Mass Evacuation Transportation Model: Description

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Contents

1. Summary

With funding from the Agency for Healthcare Research and Quality (AHRQ), Abt Associates developed the Mass Evacuation Transportation Model, which estimates the time required to evacuate patients from healthcare facilities. The Transportation Model is accessible from the AHRQ Web site at massevacmodel.ahrq.gov. This document describes the Transportation Model and how the model was pilot tested in two test sites – New York City and Los Angeles. A companion report (the Mass Evacuation Transportation Model: User Manual) provides instructions on how to run the model.

This work is part of an AHRQ Task Order with Abt Associates and its subcontractor, Partners Healthcare, to support development of a national strategy for the design, development, and implementation of an interagency mass patient and evacuee movement, regulating and tracking system. The National Response Plan assumes that up to 100,000 patients and evacuees may require transport, regulating, and tracking during a catastrophic incident. The AHRQ project was undertaken in collaboration with the Federal Emergency Management Agency, the U.S. Department of Defense (DoD), and the U.S. Department of Health and Human Services' Office of Public Health Emergency Preparedness. AHRQ and DoD jointly led the project. A project steering committee was also convened that guided the project and three day-long meetings were held. (See Appendix 1 for a list of committee members.)

The larger project had two overall goals:

- Build a Web-based Mass Evacuation Transportation Planning Model for use ***before*** a mass casualty/evacuation incident to estimate the transportation resources needed to evacuate patients and evacuees from healthcare facilities and other locations.

- Develop recommendations for a National Mass Patient and Evacuee Movement, Regulating, and Tracking System that could be used ***during*** a mass casualty or evacuation incident for the purposes of locating, tracking, and regulating patients and evacuees, as well as provide decision support to persons and organizations with responsibility for patient and evacuee movement and care, healthcare and transportation resource allocation, and incident management.

This report addresses the first of these two project goals. A separate AHRQ report details the recommendations for the National Mass Patient and Evacuee Movement, Regulating, and Tracking System.

Model Summary

The model calculates the time required to transport patients from evacuating facilities to receiving facilities. The model considers:

1. Evacuation Resources: The fleet of vehicles available in an emergency is a key input of the model. The user must identify how many advanced life support (ALS) and basic life support (BLS) ambulances, wheelchair vans, and buses are available for use during the evacuation, and how many patients each vehicle can carry at a time.

2. Facilities: Users can input any number of facilities into the model. The key attributes of each facility are whether it is an evacuating or receiving facility, the assumed transportation needs of the patients at the facility during the evacuation (i.e., the percent requiring an ALS ambulance, BLS ambulance, wheel chair van, or bus), the facility capacity and occupancy rate, and its location. Each facility may have a different patient mix. Patients are thus grouped by acuity rather than the specific diagnosis and are prioritized during the evacuation to ensure that the most severely ill patients travel the least distance.

3. Additional inputs: Additional features include: accounting for traffic congestion by lengthening expected travel times, specifying the loading or unloading time for each vehicle type, and designating an "overflow facility" for patients who cannot be accommodated in the designated receiving facilities.

The primary output of the model is the number of hours necessary to transport patients from the evacuating facilities to the receiving facilities. In addition to the total hours for evacuation, the model shows the number of trips made by each vehicle type, thus indicating which vehicles are most in demand. This will help planners anticipate resource needs.

Application

New York City and Los Angeles participated in this project and served as pilot test sites for the model. In New York City, AHRQ and project staff worked with the City's Office of Emergency Management (OEM) to assist them in developing plans to evacuate coastal hospitals and nursing homes in the event of a Category 4 hurricane. Working closely with OEM, project staff obtained input data, ran the model under a variety of assumptions, and delivered an analysis of the output to OEM and AHRQ. A copy of the analysis is in Appendix 2.

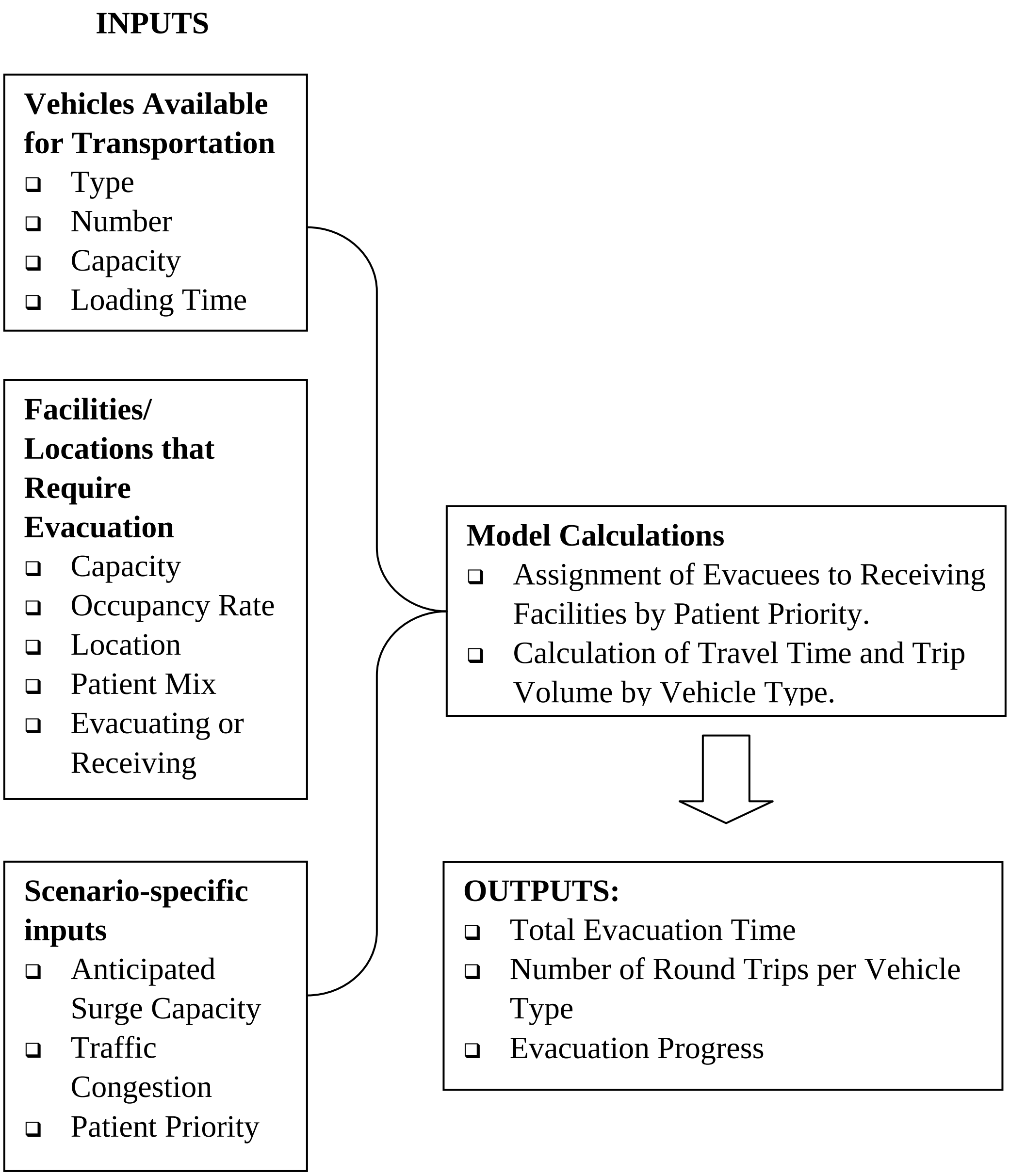
In Los Angeles, AHRQ and project staff worked with the Los Angeles Emergency Preparedness Department (EPD) to prepare and conduct an earthquake tabletop exercise that required the evacuation of three hospitals. The model was used to estimate the transportation resources needed to evacuate the three hospitals under a variety of assumptions.

The remainder of this report includes a detailed description of user inputs, assumptions, model processes, and outcomes.

2. Model Description

Exhibit 1 shows the overall structure of the model. On the Web implementation of the model (see the separate report, Mass Evacuation Transportation Model User Manual), the user specifies a number of different inputs. Based on the specified inputs, the model determines where patients need to be transported and estimates how long it will take for the available vehicles to transport them to the receiving facilities. The output includes the total evacuation time, the number of round trips required for each vehicle type, and a graph of evacuation progress by patient type.

Exhibit 1: Transportation Model Structure



2.1. Inputs

Before the model can be run, several inputs describing the available resources, the facilities involved in the evacuation, and the scenario-specific inputs must be provided. The following describes each in detail.

2.1.1 Vehicle Inputs

The number and capacity of vehicles are considered to be the primary resources determining the eventual total evacuation time. In order to calculate evacuation time, the user must input the following information:

- **Vehicle Type:** The model assumes buses, wheelchair vans, BLS vehicles and ALS vehicles are used in the evacuation. If public transit buses and private coaches are both used to transport ambulatory patients, only one vehicle “type” should be entered using the average characteristics for both. Thus, vehicle types are roughly organized by the type of patient they are able to transport and do not reflect the specific models or ownership of the vehicles.

- **Number of Available Vehicles:** This number is the total number of vehicles of a single type that can be used for the evacuation. It may be that only a subset of the total emergency vehicle fleet could be used. If that is the case, then only those units that will be available during the evacuation should be specified.

- **Capacity:** This is the number of patients a particular vehicle is capable of transporting in one trip. The capacity number should not include the driver. The number should reflect a reasonable capacity under emergency conditions. Thus, a BLS ambulance might be able to accept two patients under emergency conditions even if one is recommended for normal use.

- **Per Patient Load Time:** The loading time is considered in the model. The loading time will obviously be shorter if the scenario assumes that patients are already in the hospital lobby or a nearby staging area (e.g., a parking lot) rather than still in their hospital room. The unloading time at the receiving facilities is assumed to be equal to the specified loading time.

2.1.2 Facility Inputs

For any facility, the following information needs to be input:

- **Name:** The name of the facility (e.g., "Westshore Hospital").

- **Capacity and occupancy rate:** For evacuating facilities, the capacity and occupancy together determine the total number of persons to be evacuated from the facility. For receiving facilities, these two numbers determine the number of persons that the facility can receive during the evacuation, although the user can also specify a surge capacity (see below).

- **Patient mix:** The patient mix is the percent of patients or evacuees that can be transported by each vehicle type. For example, a hospital may have some ambulatory patients that could be transported on buses, some wheelchair bound patients who do not require additional care in wheelchair vans, some bedridden patients who need BLS transport, and ICU patients that require ALS transport. Patients are thus grouped by acuity rather than the specific diagnosis, and are prioritized to ensure that the most severely ill patients travel the least distance. The percentages must sum to a total of 100 percent. Facility patient mix of course varies daily, but an estimate must be input in order to estimate the evacuation time.

- **Location:** In order to calculate the transportation times, the location of each facility must be input. This location should be entered as a latitude and longitude. Transportation times are calculated based upon driving time and traffic conditions. For further information on the calculation of travel times, see Section 2.2.1 below.

- **Receiving/evacuation:** The user must identify whether this is a receiving or an evacuating facility. Evacuees who cannot be transported to receiving facilities, because of capacity constraints, are transported to the "overflow facility" (see section 2.1.3).

2.1.3 Scenario-Specific Inputs

Additional inputs are necessary to characterize the scenario, including how many additional patients a facility can accommodate and whether the traffic routes are impaired. The scenario-specific inputs include those assumptions that are most likely to change from one run to the next. In order to view several evacuation time estimates, one can vary the following scenario-specific inputs:

- **Surge capacity:** The surge capacity input represents the percentage over normal capacity that a receiving facility could accommodate in an emergency. It is shown as a percentage because large facilities can typically accommodate many more individuals than smaller facilities. This factor is an important factor in determining evacuation times. If surge capacity within a city's facilities is only 5 percent, then the vast majority of evacuees might need to be transported to other cities, incurring hours of time for each trip and potentially increasing the evacuation time from hours to days. By contrast, a surge capacity of 15 percent could accommodate many more individuals within the system, thus reducing total evacuation times.

- **Traffic congestion:** It is expected that traffic congestion during an evacuation will be significantly higher than normal. The travel time estimator (see section 2.2, below) calculates an average driving time for normal traffic. This congestion multiplier allows planners to add additional time to each trip as a multiple of the travel time under normal traffic conditions. The travel time estimator also takes into consideration the population density of the metropolitan area where the facilities are located. The model is pre-loaded with population densities of all the Metropolitan Statistical Areas (MSAs).

- **Location of overflow receiving facility:** The model includes an "overflow" receiving facility that is used in the event that the specified receiving facilities do not have capacity to accept the patients from all the evacuating facilities. In reality, the overflow facility may represent an airport where patients are taken to be transported out of state. The user specifies the travel time to the overflow facility from evacuating facilities.

2.2. Model Calculations

The model works by transferring patients between evacuating facilities and receiving facilities including overflow facilities. The model assumes a priority to how patients are moved, which is based on patient acuity – e.g., those requiring advanced ALS ambulance are transferred to the nearest facilities in order to avoid lengthy transfers for the sickest patients.

In order to calculate the estimated time required to evacuate all the patients from evacuating facilities, the model performs the following steps:

- Calculates travel time between all facility-facility pairs

- Assigns evacuees from evacuating facilities to receiving facilities based on patient priority

- Iteratively assigns vehicles to transport as available and tabulates total travel time and total number of trips per vehicle type.

These processes are described in more detail below.

2.2.1 Calculation of Travel Time

In order to appropriately determine the shortest evacuation time, travel time between all facility pairs is needed. In developing the model, we considered a number of options for handling travel time. One option we considered was to require inter-facility travel time as a user input, but when the number of facilities increases the number of travel times increases geometrically. With as few as a few dozen facilities, entering inter-facility travel time would simply be too burdensome to the user. Another option considered was to link the model to a Web-based real-time drive time calculator, such as Google Maps. We elected not to use this approach because we wanted to avoid linking the model to a service that, while currently free, may not be in the near future. In addition, this approach would have locked the model to a particular third-party vendor.

The project team instead developed an alternative approach that estimates inter-facility travel time based on the user-specified facility locations. Abt Associates teamed with the firm GIS Dynamics to create a database of driving times in 25 of the largest 50 metropolitan statistical areas (MSAs) in the United States, selected to represent a wide geographic diversity. In each of these MSAs, 16 geographically dispersed hospitals were selected as representative points and GIS Dynamics created a matrix representing the 120 unique travel times between each hospital-hospital pair. This database of 3000 travel time pairs was used to build our travel time model.

In order to determine whether geographical barriers contributed significantly to travel time, project staff categorized the 25 cities into those with or without significant geographical barriers (e.g., requiring travel via bridges) and those with and without grid-based road systems. Additional information on total population, population density, and land and water area was also collected for the analysis. All available variables (grid-based, bridge-dependent, population, land area, etc) were analyzed for potential contributions to regional variations in travel time.

Several model types were evaluated to determine whether a linear model or another model was the best form. A good fit was found with a spline model, which is characterized by two regions each with its own linear regression. It was found that within-city travel rates were slower than travel at the greatest distances within an MSA. This is likely due to highway travel once you travel greater than 50 miles from a city center. The city-specific variables of population, land area, and others did not affect travel times for large distances, highway travel being equivalent from one region to the next. However, the population density did have a very appreciable effect on shorter distances.

A new travel time model was developed with these results in mind. A density-driven rate is applied to shorter distances while a lower non-density-dependent rate is applied to longer distances. The model is also constrained such that both regressions arrive at the same join point for each city. The new model was compared against the existing New York travel time database (obtained during project staff's collaboration with the City – see Section 3) and the data for the 25 cities to ensure that residual times were as low as possible. This model now allows travel distances to be calculated for any location in the United States based upon a limited number of parameters.

2.2.2 Assignment of Patient Destinations

Before travel time can be calculated, evacuees must first be assigned a destination. This is done based on *patient priority*. Patient priority determines which patients (labeled by vehicle type) should be moved the least distance. Patients are then assigned by priority from facilities which are evacuating to the nearest receiving facility that can accommodate them. Receiving facilities are considered to be able to accommodate them up to their *capacity* (if occupancy rate is below 100%) and additionally up to the *surge capacity* percentage.

In some cases the surge capacity alone will not be sufficient to accommodate all evacuees. In this case the overflow facility is used. For instance, patients who need to be transported out of the city will be transported to locations greater than, say, two hours away. This will only occur after all receiving facilities have been filled.

The program loops through vehicle types, beginning with the first vehicle type listed by the user. The program first identifies all evacuating facilities that have patients who need transport by that vehicle type. Before it considers any other patients, the program assigns patients of that priority (such as patients requiring ALS transportation) to the nearest facilities that can accept them. This assignment follows its own rule. Starting with the list of evacuating facilities that have patients requiring that vehicle type, the program searches for the nearest facility that can accept patients from that evacuating hospital. This provides a one-to-one match between the list of evacuating facilities and the nearest receiving facilities. The program then finds which of these one-on-one pairs has the shortest travel distance, and it assigns patients for movement between that pair. The number of patients thereby assigned is the lesser of the number of patients in the evacuating facility and the number of available beds in the receiving hospital. The program decreases the number of patients in the evacuating facilities and the number of available beds in the receiving facility by this number. It then repeats the entire process until it has assigned all patients who require this conveyance type. When that condition is met, the program turns to the next conveyance mode until all patients have been evacuated. Note that the program assigns transfers; it does not actually move patients at this point.

2.2.3 Iterative Modeling

Once the travel time and allocation of evacuees is determined, the evacuation time can be calculated. At the beginning of the evacuation, vehicles are assigned to evacuating facilities. They each fill to capacity or to the number of patients available (whichever is less) using the loading time per patient that is one of the user inputs. Vehicles then transport these patients to the facilities assigned using the travel time. After discharging patients (including unloading time), the vehicle then returns to the evacuating facility and is available for reloading. Based upon the destinations for each patient, total required trips for each vehicle type are tabulated including the total time required for the trips. The total evacuation time is based upon the maximum total time for any vehicle type. Thus, if ALS vehicle transport takes more time than any other vehicle, then ALS total time is used for total evacuation time.

2.3 Outputs

2.3.1 Total Evacuation Time

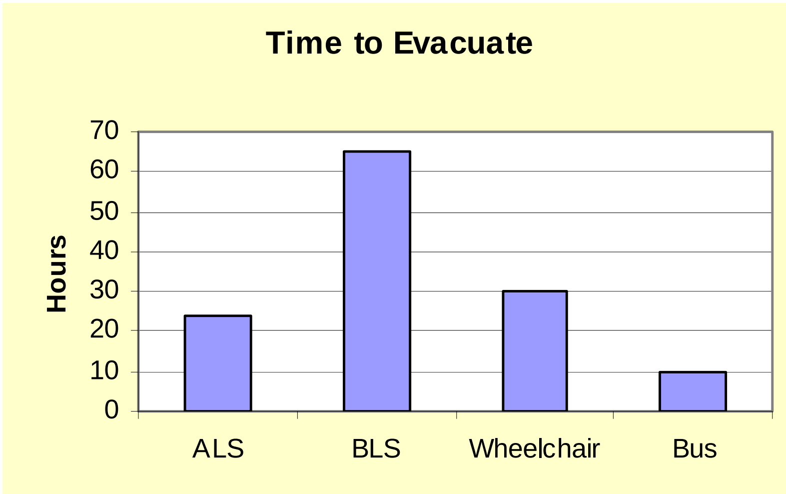
The primary output of the model is the *total evacuation time*, or the total time from the beginning of the evacuation until the last evacuee is on a vehicle for transport to a receiving facility. This result is given in hours.

In the model, total evacuation time is defined as ***the elapsed time from when the first patients begin loading on vehicles at evacuating facilities to when the last patient has been loaded on a vehicle at an evacuating facility***. Total evacuation time includes (1) the time to load and unload patients from transporting vehicles and (2) round-trip travel time between evacuating and receiving facilities. Total evacuation time does not include:

- the time from when the evacuation decision is made to when the actual evacuation begins;
- the travel time from vehicle staging areas to an evacuation facility at the beginning of the evacuation process; and,
- the travel time for the last evacuated patient from an evacuating to receiving facility. In other words, the elapsed time for evacuation ends when the last patient is loaded on the vehicle at an evacuating facility. An alternative definition (not used in the model) would end evacuation time when the last patient arrives at a receiving facility.

2.3.2 Evacuation Time by Vehicle Type

The output also includes the time required to evacuate each type of patient. The figure below shows an illustrative graphic of evacuation time by patient type. For example, patients requiring BLS transport will require roughly 65 hours to evacuate.



Because a given patient can be transported on only one vehicle type, the total evacuation time is dependent only upon the evacuation time for the vehicle type that requires the most time. This evacuation time may be long due to small capacity (necessitating frequent trips), a large population of evacuees compared with the number of available vehicles, long distance per trip, long loading time, or other characteristics. The table above (*Time to Evacuate*) shows the total evacuation time for each of the vehicle types. This will allow a user to see the bottleneck and potentially reallocate resources to mitigate the problem.

Another model output, which is highly correlated to the evacuation time by patient type, is the number of round trips made by each vehicle during the evacuation. As discussed below, ALS and BLS ambulances each had far more round trips than wheel chair vans or buses.

Users should run a model several times under different scenario conditions to observe the sensitivity of evacuation time to such characteristics as surge capacity, loading time per vehicle, traffic congestion, and other variables. We used this approach in New York City and Los Angeles, as discussed in the Appendixes 2 and 3.

3. Pilot Test Sites

New York City (NYC) and Los Angeles served as pilot test sites for the Mass Evacuation Transportation Model.

3.1. New York City

During the Task Order, project staff had the opportunity to test the model in New York City. In early 2006 the New York City OEM was developing a plan to evacuate hospitals and nursing homes that would be affected by a major hurricane. AHRQ and project staff met with OEM officials and agreed that the pilot test would benefit both OEM and the AHRQ project. A working group with representatives from OEM, City hospitals and nursing homes, and City transportation agencies was formed to help guide the project.

The scenario was a Category 4 hurricane. A hurricane of this magnitude has reached the City on average every 50 years, and it had been roughly 50 years since the last Category 4 hurricane. OEM officials determined that 24 hospitals and 61 nursing homes located in areas in NYC would be underwater in such an incident. It was also assumed that an evacuation would begin 72 hours before the hurricane reached the City.

As detailed in Appendix 2, project staff, with help from the working group, obtained a variety of data needed to run the model for this scenario, including patient acuity levels, inter-facility transport times, vehicle fleet sizes, and loading and unloading times. Project staff also worked closely with OEM staff throughout the project to refine assumptions. The modeling results are summarized in Appendix 2. In addition to estimating the total evacuation time, project staff ran the model will a wide variety of inputs in order to understand the sensitivity of different inputs to the total evacuation time.

3.2. Los Angeles

During the first half of 2007, project staff worked with the Los Angeles Emergency Preparedness Department (EPD) to plan and conduct an earthquake table top exercise. In the scenario, three local hospitals – Kaiser/Los Angeles, Children’s Hospital/Los Angeles, and Hollywood Presbyterian – had to be evacuated because of a major (7.1) earthquake.

The exercise was held on June 6, 2007 in Los Angeles. Approximately 75 persons attended, including representatives from the three evacuating hospitals, the regional hospital association, various city and county agencies, and the military. Dr. Paul Biddinger, the project's co-principal investigator, designed the table top and was the lead facilitator.

Prior to the table top, project staff worked with officials from the Los Angeles EPD to agree on modeling assumptions and to obtain data for the baseline evacuation time estimate (see Appendix 3 for all the assumptions and input data). The most important assumptions included:

- Roughly 40 percent of the patients at the three hospitals would need transport via an ALS ambulance.
- Only 5 percent of the county's fleet of ALS ambulances could be dedicated to the evacuation.
- Traffic would be significantly slower – travel times were assumed to be twice the normal travel time.

Based on these assumptions, the estimated total evacuation time for all the patients in the three hospitals was 105 hours. During the table top, the attendees were shown how total evacuation time varied under different conditions, including different traffic conditions, number of available ALS ambulances, patient loading times, and standards of care (see Appendix 3 for the graphs presented to the attendees). This prompted attendees to consider the importance of:

- securing additional ALS ambulances (because of, for example, the non-linear effects on evacuation time of increasing the percentage of the ALS fleet available for the evacuation from 5 percent to 10 percent), and
- the dramatic reduction in evacuation time from transporting ALS patients in BLS ambulances (which, of course, raises difficult questions regarding the standard of care).

Appendix 1: Project Steering Committee Members

As noted in Section 1, development of the Mass Evacuation Transportation Model was one task in a larger project to support development of a national strategy for the design, development, and implementation of an interagency mass patient and evacuee movement, regulating and tracking system. A project steering committee was convened to inform this project. The meetings focused on both of the overall goals of the project – that is, development the model and development of recommendations for a National Mass Patient and Evacuee Movement, Regulating, and Tracking System.

The persons listed below attended at least one of the three day-long meetings held on December 1, 2005, April 12, 2006, and October 27, 2006.

Sally Phillips (Project Officer)	Director, Public Health Emergency Preparedness Research Program Agency for Healthcare Research and Quality U.S. Department of Health and Human Services
F. Christy Music	Office of the Assistant Secretary of Defense for Homeland Defense U.S. Department of Defense
Knox Andress	Emergency Preparedness Coordinator CHRISTUS Schumpert Health System
Brad Austin	Office of the Assistant Secretary for Preparedness and Response U.S. Department of Health and Human Services
Janet Benini	Senior Advisor, Intelligence Security and Emergency Response U.S. Department of Transportation
Kathryn Brinsfield	Associate Medical Director Boston Emergency Medical Services
Stephen Cantrill	Department of Emergency Medicine Denver Health Medical Center

Michael Feeser	Office of Policy, Plans and Preparedness Department of Veterans Affairs
Edward Gabriel	Director of Crisis Management Walt Disney Corporation
Derek Goldstein	Agency for Healthcare Research and Quality U.S. Department of Health and Human Services
Dan Hanfling	Emergency Management and Disaster Medicine Inova Health System
Scott Henderson	Manager, Web and Applications Development Northrop Grumman Force Health Protection
Nathaniel Hupert	Department of Public Health Weill Medical College of Cornell University
Ann Knebel	Office of the Assistant Secretary for Preparedness and Response U.S. Department of Health and Human Services
Harry Koerner	Operations Support Center Manager Federal Emergency Management Agency
Bill Kormos	Office of the Assistant Secretary of Defense Force Health Protection & Readiness Department of Defense
James Lawler	Director for Biodefense Policy Homeland Security Council
Deborah Levy	Division of Healthcare Quality Promotion Centers for Disease Control and Prevention
Teresa Lustig	Science and Technology Directorate U.S. Department of Homeland Security
Leonard Marcus	National Preparedness Leadership Initiative Harvard School of Public Health

Michael Meit	Department of Health Policy & Evaluation NORC at the University of Chicago
Vincent Mercadante	Office of Intelligence, Security and Emergency Response U.S. Department of Transportation
David Persse	Department of Health and Human Services City of Houston
Mark Roupas	Office of the Assistant Secretary of Defense for Homeland Defense Department of Defense
Bill Savage	Research Computing Division RTI International
James Sims	Emergency Preparedness Department City of Los Angeles
Arlene Stephenson	Springfield Hospital Center Maryland Department of Health and Mental Hygiene
Jennifer Todd	Agency for Healthcare Research and Quality U.S. Department of Health and Human Services
Scott Wetterhall	Health Security & Systems Research RTI International

Appendix 2: New York City Pilot Test

In this appendix, the modeling assumptions and output from the New York City pilot test are described. The scenario involved a category 4 hurricane that required evacuation of 24 hospitals and 61 nursing homes.

Modeling Assumptions

Listed below are key assumptions used in the model for the New York City pilot test. In the discussion of the modeling results, we have varied some of these assumptions in order to understand their effect on evacuation times.

Vehicles used in the evacuation

- *Four types of vehicles are used to transport patients* – buses, wheel chair vans, BLS ambulances, and ALS ambulances. (Notably, we have not included helicopters, which could be used to transport the most critical patients.) The capacities of the vehicles are:

Vehicle Type	Capacity (Patients)
Bus	
o Standard bus	32 [1]
o Mini-wagon	8
Wheel chair van	
o Hydraulic lift	8 wheel chair patients
o Ramp-wagon	3 wheel chair patients
o Ambulette	2 wheel chair patients
BLS ambulance	2
ALS ambulance	1

[1] Actual capacity is 35 passengers; we assume 3 will be hospital staff and/or guardians in the evacuation.

- *The number of vehicles, by type, that are available for the evacuation:*

Vehicle Type	**Number available**	**Assumptions**
Bus		
o Standard bus	1,159	90% of the NYC Department of Education (DOE) fleet (1,288)
o Mini-wagon	2,334	90% of the DOE fleet (2,593)
Wheel chair van		
o Hydraulic lift	337	90% of the DOE fleet (374)
o Ramp-wagon	397	90% of the DOE fleet (441)
o Ambulette	913	40% of the Paratransit fleet (2,282)
BLS ambulance	245	40% of the volunteer sector fleet (131) 40% of the private sector fleet (482)
ALS ambulance	34	40% of the private sector fleet (85)

Patients to be evacuated

- *24 hospitals and 61 nursing homes are evacuated*.

- *Evacuating facilities are at 100% capacity*. Based on capacity data provided by NYC Office of Emergency Management (OEM) staff, the total number of patients to be evacuated is 24,393 – 9,885 in hospitals and 14,508 in nursing homes.

- No *patients will self-evacuate*. All evacuated patients will be transported to another facility on one of the vehicles described above.

- *Evacuated patients are divided into four types*. Each patient type is assumed to be evacuated on a specific type of vehicle:

Patient Type	**Vehicle Used for Patient Transport**
Ambulatory patients	Bus
Wheel chair bound patients	Ambulette
Bedridden patients requiring constant medical attention at the BLS level during transport	BLS ambulance
Bedridden patients who need constant medical attention at the ALS level during transport	ALS ambulance

- *The percentage of patients requiring each vehicle type for transport is the same at all evacuating hospitals*. The percentage of patients requiring bus, wheel chair van, BLS, and ALS transport is based on (1) a census count at New York Presbyterian/Weill Cornell Medical Center on April 4, 2006 and (2) a study of evacuation transport requirements at four hospitals in the North Shore LIJ Health System. We used a weighted average of these two sources, assuming two-thirds of the evacuating hospitals had the New York Presbyterian patient mix and one-third had the North Shore patient mix. The resulting percentages are:

Vehicle Type	**Percent of Patients Requiring Vehicle Type (Hospitals Only)**
Bus	33%
Ambulette	40%
BLS ambulance	13%
ALS ambulance	14%

- *The percentage of patients requiring each vehicle type for transport is the same at all evacuating nursing homes*. The percentage of patients requiring bus, wheel chair van, BLS, and ALS transport is based on patient mobility data that NYC nursing homes reported to Centers for Medicare & Medicaid Services (CMS) on the CMS-672 form. The model assumes the following percentages:

Vehicle Type	**Percent of Patients Requiring Vehicle Type (Nursing Homes Only)**
Bus	27%
Ambulette	70%
BLS ambulance	2%
ALS ambulance	1%

Facilities receiving evacuated patients

- *Any hospital or nursing home in NYC that is not being evacuated will accept evacuating patients*. "Receiving" hospitals will only accept patients evacuated from hospitals; "receiving" nursing homes will only accept patients evacuated from nursing homes.

- *Receiving facilities are at 100% capacity*.

- *Receiving facilities have 15% surge capacity*. That is, the number of patients a facility can accept is equal to 15% of their capacity.

- *Patients who cannot be accommodated in NYC receiving facilities are transported to a generic out-of-NYC facility*. The travel time from an evacuating facility to the out-of-NYC facility is 90 minutes.

- *The model does not consider the capacity of different units within a receiving facility.* An evacuated patient can be placed in any bed in the receiving facility. In other words, we assume acuity affects only the transport vehicle requirement, and not the bed requirements in the receiving facility (e.g., an ICU patient in an evacuating hospital can be relocated to a floor room, with additional equipment brought in, at the receiving hospital).

Staff available to carry out the evacuation

- *The model does not consider staff availability*. It assumes that sufficient staff are available to move patients from their rooms to the facility lobby, load them on the vehicle, transport them to the receiving facility, and move them from the vehicle to their new room. In particular, we assume that:
    - sufficient facility staff are available to move patients from their room to the lobby of the facility, so that vehicle staff do not have to retrieve patients from their room;
    - sufficient facility staff are available to accompany patients in the vehicle to the receiving facility, if required (e.g., high-risk patients or minors); and
    - enough drivers, EMTs, and paramedics are available to staff the vehicles 24/7 during the entire evacuation period.

Steps in the evacuation process

- *Facility staff move patients from their room to the lobby of the facility*. **The time required to move patients from their room to the lobby of the facility is not included in the total evacuation time**. The model does not calculate the time required to move patients from their room to the lobby, and assumes that facility staff will be able to deliver patients to the lobby so that when an evacuation vehicle arrives at the facility, the patients to be transported on that vehicle are waiting in the lobby.

- *Once a vehicle arrives at the facility, patients are immediately loaded onto vehicles*. As noted above, patients are waiting in the facility lobby for the vehicle. The model assumes no vehicular congestion at the facilities that would delay loading or unloading. The assumed loading time for vehicles is:

Vehicle Type	Loading Time (minutes)
Bus	
o Standard bus	30
o Mini-wagon	15
Wheel chair van	
o Hydraulic lift	30
o Ramp-wagon	15
o Ambulette	10
BLS ambulance	10
ALS ambulance	20

- *Evacuated patients will be transported to the nearest available facility that has capacity*. Hospital patients are transported only to hospitals, and nursing home patients only to nursing homes. The model ignores "preferred" receiving facility lists for each evacuating facility (e.g., pairs of facilities with memorandums of understanding [MOUs] regarding evacuation).

- *The model sends ALS patients to the nearest facilities*. Given that assignment, the model sends BLS patients to the nearest facilities that still have available capacity. Van patients have the next highest priority, and bus patients have the lowest priority.

- *All facilities are evacuated simultaneously, depending on vehicle availability*.

- *Travel times between facilities are based on actual travel times between New York Presbyterian hospitals and other NYC facilities during 2005*. **Ambulances making these trips averaged 20 miles per hour**. In the model, all vehicles are assumed to have the same travel speed. To estimate the travel times between all pairs of facilities, we developed a statistical model that relates the New York Presbyterian travel times and the distances between pairs of facilities (using the facility latitude and longitude) and whether inter-borough travel is required.

- *The time required to unload patients from a vehicle is the same as the loading time* (see above). The model assumes no vehicular congestion at the facilities that would delay patient unloading.

- *Staff at the receiving facility move patients from the vehicle to the patient's new room*. **The elapsed time from the curb to the patient's room is not included in the total evacuation time.**

Modeling Results

Results with baseline assumptions

Using the baseline assumptions described above, the estimated total evacuation time is 54 hours. As noted earlier, the "evacuation clock" starts when the first patients begin loading on vehicles at evacuating facilities and ends when the last patient has been loaded on a vehicle at an evacuating facility. Total evacuation time ***does not include***:

(1) time from when evacuation decision is made to when the first patient is in the facility lobby available for transport;
(2) travel time from "vehicle fleet garages" to an evacuation facility at the beginning of the evacuation process;
(3) time to move the patient from their room to the lobby of the evacuating facility; and
(4) time to move patients from the curb at the receiving facility to their room.

Total evacuation time depends entirely on transport of ALS patients. The model predicts that the total time to evacuate ALS patients far exceeds the time required to evacuate BLS, van, or bus patients. Therefore, the total evacuation time is determined by the total time to evacuate ALS patients from facilities (primarily hospitals). Although the majority of patients can be moved in wheelchair vans or buses, the small number of ALS ambulances (34) and the fact that they can only move one patient at a time means that those patients (1,529 of them) take the longest time to evacuate. With a 20-minute loading and 20-minute unloading time, the minimum time for each trip is inflexible and drives the total evacuation time.

The model prioritizes ALS ambulances to go the shortest distance (to limit travel time for those patients), but they make on average 45 round trips during the evacuation (see the table below). BLS ambulances taking two patients each and with a greater fleet of vehicles make only four trips each. Wheelchair vans (hydraulic lifts) can take more people but there is a much greater pool of patients to transport. These vans each make six trips to evacuate. Buses are plentiful and each only needs to make one trip in order to evacuate all ambulatory patients. The number of round-trips required during the evacuation for each vehicle is summarized below:

Vehicle Type	Number of Round-Trips Required per Vehicle
Bus	1
Ambulette	6
BLS ambulance	4
ALS ambulance	45

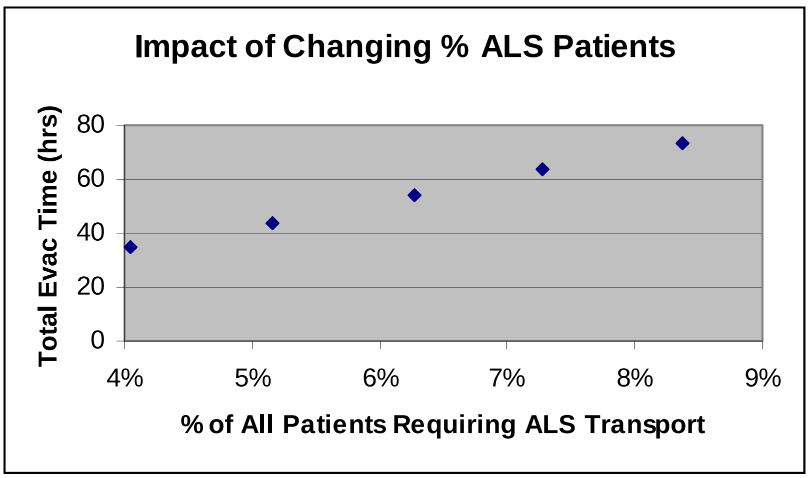
Using the baseline assumptions, 69% of nursing home patients and 67% of hospital patients would have to be transported outside NYC. We assume that hospitals and nursing homes are at 100% capacity, no one self-evacuates, and facilities have 15% surge capacity. The model prioritizes patients by acuity to ensure that ALS patients travel the least distance and ambulatory patients travel furthest. ***All ambulatory patients are transported out of NYC along with two thirds of the wheelchair patients***. All ALS patients, BLS patients and one third of the wheelchair patients fill the surge capacity of the local facilities.

ALS patient evacuation time under alternative assumptions

Given that the total evacuation time is equal to the total time required to evacuate ALS patients, it is important to determine to what extent assumptions regarding ALS patients and transport can be changed and still achieve the desired maximum total evacuation time of 72 hours. We have made only one-at-a-time changes in assumptions.

Percentage of patients in evacuating facilities requiring ALS transport

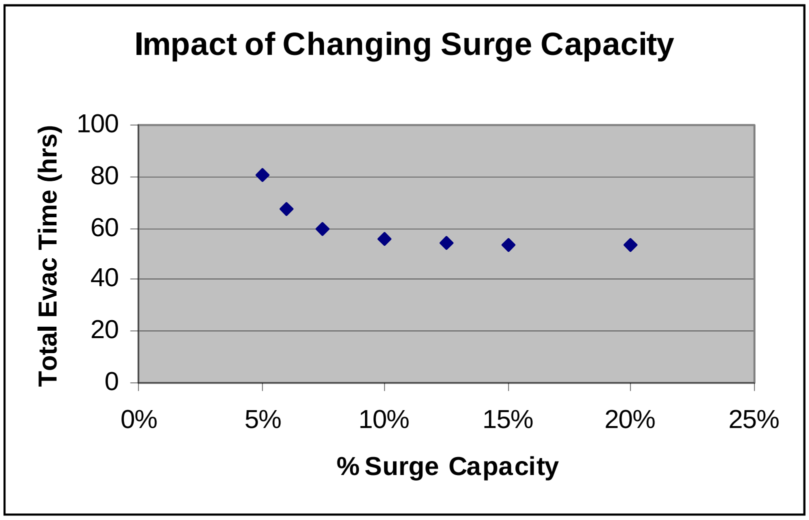
The baseline assumption is that 6.3% of all patients will require ALS transport, which includes 14% of hospital patients (i.e., 1,384 patients) and 1% of nursing home patients (i.e., 145 patients). The actual percentage of patients requiring ALS transport will very likely be different in a real evacuation. The graph below shows the time required to evacuate all ALS patients assuming higher percentages of ALS patients. ***If we assume that 8% of all patients require ALS transport (a re-classification of only 440 patients), the model predicts a 71 hour evacuation time for ALS patients***.



Because each ALS unit can only transport one patient and because the load and unload time for ALS patients is long relative to travel time, the percentage of ALS patients affects the evacuation time in a nearly linear fashion. In this model the percentage of ambulatory patients was left constant while the percentage of BLS and wheelchair was decreased (with the remainder reclassified as ALS).

Capacity of nearby receiving facilities to accept ALS patients

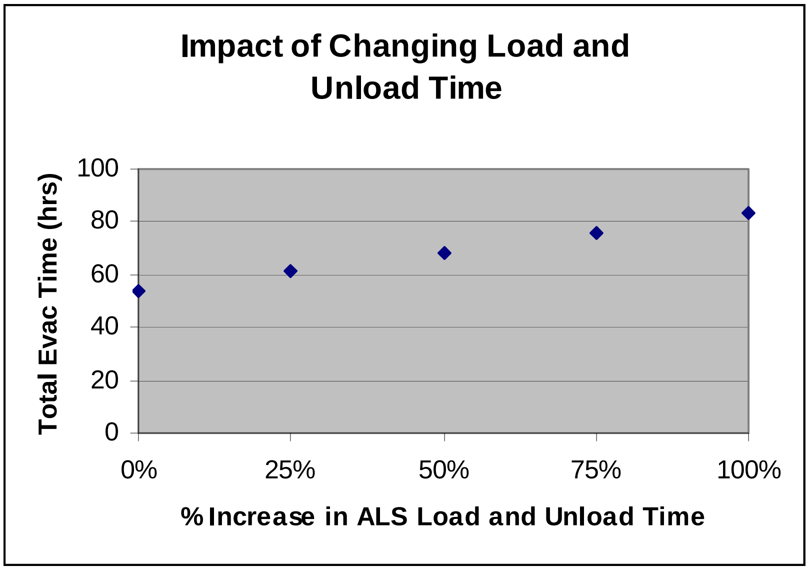
The model assumes that the highest acuity patients go to the closest facilities, and the lowest acuity patients go to the furthest facilities. As a result, facilities that are the closest to the evacuation zone receive a high percentage of ALS patients compared to other facilities, which of course begs the question of whether they can accommodate that many ALS patients. In the model we can reduce the number of ALS patients that any facility receives by reducing the surge capacity.



Reducing the surge capacity reduces the total number of ALS patients each facility must take. ALS patients will still be transported first to nearby facilities, so these facilities will continue to receive only ALS patients. However, the total population of ALS patients will be spread over a greater area. As surge capacity decreases, the length of evacuation time greatly increases, with ALS patient travel time increasing as they are transported to further and further facilities. At 5% surge capacity, evacuation of ALS patients exceeds the 72-hour limit.

Load and unload times

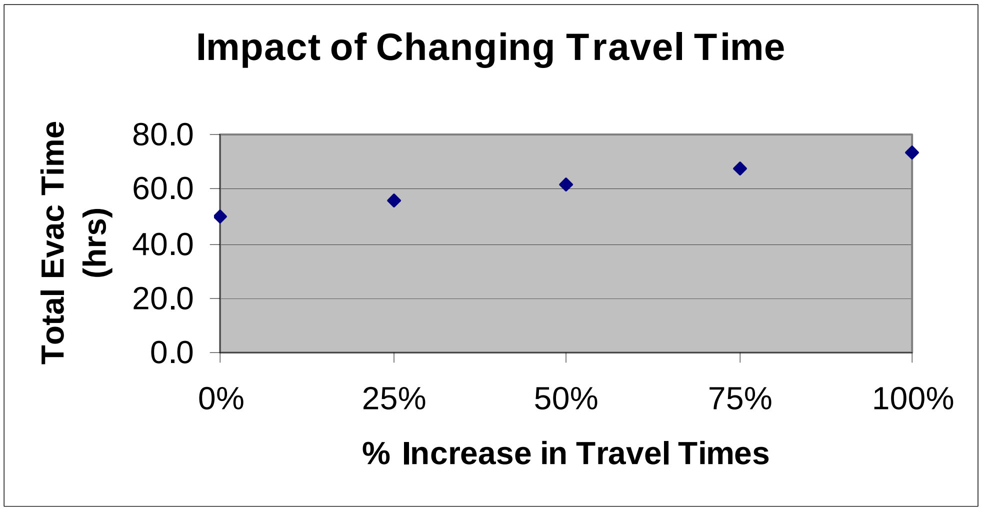
While the baseline assumptions include a 20-minute loading time and 20-minute unloading time for ALS ambulances, the model implicitly assumes that there is no congestion at the ambulance load/unload area. Below, we account for congestion by varying the loading and unloading times – the additional time could be viewed as queue delays at the load/unload area.



ALS patient evacuation is very sensitive to increases in load/unload time. For ALS patients who are traveling very short distances, the 20 minute load time and 20 minute unload time is a significant proportion of the total time for evacuation. Doubling the load and unload time quickly brings the total evacuation time from 54 hours to 83 hours, and the 72-hour limit is already exceeded at a 75% increase in load/unload time. Other vehicles for which the load/unload time is a smaller percentage of total evacuation time, and which are not required to make as many round trips, are not affected to the same degree.

Travel times

As noted in Section 1, travel times in the model are based on actual travel times experienced in inter-hospital transports to New York Presbyterian hospital. Ambulances traveled an average of 20 miles per hour on these trips. Below, we change the travel time assumptions to simulate more congested conditions.



Changes in travel time have the greatest effect on ALS ambulances, because they do multiple round trips during the evacuation (by contrast, each bus requires only a single trip during the evacuation). Slowing travel speed (accomplished in the model by proportionately increasing travel time) gradually increases the amount of time to evacuate ALS patients, but not to the same extent as changes in load time.

Changes in baseline assumptions that result in no patients transported out of NYC

As noted above, the model predicts that 69% of nursing home patients and 67% of hospital patients are transported outside NYC. ***To keep all patients in NYC facilities, the surge capacity would have to be 45% for hospitals and 48% for nursing homes.***

For comparison purposes, changing the assumptions regarding capacity and self-evacuation have the following effects:

- *Capacity:* If all facilities were at 95% capacity, they would need to reach 38% and 41% surge capacity for hospitals and nursing homes, respectively, to ensure all patients stay in NYC. At 90% capacity, the required surge capacity would drop to 31% and 33%.

- *Self-evacuation*: If we assume 100% capacity, but assume 5% of individuals self-evacuate, the required surge capacity to keep all patients in NYC facilities drops from 45% to 43% for hospitals and from 48% to 46% for nursing homes. A 10% self-evacuation rate drops it further to 41% and 43%, respectively.
- Using both capacity and self-evacuation adjustments, if we assume 90% capacity and 10% self-evacuation rate, then NYC hospitals and nursing homes would be able to accommodate all patients with 27% and 29% surge capacity, respectively.

Appendix 3: Los Angeles Pilot Test

In this appendix, the modeling assumptions and output from the Los Angeles pilot test are described. The scenario involved a major (7.1) earthquake that resulted in the need to evacuate three hospitals.

Modeling Assumptions

The modeling assumptions for the baseline evacuation scenario are described below.

Vehicles used in the evacuation

- *Four types of vehicles are used to transport patients* – buses, wheel chair vans, BLS ambulances, and ALS ambulances. The capacities of the vehicles are:

Vehicle Type	Capacity (Patients)
Bus	34 ambulatory patients
Wheel chair van	3 wheel chair patients
BLS ambulance	2
ALS ambulance	1

- *The number of vehicles, by type, that are available for the evacuation:*

Vehicle Type	Number available	Assumptions
Bus	125	5% of the fleet (2500)
Wheel chair van	15	5% of the fleet (300)
BLS ambulance	38	5% of the fleet (750)
ALS ambulance	12	5% of the fleet (240)

Patients to be evacuated

- *3 hospitals are evacuated*. The three are: Kaiser/Los Angeles, Children's Hospital/Los Angeles, and Hollywood Presbyterian. The three are all located within 4 blocks of each other.

- *Number of patients to evacuate.* Each of the three hospitals provided census figures by patient type:

	Patient Type			
	Average Daily Census	# in ICU/CCU	# on Ventilators	# on Monitors
Kaiser/Los Angeles	295	54	25	180
Children's/Los Angeles	254	65	47	131
Hollywood Presbyterian	279	25	9	25
TOTAL	828	144	81	336

We also assumed that there would be patients in the Emergency Department (ED) that would need to be evacuated. Typically, the number of patients in the ED is between 5 and 10 percent of the average daily census; we assumed 7.5 percent. Including the ED patients increased the total number of patients to be evacuated to 890:

	Average Daily Census	Add in Estimated # ED Patients	Total Evacuated
Kaiser /Los Angeles	295	22	317
Children's/Los Angeles	254	19	273
Hollywood Presbyterian	279	21	300
TOTAL	828	62	890

- *No patients will self-evacuate*. All evacuated patients will be transported to another facility on one of the vehicles described above.

- *Evacuated patients are divided into 4 types*. Each patient type is assumed to be evacuated on a specific type of vehicle:

Patient Type	**Vehicle Used for Patient Transport**
Ambulatory patients	Bus
Wheel chair bound patients	Ambulette
Bedridden patients requiring constant medical attention at the BLS level during transport	BLS ambulance
Bedridden patients who need constant medical attention at the ALS level during transport	ALS ambulance

- *The percentage of patients requiring each vehicle type for transport varies by evacuating hospitals*. To determine the number of patients that require a bus, wheel chair van, BLS, and ALS ambulance, we assumed (1) all patients on monitors will need ALS transport; (2) admitted patients not on monitors are divided evenly between BLS, wheelchair van, and bus transport; and (3) ED patients are divided evenly between ALS, BLS, wheelchair van, and bus. With these assumptions, roughly 40 percent of patients required an ALS ambulance and 20 percent each required a BLS ambulance, wheel chair van, and bus:

	# Needing ALS	# Can Use BLS	# Can Use Wheelchair Van	# Can Use Bus	TOTAL
Kaiser/Los Angeles	186	44	44	44	317
Children's/Los Angeles	136	46	46	46	273
Hollywood Presbyterian	30	90	90	90	300
TOTAL	352	180	180	180	890
% of TOTAL	39%	20%	20%	20%	100%

Facilities receiving evacuated patients

- *Any hospital in Los Angeles County (other than the three evacuating hospitals) will accept evacuating patients*.

- *Receiving facilities are at 100% capacity*.

- *Receiving facilities have 15% surge capacity*. That is, the number of patients a facility can accept is equal to 15% of their capacity.

- *The model does not consider the capacity of different units within a receiving facility.* An evacuated patient can be placed in any bed in the receiving facility. In other words, we assume acuity affects only the transport vehicle requirement, and not the bed requirements in the receiving facility (e.g., an ICU patient in an evacuating hospital can be relocated to a floor room, with additional equipment brought in, at the receiving hospital).

Staff available to carry out the evacuation

- *The model does not consider staff availability*. We assume that:
  - sufficient staff are available to move patients from their room to the lobby of the facility;
  - sufficient facility staff are available to accompany patients in the vehicle to the receiving facility, if required (e.g., high-risk patients or minors); and
  - sufficient drivers, EMTs, and paramedics are available to staff the vehicles 24/7 during the entire evacuation period.

Steps in the evacuation process

- *Facility and / or vehicle staff help move patients from their beds onto the vehicles*. The assumed loading time for vehicles per patient is:

Vehicle Type	**Loading Time (Minutes)**
Bus	1
Wheel chair van	5
BLS ambulance	10
ALS ambulance	20

- *Evacuated patients will be transported to the nearest available facility that has capacity, with two exceptions*. The exceptions are: Kaiser patients are only transported to other Kaiser hospitals, and the ICU patients at Children's Hospital are only transported to hospitals that have pediatric ICU units. Other than these two exceptions, the model ignores "preferred" receiving facility lists for each evacuating facility (e.g., pairs of facilities with MOUs regarding evacuation).

- *The model sends ALS patients to the nearest facilities*. Given that assignment, the model sends BLS patients to the nearest facilities that still have available capacity. Van patients have the next highest priority, and bus patients have the lowest priority.

- *All three hospitals are evacuated simultaneously, depending on vehicle availability*.

- *Travel times between facilities are based on straight-line distance and population density*. In the model, all vehicles are assumed to encounter the same traffic. To estimate the travel times between all pairs of facilities, we used known travel times for the inter-location travel between all pairings of 10 selected locations to create a model of travel time based solely on geographic distance and characteristics of the city. We assumed that travel times during the evacuation were twice the time during normal conditions.

- *The time required to unload patients from a vehicle is the same as the loading time* (see above). The model assumes no vehicular congestion at the facilities that would delay patient unloading.

- *Staff at the receiving facility and / or vehicle staff move patients from the vehicle to the patient's new room*.

Modeling Results

Results with baseline assumptions

Using the baseline assumptions described above, the estimated total evacuation time is 105 hours.

Total evacuation time depends entirely on transport of ALS patients. The model predicts that the total time to evacuate ALS patients far exceeds the time required to evacuate BLS, van, or bus patients. Therefore, the total evacuation time is determined by the total time to evacuate ALS patients from facilities (primarily hospitals). Although the majority of patients can be moved in wheelchair vans or buses, the small number of ALS ambulances (12) and the fact that they can only move one patient at a time means that those patients (374 of them) take the longest time to evacuate.

The model prioritizes ALS ambulances to go the shortest distance (to limit travel time for those patients), but they make on average 32 round trips during the evacuation (see the table below). BLS ambulances taking two patients each and with a greater fleet of vehicles make only 2 trips each. Wheelchair vans can take more people but there is a much greater pool of patients to transport. These vans each make six trips to evacuate. Buses are plentiful and each only needs to make one trip in order to evacuate all ambulatory patients. The number of round trips required during the evacuation for each vehicle is summarized below:

Vehicle Type	Number of Round-Trips Required per Vehicle
Bus	1-2
Wheel chair van	3-4
BLS ambulance	2
ALS ambulance	32

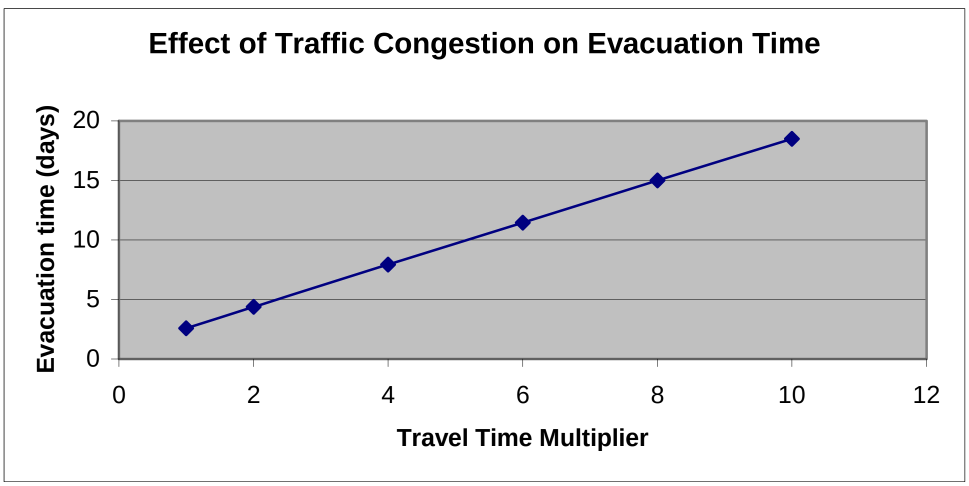
All patients would be transported to hospitals within Los Angeles County.

ALS patient evacuation time under alternative assumptions

The figures below, which were presented at the Los Angeles table top exercise, show how different model inputs affect total evacuation time. In each exhibit we have assumed all of the baseline assumptions stated above except for the parameter that is shown on the X axis.

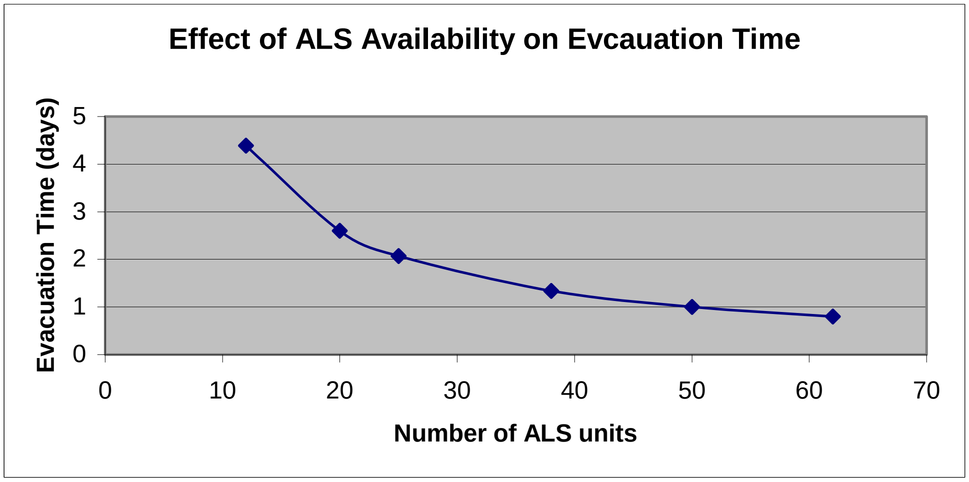
Traffic Congestion

A key variable in determining total evacuation time is the traffic congestion. The graph below shows the evacuation time, in days, if the travel time is multiplied by different factors above normal travel times. The baseline evacuation time assumed a travel time multiplier of two.



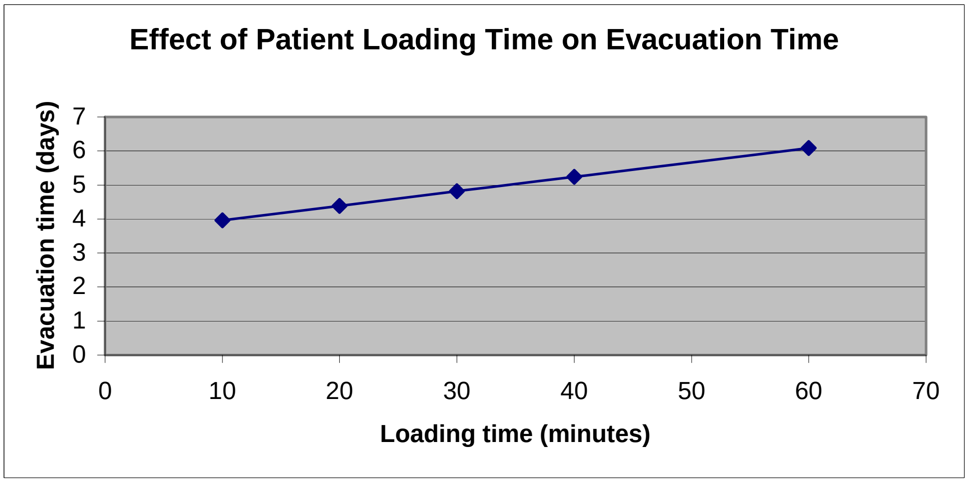
Number of Available ALS Ambulances

The effect of the number of the available ALS ambulances on total evacuation time is shown in the figure below. Unlike traffic congestion, the effect is non-linear – as the number of ALS decreases, the evacuation time increases be a disproportionate amount. The policy implication of this exhibit is the importance of increasing the number of available ALS ambulances from 12 (the baseline assumption) to at least 20 or 25.



Loading Time

The linear effect of changes in patient loading time is shown below.



Standard of Care

The exhibit below shows the effects on evacuation time from transporting some ALS patients on BLS ambulances. "Standard" is the baseline assumption (40 percent of patients require ALS ambulances and 20 percent require BLS ambulances). The next category shows the time if half of the ALS patients were transported via BLS. The last shows the time if the proportions were reversed, i.e. if 40% of patients required BLS and only 20% ALS transport. This takes advantage of the greater number of BLS ambulances and the greater capacity of BLS ambulances. The exhibit illustrates the dramatic effect on evaluation time of reclassifying patients in this manner. (The model does not estimate the "costs" resulting from the reduced standard of care.