response agencies to address upon discovery of the source of the pending illness.

3.1 Response to the Incident

Over a twenty four to forty eight hour period, various local city, state, and federal agencies in New Mexico and Texas undertake actions to isolate potential victims, identify and quarantine contaminated areas, determine source of contamination, assist local health agencies in patient management, and secure evidence for potential criminal prosecution. Other activities are the decontamination and relocation of patients, distribution of prophylactic agents to exposed persons, public announcements, and media interaction.

4 THE MODELS

The incident or scenario described above helped provide a definition of the necessary models and activities to be developed as well as guidelines for development of to operational analysis models. The analysis required that models be developed for the emergency operations center (EOC), hospital, distribution center, population and an anthrax disease/worried well progression.

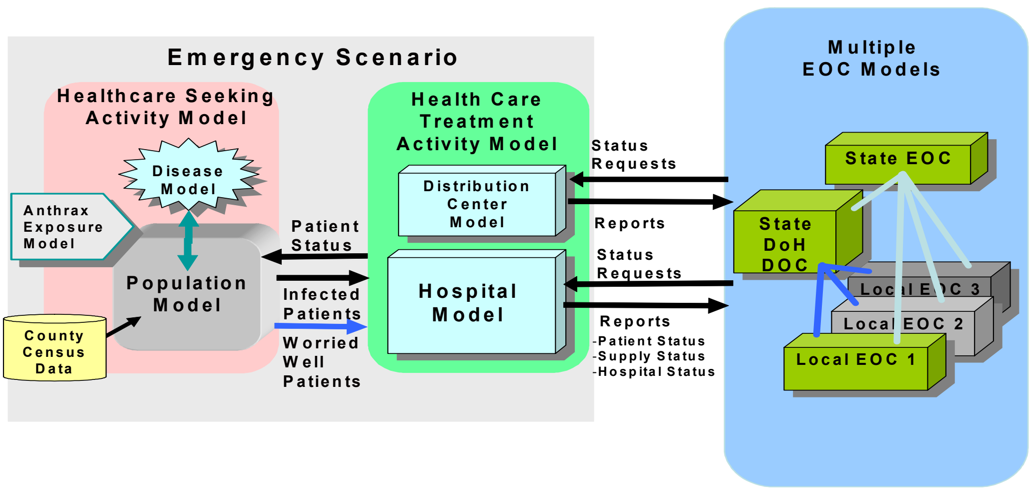

Figure 2: Conceptual Scenario Architecture

Arena, a modeling and simulation tool, was used to implement the submodels that compose the operational analysis simulation. The submodels were first developed as standalone models and then combined into one large Arena model for the purpose of this analysis.

4.1 Emergency Operations Center Model

The emergency operations centers are modeled after the Incident Command System (ICS) specification. The model, as shown in Figure 3 includes staff positions for command, operations, planning, logistics and finance and is instantiated for several local city and state operations centers including the Department of Health (DOH). Any staff position in any instance of an EOC has physical resources identified as fax, e-mail, telephone, computers, and meeting rooms.

A statistical analysis of the EOC staff activities was performed using a Master Scenario Events List (MSEL) prepared for the hypothetical anthrax scenario. The MSEL is a list or table that chronologically lists and synopsizes key events and responses with scenario times and objectives as described in USDHS (2003). This data provided the timing and frequency for EOC staff activities. The model allows for such activities to include interoffice communication via phone or email, computer work to be completed such as the filling out of the necessary computer generated forms and procedurals, and the entire decision making processes needed within a given scenario. Within this incident an example of a decision made by the EOC model is the timing of the opening of the aforementioned distribution center.

The Arena M&S tool allows for model templates to be defined which have graphical user interfaces (GUIs). This feature can be used to allow the user to select the resources each staff member has and the type of contacts, communications, and activities performed by the EOC staff member like the one shown in Figure 4. This allows the user to change any of the given parameters without actually having to delve into the model itself, thus creating a generic interface to inter-workings of the model.

During the hypothetical scenario, a local city EOC is initially stimulated by the hospital model, which generates reports when hospital overcrowding conditions are reached. The integrated activity is achieved by local EOCs requesting status reports for hospital, patients and supplies from overcrowded hospitals. Communications are generated between local and state EOCs as the incident progresses. A generic event routing capability was developed to provide the flexibility necessary to allow the user to define EOC staff communication "connectivity".

4.2 The Hospital Model

The hospital model includes waiting room, patient check in and check out, examination, bedrooms and patient transfers when overcrowding conditions exist. Figure 5 depicts the inputs and outputs of the hospital model.

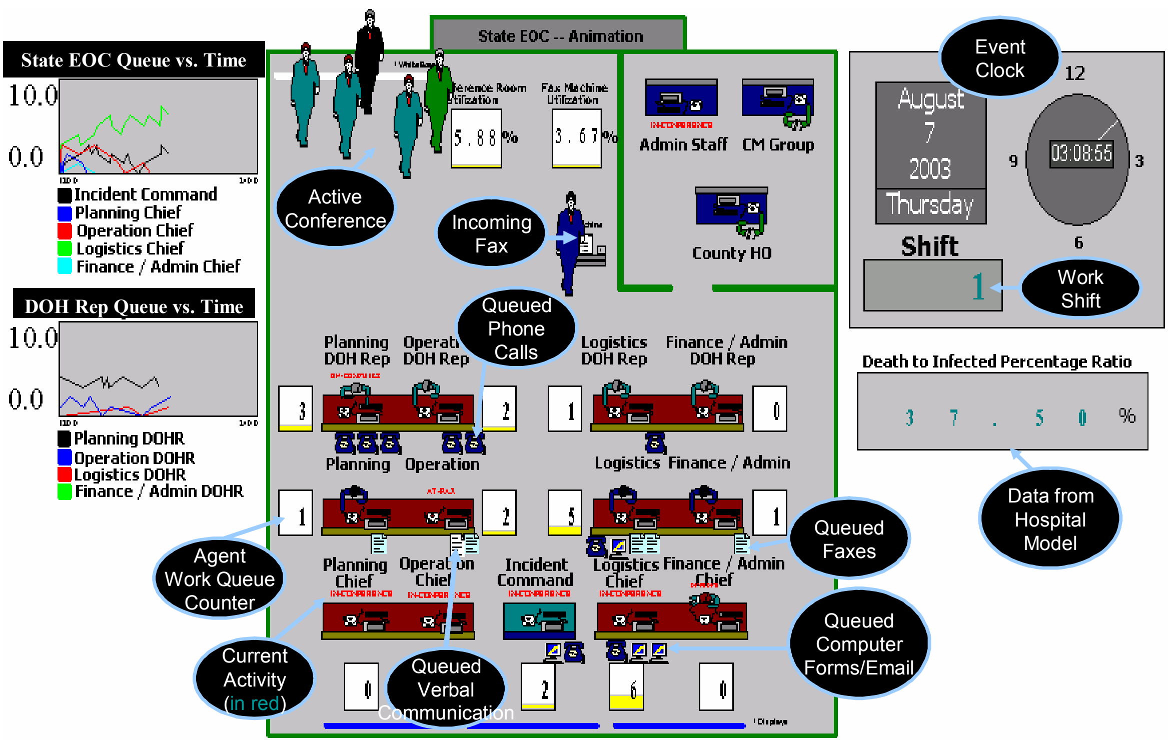

Figure 3: Sample Emergency Operations Center

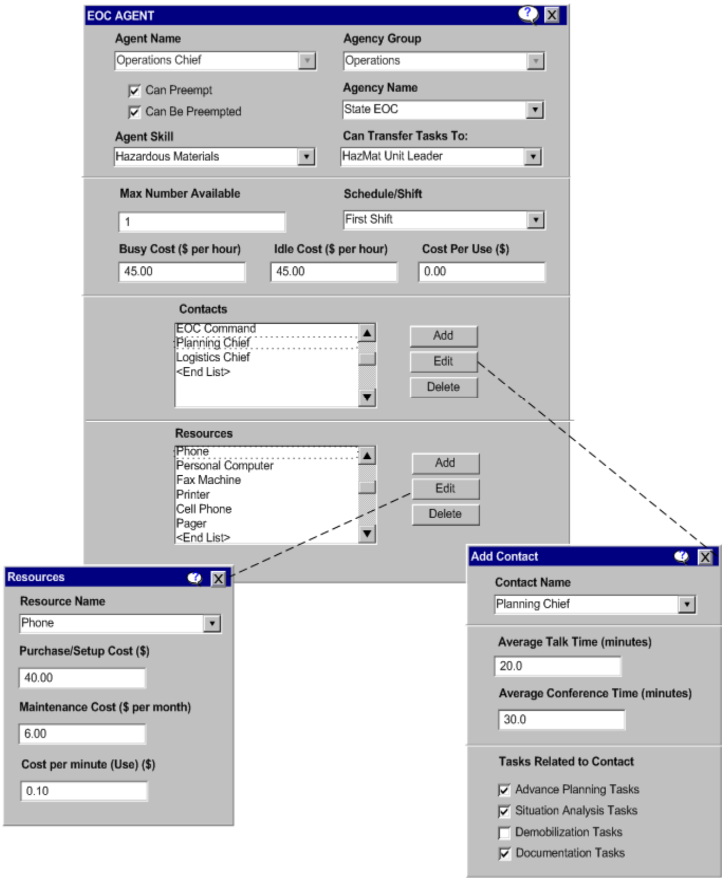

Figure 4: Sample EOC GUI

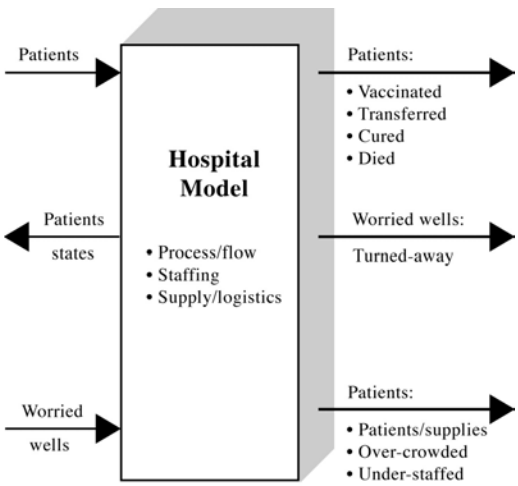

Figure 5: Hospital Model Data

4.2.1 The Hospital Check-In

The entities within the population check in with the receptionist for 1-2 minutes. Since most patients that enter triage in hospitals are normally checked, only 10 % of worried well are turned away. The reason the hospital must turn away these individuals is based on the assumption that during an outbreak, resources are limited, and those who are deemed to have a perfect bill of health and no symptoms are turned away to make room for other patients. When the waiting room exceeds 200 patients, patients that need to be examined will be transferred to another hospital. As with all the staffing resources, the number of available resources do not indicate specific individuals, rather the number of individuals in a given shift (i.e., there are many receptionists throughout the day, but only one receptionist at any given time).

4.2.2 The Hospital Waiting Rooms

An assumption is that patients will have to fill out paperwork for insurance and symptoms while waiting to be examined in an examination room. Once an exam room is free, the next patient in the queue seizes this room.

4.2.3 The Hospital Examination Rooms

The following processes must be completed before a patient can enter an examination room. The processes and resources are all assumptions that are derived from a typical emergency room visit. The patient seizes the same examination room, nurse, and doctor in all processes. If a nurse leaves and re-enters the examination room at a later time, this is the same nurse that previously saw the patient.

4.2.4 The Hospital Patient Rooms

If available, an admitted patient enters a hospital room. This process seizes a room and overnight nurse for assistance. The amount of time a patient is held in the hospital is determined by their disease stage and is indicated in the following table.

	Days in Hospital
Incubation Stage	1 – 2 days
Symptomatic Stage	2 – 3 days
Severely Symptomatic Stage	5 – 6 days

After the duration of stay, the hospital room and the patient are routed to the disease progression algorithm to determine their outcome. Next, the patient is routed to hospital checkout.

4.2.5 The Hospital Checkout

This submodel logs the outcome of each patient. Patients who are still infected return to the hospital submodel after a waiting period of ten days. This makes it possible for entities to enter the hospital checkout submodel multiple times. Patients entering the checkout model for the first time will enter a subroutine which logs the total number of infected, deceased, and worried wells based on their gender, ethnicity, and age. This subroutine will then flag the entity as logged and return the entity to the submodel. This prevents a patient from being logged multiple times and keeps calculations accurate. The remaining logic of the submodel routes the patient to other portions of the model based on their outcome. With the exception of deceased patients, entities that re-enter the checkout model will bypass the log update subroutine. Healthy patients are disposed from the simulation, infected patients return to the hospital submodel, and deceased patients are routed to the census calculations submodel.

4.2.6 The Patient Transfer

Patients turned away during hospital check-in are routed to patient transfer. If the patient is a worried well, the simulation will dispose of the entity. A patient turned away that is not a worried well indicates that the queue in Hospital has exceeded 200 patients and the entity is transferred to another Hospital. The current equation used to determine how long a patient waits is given by:

$$\text{Max (60, Number in Hospital Waiting Room).} \quad (1)$$

The assumption is that a patient waits for a minimum of one hour. If there exceeds 60 patients in hospitals waiting room, the patient waits an additional one minute for each additional patient waiting at their time of arrival past 60.

4.2.7 The Patient Has Been Logged

The outcome of the disease progression algorithm determines whether or not the patient is still infected. If an entity is still infected, they must return to the hospital in 10 days as advised by their doctor. If the patient is not infected and is still alive, they are routed to hospital checkout. If the patient is not infected because they have died, their death is logged and the patient is then sent to census calculations.

4.3 Distribution Center Model

Distribution centers are used to provide preventative treatment to the mass population by taking the treatments to the communities, thus relieving load at hospitals. Distribution centers are temporary and set up in existing facilities such as shopping malls, schools, churches, etc. In this scenario the distribution centers are used to distribute antibiotics to counter the spread of anthrax.

4.3.1 The Opening of a Distribution Center

The Joint Operations Center (JOC) liaison is a resource in the hospital model. Upon creation, the liaison waits for the signal that the hospital supply of antibiotics needs to be restocked. At this time, not only does the hospital supply get restocked, but the distribution center also received a supply of antibiotics. Upon the arrival of antibiotics, the distribution center officially opens, and now entities are routed there as well as the hospital.

4.3.2 The Distribution Center

Entities immediately receive antibiotics when entering the distribution center. The distribution center checks supplies and restocks when necessary. If a patient is infected and ends up in the distribution center, they are routed to the hospital within 10 days.

4.4 The Population

The population model provides a representation of the general population and is initialized using census data. Initially, an average of four uninfected entities is generated every 10 minutes. These entities' attributes also align to census data to generate an accurate depiction of the general population. The number of worried wells created every 10 minutes is given by the following equation

$$\text{Min ((number patients died) / Max (1, (number infected patients))*6.25 + 4, 20).} \quad (2)$$

The worried wells to infected ratio should range from 4:1 to 20:1. The above equation has the following properties:

- The values range from 4 to 20 inclusive.
- The value begins at 4 in the beginning of the simulation.
- The value is incremented by 1 for every 6.25% increase in deceased to infected ratio.
- The value is decremented by 1 for every 6.25% decrease in deceased to infected ratio.

Calculating the ratio in this manner keeps the worried well to infected ratio varied, yet stable. If the distribution center is open, then 98% of worried wells go to the distribution center to get antibiotics, the remaining 2% route to the hospital. If the distribution center has not yet been opened, then 100% of the worried wells are sent to the hospital. The basis and logic for the origin of anthrax model is taken from the diagram shown in Figure 6.

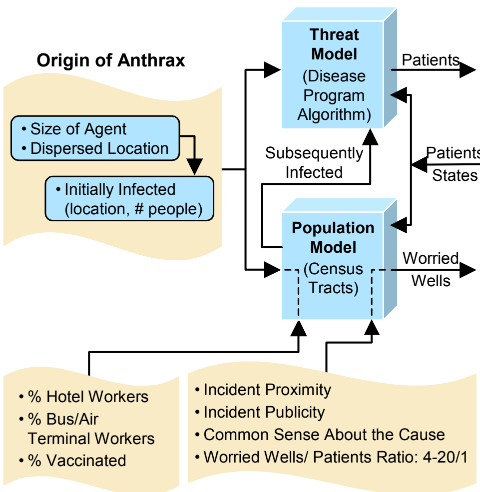

Figure 6: Threat Model

4.5 The Threat (Anthrax)

4.5.1 The Disease Progression Algorithm

When entities first enter this station, their disease stage is calculated. Disease progression data was derived from Chen et al. (2003). The following table of percentages gives the likelihood an entity will be in a given disease stage.

Individuals are initially infected while publicity and common sense play into the generation of worried wells. Since anthrax is a non-contagious disease that progresses through time, the assumption is that after the population and media are aware of this outbreak, they will be aware of symptoms sooner, thus many more individuals will reside in the clean and incubation stages of the disease.

	Origin of Anthrax	Threat Model	Population Model
Clean Stage	0.00%	0.00%	100.00%
Incubation Stage	33.00%	70.00%	0.00%
Symptomatic Stage	33.00%	14.99%	0.00%
Severely Symptomatic Stage	33.00%	14.99%	0.00%
Death Stage	1.00%	0.01%	0.00%

The following durations of each stage (untreated) were obtained from the Centers for Disease Control and Prevention (2002).

	Disease Progression if Untreated
Clean Stage	0 days
Incubation Stage	1 – 7 days
Symptomatic Stage	8 – 10 days
Severely Symptomatic Stage	11 – 13 days
Death Stage	14 days

From this data, the treatment type is determined. Since there were five treatment types, it is assumed that these treatments align with the five disease stages, and the treatment type is given by the following table.

	Length of Disease at Time of Treatment
No Treatment	0 days, 14 days
Light Treatment	1 – 4 days
Medium Treatment	5 – 8 days
Heavy Treatment	9 - 11 days
Hospitalization	12 – 13 days

If a patient is under the age of 5 or over the age of 64 the algorithm will increase the level of treatment by one to two stages. There is an 80.000% probability that the patient will be given treatment one level higher than suggested and a 20.000% chance that the patient will be given treatment two levels higher than suggested. Treatment time will not exceed time for Hospitalization. If the distribution center is open, 1% of all infected patients are routed there, regardless of their disease stage. The remaining 99% go to the hospital. When the distribution center is not open 100% of the infected entities go to the hospital.

The basis and logic for the Disease Progression algorithm was based on the diagram shown in Figure 7.

4.5.2 The Outcome of the Disease Progression Algorithm

After the patient has been examined, the logic returns to the disease progression algorithm to determine the out-

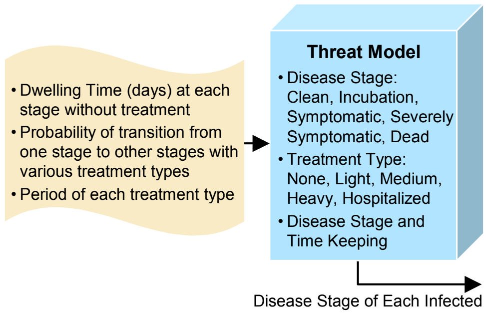

Figure 7: Disease Progression Model

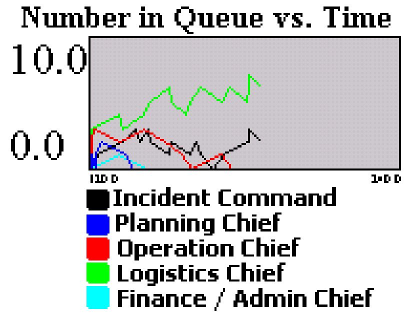

Figure 8: State EOC Staff Work Queue vs. Time in Minutes

come for the patient. The following mortality rates of each disease stage given below were been taken from the Internet data from CDC.

	Mortality Rate
Clean Stage	0 %
Incubation Stage	20 %
Symptomatic Stage	90 %
Severely Symptomatic Stage	93 %
Death Stage	100 %

The algorithm decides the probability of disease progression based on the patient's current stage. For each disease stage of the patient upon entry into the hospital, a probability of the patient progressing into the next stage within 10 days of treatment is specified. The exception to the treatment length is hospitalization, in which a patient in the incubation stage is treated for 1-2 days, a patient that is symptomatic is treated for 2-3 days, and a patient who is severely symptomatic is treated for 5-6 days.

Entities from the disease progression algorithm are routed to the hospital, then return to the outcome from the disease progression algorithm, and are finally routed to the hospital checkout. The outcome of an entity is already determined before reaching the hospital checkout flow.

5 RESULTS

The EOC, hospital and distribution center models were integrated to provide results indicative of the execution of all models combined. Statistics are gathered for the EOCs activities, the general population, and the hospitals.

5.1 EOC Statistics

As the simulation executes, runtime statistics are displayed for each of the EOCs indicating staff load versus time as shown in Figure 8.

The EOCs statistics include utilization of the resources, fax, telephone, computer, e-mail, conference room and verbal conversations by staff position and location. By location we mean Texas State EOC, New Mexico EOC, Austin, Lubbock EOCs and so forth. Sample reports for collected statistics are illustrated in Figures 9 and 10.

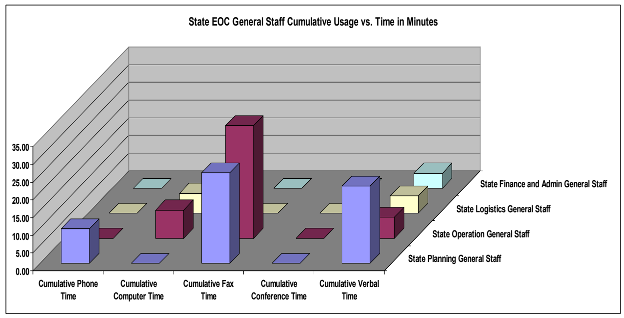

Figure 9: State EOC General Staff Cumulative Usage vs. Time in Minutes

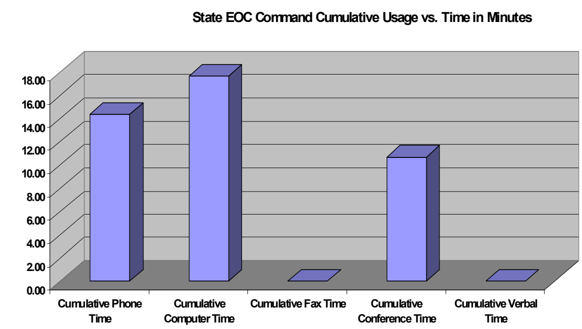

Figure 10: State EOC Command Cumulative Usage vs. Time in Minutes.

5.2 Hospital Statistics

The hospital model statistics include staffing, supply resource utilization costs as follows:

- Utilization – Doctor, Nurse, Receptionist, Examination Room and Beds.
- Staffing - Doctor, Nurse, Overnight Nurse and Receptionist.
- Supplies – Bandages, cotton balls, needles, Petri dishes and antibiotics.

Some sample statistics are graphed in the diagrams of Figures 11 and 12.

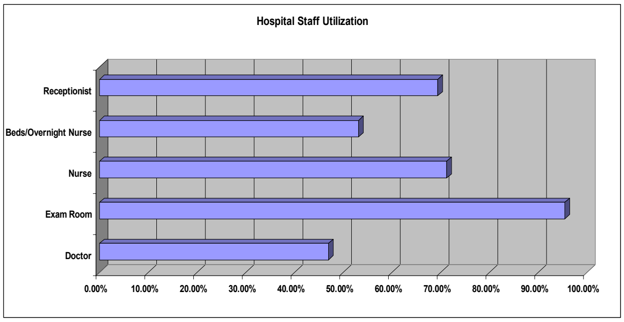

Figure 11: Hospital Staff Utilization

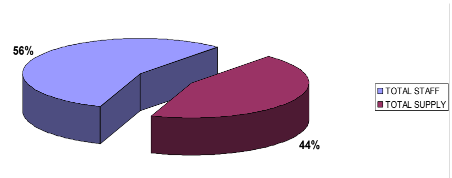

Figure 12: Total Staff Cost vs. Total Supply Cost

6 CONCLUSION

The current US Homeland Security initiatives provide a unique opportunity to leverage modeling and simulation capabilities to help explore and define how the current and evolving operating procedures and infrastructure will address the emerging requirements from local, state, and regional operations centers and agencies. Since these facilities are being tasked to respond to incidents involving catastrophic events, it is important that the centers standard operating procedures and communications between centers and agencies be exercised and tested. Currently, there are limited opportunities, such as TOPOFF, which test or exercise agencies standard operating procedures in a multi agency environment under a WMD like incident. The exercises occur infrequently, are costly to plan and execute and involve a relatively small portion of the overall community.

Modeling and simulation technologies offer a clear opportunity to design, test and train staff regarding a center's internal operations and communications and coordination between agencies. A framework that allows for multi-agency requirements and knowledge data inputs is essential to the successful implementation of emergency response simulations. This combined with graphical user interfaces and scenario control via a workflow engine can provide an integrated, versatile, and interoperable operational analysis system as required by the DHS Science & Technology Directorate Emergency Preparedness & Response (2004).

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