Emergency Evacuation Modeling Based On Geographical Information System Data

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ABSTRACT
Disasters such as hurricanes, floods, chemical spills, or terrorist attacks have the potential to cause great loss of life and extreme property damage. Emergency evacuation is often the most feasible strategy that can be undertaken in response to these types of disasters. This paper describes the development of traffic simulation models based on geographical information system (GIS) spatial data, which can be used by emergency management personnel to develop evacuation plans. ArcView 3.2, a GIS software package, and Oak Ridge Evacuation Modeling System 2.5 (OREMS), a traffic modeling software package, were used to develop evacuation models for two counties along the Alabama Gulf Coast. GIS was used to define the road network, population, and area being evacuated, and OREMS was used to model the effect of evacuation on the traffic network. By employing GIS techniques, evacuation routes, their feeder routes, and the affected population were determined and spatially joined to produce an estimate of traffic entering evacuation routes. These data are then used in OREMS as network entry points having specific traffic capacities. The results from the GIS/traffic simulation models developed, show that the evacuation of Baldwin and Mobile Counties takes approximately 21 hours and 8 hours, respectively, which compares well with actual evacuation times recorded during a hurricane evacuation event. It was also found that the least traffic congestion occurred when speeds were limited to 60 mph on interstates and 40 mph on other roads.
INTRODUCTION

Large-scale natural or man-made disasters can have devastating impacts in terms of loss of life, human injury and property damage. There are a limited number of protective actions that can be taken for these kinds of disasters. The most common action during an extreme event is to evacuate threatened people. The responsibility of evacuation falls primarily on state officials who convene in emergency operation centers and coordinate activities with county and local managers. Until recently, state emergency operation centers did not have the ability to anticipate traffic flow resulting from mass evacuation, which made them unprepared for the problems that result from the large number of vehicles entering a road network and potentially crossing state lines in search of safety and shelter (1).

The southeastern United States is vulnerable to hurricanes. This was demonstrated during hurricane Opal, which threatened the Gulf Coast region on October 4, 1995. Hurricane Opal evolved from a tropical storm to a strong category-4 hurricane (131 to 155 mph winds according to Saffir-Simpson hurricane scale) in 48 hours. Combined storm surge and wave effects reached a maximum of 24 feet causing extensive property damage along approximately 120 miles of the Florida Coast from Pensacola Beach to Mexico Beach. An estimated 100,000 people evacuated for hurricane Opal (2). As with the evacuation associated with hurricane Opal, evacuations in the US primarily consist of people gathering a few belongings and driving to safety. Therefore, people are constrained during an evacuation by the capacity of the road network, which in turn dictates evacuation times (3).

Consequently, there is a need for the transportation engineers involved in evacuation operation to develop effective evacuation plans produced from multiple simulations. These plans can be used to estimate the time required to evacuate a given population within a user defined spatial boundary. This allows for the proper traffic management strategies to be developed to reduce the expected traffic bottlenecks, thereby reducing evacuation time.

The main objectives of effective evacuation management are to: 1) keep traffic moving, 2) clear the roadway, 3) get the population under risk to a safe area, and 4) re-establish normal conditions in a timely manner (4). The most critical decision for state and local authorities is when to order an evacuation to the general population at risk before hurricane hazards arrive. Early evacuation orders may give more time for the evacuees to evacuate, however, if the evacuation order is issued too early then there is a possibility that the hurricane may change course, rendering the evacuation unnecessary or placing evacuees in a more dangerous location (5).

A need exists for a methodology that accurately and easily formulates population-data based on location to be used as input for traffic simulation models. The methodology should include a model to generate and evaluate different transportation strategies, which can be used by emergency planners to reduce evacuation times of the population. The model should be useful both for analysis and planning. In this research Geographic Information System (GIS) technology and Traffic Simulation Modeling have been used concurrently to develop an emergency evacuation modeling methodology.

This paper presents a methodology for evacuation modeling by using ArcView 3.2 combined with Oak Ridge Evacuation Modeling System 2.5 (OREMS) to produce quick and accurate evacuation predictions. This paper discusses the development of a traffic simulation methodology using GIS and OREMS spatial data, which can be used for emergency evacuation planning purposes as well as for real time operational purposes. This methodology is demonstrated along the Gulf Coast of Alabama. The methodology will give optimal evacuation alternatives in the form of safest and most efficient routes for evacuation of the population from the affected region. The methodology is divided into two phases. The first phase is to produce maps, tables, and raw data required for evacuation modeling using ArcView. During the first phase, it is necessary to capture information about the population, and associate that information with the roadway network. The second phase uses the results of the GIS as input to OREMS to generate traffic simulation models for extreme events. The traffic model predicts the effect of traffic and its operational performance as the road network receives and releases traffic.

In emergency planning, GIS is valuable because it can be used to provide the data required by the evacuation models. Conventional evacuation planning methods based on aggregated land-use information and countywide census data may lead to large errors in the development of evacuation strategies. More sophisticated methods based on GIS, that attempt to increase the resolution of population data, may become suitable substitutes (6). This paper presents such a method.

Evaluating traffic flow during emergency evacuation is a difficult task and requires simulation software for analysis and optimization. OREMS is a traffic modeling system that specifically simulates traffic behavior during emergency evacuations (7). OREMS can be used to test traffic at severe and extreme conditions that are difficult or impossible...
to directly produce in the field. By improving the accuracy and efficiency of producing input for OREMS with GIS technology, multiple accurate scenarios can be evaluated and evacuation planning improved.

**METHODOLOGY**

This section is divided into two sections. The first section describes the GIS approach to produce data for OREMS based on several location criteria including, population, road network, and area to be evacuated. The GIS data files are used to organize the input data for the simulation model. The second section describes the approach used to develop the simulation models in OREMS to predict the effect of evacuating traffic during severe conditions. The simulation model is used to analyze the evacuating vehicles and determine the time required for the evacuation of population within an “at-risk” area.

**Geographic Information System**

GIS is a technology that has the ability to capture, store, manipulate, query, analyze, and most importantly visualize digital data graphically. A GIS system can take data from numerous sources and display the information based on location. Because population, evacuation routes, and affected area are all spatially related, GIS is a logical choice for data manipulation for evacuation modeling. Counties typically have very limited resources in terms of manpower and equipment. GIS can play a vital and economic role in emergency planning by allowing personnel not only to reach information about the geographical, geophysical, and socio-economic characteristics of their county, but also to determine, visualize, and analyze the possible extent of a disaster (8). Emergency management personnel can apply GIS to evaluate, send, receive, and display various information that can be used for disaster forecasting, vulnerability analysis, maintaining resource inventory, illustrating transportation network infrastructure, providing mass care/shelter status, etc. GIS has been used in this research to provide input data for the simulation model. The primary input data provided by GIS are the traffic inflow (the number of vehicles entering the model) and the network geometry (roadway links, roadway intersection, roadway link lengths, lane counts, speed limits, and grades).

ArcView GIS 3.2 developed by Environmental Systems Research Institute (ESRI) is the GIS software package used in this research. ArcView visualization tools are used to create maps, add data to these maps, access records from existing databases, and display that data on maps. These maps and associated data are loaded into a window called a view. A view enables a user to display, explore, query and analyze geographic data in ArcView. These views can present a series of layers called themes that display features linked to attributes. Each theme is a different form of spatially distributed data displayed as points (such as showing the location of a city or building), lines (such as roads or rivers), or polygons (such as census tracts, counties, or states). Themes are stored in ArcView GIS as shape files. A shape file represents a set of geographic features such as hospitals, roads, or counties. An attribute table is associated with each theme to store and present GIS attribute data. Charts or maps can be produced and organized on a layout for printing. To manage all the data associated with a specific task, a project is setup in ArcView that organizes GIS components such as views, tables, charts and layouts.

The GIS approach for distributing traffic to the evacuation road network is explained with an example traffic network shown in Figure 1. This approach categorizes roads into two types: “feeder roads” and evacuation routes. Feeder roads are the roads that feed traffic volume data to the evacuation routes. Evacuation routes are the roads along which all traffic flows during an evacuation and are in the traffic network model. Thus the traffic enters the network through the feeder roads, and then moves onto the evacuation routes, and finally exits the network at suitable exit locations. In Figure 1(a), evacuation routes are shown as solid black lines, whereas feeder roads are shown as double lines. In this figure there are two evacuation routes labeled Route X and Route Y, and it is assumed that the evacuation will occur along these roads in a northbound direction moving people away from the affected zone (shaded area).

Population data in a GIS can be in two forms: polygons (such as census tracts or counties) or points (such as the centroids of census tracts). In Figure 1, population data are shown as points with an associated population (shown as a number next to the point). In this example, GIS determines the nearest feeder road to a population point using a spatial join. The population data is then associated to the nearest feeder road. The population data then moves along a feeder road to a node that is the intersection of a feeder road and an evacuation route, shown as the circles in Figure 1. For this example, looking at feeder roads A, C, and E in Figure 1, a total of 100, 200, and 32 people will enter the evacuation network at nodes 1, 2, and 3 respectively. Whereas in the case of feeder roads B and D, shown in Figure 1(a), the same feeder road intersects more than one evacuation route, therefore the direction (east or west) in which the population should be distributed is ambiguous. In order to distribute the population along
roads B and D, road B is split into roads B1 and B2, and road D is split into D1 and D2 as shown in Figure 1(b). This allows traffic to flow in either an east or west direction depending on if the segment of feeder road goes to an east or west evacuation route. Therefore, for this example, in Figure 1(b), after splitting road B, a total population of 80 and 140 enters feeder roads B1 and B2 respectively. This approach is done for every feeder road in the network.

Evacuations have spatial boundaries. For example, depending on the severity of a hurricane, different areas may be evacuated. Therefore, only the population in an affected zone needs to be evacuated. In Figure 1, a shaded area representing the “effected zone” is shown. This area is defined in the GIS as a polygon. Only people within the effected zone are selected to enter feeder roads and proceed to evacuation routes. In this method, an unaffected population will not enter the simulation model, thereby producing a more accurate model.

GIS was employed for six major tasks in this work, they are: 1) preparation of evacuation routes, 2) preparation of feeder roads, 3) preparation of population data, 4) association of population data to the feeder roads, 5) preparation of hurricane evacuation zones, and 6) summation of population data within each hurricane evacuation zone. An explanation of each step is presented below.

The first step in producing GIS data is to prepare evacuation routes. Evacuation maps having official evacuation routes are used to draw the evacuation routes on the GIS and a new dataset is created to store the routes. The second step is to prepare feeder roads. Numerous feeder roads connect to evacuation roads, but only major feeder roads were selected, and created, in the same way as the evacuation routes. If a feeder road connects to two or more evacuation roads, then the feeder road is split. The third step is to prepare population data. Population data for an evacuation area are cut out of the overall ESRI dataset available for the entire country. It should be noted that the population data is a point theme rather than a polygon theme. This allows for population (points) to be associated with the feeder roads (lines). The fourth step is to associate population data to feeder roads. Point population data stores how many people are near a particular location. Population data are associated with feeder roads by a spatial join. This new spatially joined table is summarized on population and then rejoined to the feeder roads. This provides the nearby population that will travel down a feeder road and enter the evacuation route network. The fifth step is to prepare evacuation zones. Evacuation zones are prepared to properly select the population that may be evacuated based on the severity of the disaster (9). For the example presented, evacuation zones based on intensity of hurricanes were needed. There are five evacuation zones according to Saffir-Simpson Hurricane Scale, which correspond to the five categories of hurricane intensity. The evacuation zones were digitized and stored as polygons. The final step is to prepare population data from hurricane evacuation zones. Population data within a hurricane evacuation zone can be associated with feeder roads in the same manner as population is associated with feeder roads for a particular county as explained in the third step. Evacuating a particular hurricane zone requires only population from that specific zone to enter feeder roads, which in turn are the only data considered by the traffic simulation model.

Output needed from the GIS is in the form of maps and tables. Maps help visualize the data by presenting graphical information. This gives information such as the name and location of evacuation routes, feeder roads, and hurricane evacuation zones that create input to the simulation model. GIS tabular data, as shown in Table 1, provides information such as the exact population associated with each feeder road, length of the evacuation routes between various nodes, speed limits, and lane counts required for simulation modeling.

Traffic Simulation Modeling

Traffic simulation modeling is the computerization of a developed traffic flow model, which is run with differing inputs, to study the interaction of the parts of the system. In this research, the simulation software Oak Ridge Evacuation Modeling System 2.5 (OREMS) developed at Oak Ridge National Laboratory was used to simulate traffic during extreme events. OREMS can be used to calculate and evaluate evacuation times, develop traffic management and control strategies, identify potential bottlenecks, determine best route choices, and produce other information necessary to develop effective evacuation plans. Some uses of OREMS are determining the feasibility of evacuation, assessing alternate traffic control strategies, assessing different evacuation strategies, estimating traffic speed, and estimating clearance times at specific parts of a road network (4).

OREMS is an application-oriented simulation package, having a graphical user interface (GUI), which makes it easy to use, because it does not require programming expertise. Three major components of OREMS are: Input data manager, Evacuation SIMulations (ESIM) traffic model, and Output display manager (4). A GUI for data entry simplifies the task of creating a database or data files for simulation modeling. ESIM is a FORTRAN-based program that simulates the traffic conditions over a transportation network. Output from OREMS is displayed by the Output display manager, which shows the statistics for individual links (road segments) as well as for the entire network. The display manager also includes a graphical representation (both in a dynamic and a static form) of the
simulated traffic conditions. The OREMS model produces information in the form of animation (graphic files), tabular reports, and raw data files. OREMS can display the measures of effectiveness (MOEs) for each section of a road network. These results are used to estimate the clearance times for highway sections across the entire traffic network and to obtain statistics associated with an evacuation.

The OREMS software prompts users to input a road system in terms of nodes and links, which in this case are developed using GIS. Nodes represent the intersections or points where a geometric property, such as grade or speed changes. A model consists of two types of nodes, external and internal. An external node is one from which traffic enters or exits a network. An internal node is one completely embedded in a given model and is used for traffic control design (actuated/pretimed traffic control devices or stop/yield signs) and to control turning movements of vehicles. There are two types of internal nodes, ‘freeway’ and ‘urban streets’. An internal freeway node represents intersections on a freeway or interstate roads, and an urban street node represents intersections on all other types of roads. Links represent segments of road that connect nodes. Links are also categorized as external or internal depending on the type of node they connect.

Input data required by OREMS are: roadway links, roadway intersections, traffic signals, turn movements, speed limits, lane counts, and number of vehicles entering a network. According to a users needs, input data may be changed to different scenarios of interest. The changes to the input data may be adding lanes in the form of evacuation roads to the existing traffic network, changing turn movements of vehicles, or changing traffic controls on roadway intersections. These changes would result in different models that can be used to rapidly evaluate evacuation timings for optimization purposes.

In addition to input data OREMS requires trip generation data. Evacuation trip generations do not start immediately after the evacuation notification, because the public takes some time to begin evacuation. Thus, there is a time lag for the traffic flow to start evacuating. Once the evacuation begins the traffic flow rate reaches its peak. For the example presented here in, the distribution of vehicle arriving at an intersection is assumed to be normally distributed. This distribution can be changed by adjusting the lag time or the start of the evacuation or the shape of the distribution curve.

OREMS does not automatically optimize the trip generation rates. Further studies may be done to optimize the pattern of the curve, which may reduce the evacuation times of a simulation model. A user can also use different turning movements of vehicles in intersection for evacuation trip distributions. For the example presented here in, traffic was distributed along the evacuation roads set by the AEMA. Additional research could be performed with different evacuation routes to optimize evacuation times.

A reverse-laning method is adopted in the simulation model to evacuate the traffic. Reverse-laning involves the use of one or more lanes of inbound travel to be used for traffic movement in the outbound direction. In other words, all or some of the lanes of the interstates will be “one-wayed” to facilitate faster evacuation. Reverse-laning helps reduce congestion problem on routes since there is no traffic flowing in the opposite direction. Reverse-laning operations can be risky because improper communication between agencies can lead to traffic congestions. Also, drivers traveling in the opposite direction may not be able to see signs and markings, and they do not have access to restrooms, food, or fuel facilities. The problems associated with reverse-laning operations can be addressed by maintaining effective communication between agencies, prohibiting inbound access for any vehicles during reversal, providing pre-trip and on-route information and guidance to drivers, and keeping a single lane of travel open in the inbound direction on the freeway to have access to the reverse lanes.

The approach employed for simulation modeling in this research includes: 1) creating nodes, 2) creating links, 3) designing traffic controls, 4) associating traffic flow data, and 5) running the simulation model. An explanation of each step is presented below.

The first step in setting up an OREMS model is to create nodes within the network. All intersections on evacuation routes are entered as internal nodes. The starting or ending points of feeder roads are entered as external nodes to allow for vehicles to enter or exit the model. Nodes are created in the simulation model at the same location as the GIS maps. The second step is to create links, which represent road segments that connect nodes. Evacuation routes are entered as internal links, and the feeder roads are entered as external links. The link stores information such as the length of a road segment, speed limit, and grade of a road. These data are derived from the GIS and used as input parameters for the model. The third step is traffic control design based on the traffic flow. If the traffic flow rate is high, then a pretimed traffic control device is used, otherwise a stop/yield sign is used. The fourth step is to associate traffic flow data to the model. Traffic arriving at intersections of the feeder roads and evacuation routes enters the model. The GIS population data are used to calculate the number of vehicles by assuming appropriate vehicle occupancy (persons per vehicle). A distribution with respect to time that describes the rate at which population enters the network is also needed. The volume of vehicles arriving at an intersection during the period of study assumes that the traffic flow is normally distributed. The final step is to calibrate and run the
simulation model. Using OREMS animation and model outputs, each road segment is reviewed for accuracy and reasonableness based on matching actual evacuation data and modeled evacuation data. Once calibrated an evacuation model is then run iteratively and the input parameters changed to identify the optimum evacuation results.

Three types of model outputs are produced by OREMS in the form of animation (graphic files), tabular reports, and raw data files. These results contain details describing the amount of traffic congestion on each road segment, number of vehicles traveling past a given point, amount of time a vehicle takes to travel from one intersection to another, average traffic speed on each road segment, and total time required to evacuate. Results can be displayed in terms of measures of effectiveness (MOEs). An MOE is a parameter that describes traffic operations in terms discernible by motorists and their passengers [10]. Because an evacuation occurs over time, MOEs can be dynamically displayed in an animation process. The MOEs variations are displayed with varying the colors of the road network from the least effective (red) to the most effective (blue). The static displays of results are in tabular, line graph, or bar graph format for specific links and nodes. The results can also be queried to find links or nodes with MOE values within a certain range for a given time interval. A summary can be generated to provide evacuation data such as total evacuation time, evacuation starting time, time at which 50%, 75%, and 95% of the population was evacuated from the network, and evacuation ending time. The MOEs displayed for each road segment are average speed, number of vehicles, travel time, trips, and clearance. Average speed is the ratio of the total vehicle-miles of travel to the total vehicle-hours of travel for a specified link for each time interval and is presented as miles per hour. Travel time is the average travel time on the link in hours averaged during the current time interval. Vehicle count is the number of vehicles on a link at the end of a time interval. Trips are the cumulative number of vehicles that have traveled on a link. Clearance is the percentage of vehicles that have cleared a selected link up to the current time interval.

CASE STUDY: BALDWIN AND MOBILE COUNTY EVACUATION MODEL

Geographical Information System

ArcView GIS was used to produce maps and tables for Baldwin and Mobile counties in Alabama. GIS data for Mobile and Baldwin counties were organized and made available for traffic simulation modeling. The majority of the raw data used in this project were from the existing geographic databases, provided by ESRI. The raw data used in this work are: population data from the 1990 census provided by ESRI, evacuation routes prepared from the existing ESRI road network database, and hurricane evacuation zones. The output data in the form of a GIS map for Baldwin County are shown in Figure 2. For this case study, the evacuation routes are the roads designated by the AEMA and Alabama Department of Transportation to provide smooth traffic flow during evacuations. Although the majority of the data employed in this project originated from ESRI data sets, each of these datasets required editing in order to be used in simulation modeling.

GIS maps and tables were produced for Mobile and Baldwin Counties using the six tasks as explained in the above GIS Methodology Section. In the first step evacuation routes were drawn on the GIS maps. ESRI provides a dataset of the major road networks in the country, but evacuation roads are not automatically a subset of this road network. Hence a new dataset was created in ArcView to store these routes. The evacuation routes were digitized based on the official evacuation routes produced by the Alabama Emergency Management Agency (AEMA). Evacuation routes prepared for Baldwin County are shown as thick solid lines in Figure 2. In the second step major feeder roads connecting to evacuation routes were selected, created, and split in the same way as the evacuation routes were created from the existing ESRI road network. Feeder roads created for Baldwin County are shown as dotted lines in Figure 2. In the third step population data were obtained as a point theme from the ESRI population dataset. Because this example only deals with the population of Baldwin and Mobile counties, the population data for these counties were cut out from the overall county dataset. Moreover, in the case of Baldwin County only the population south of I-65 was evacuated. This is because it is unlikely that population north of I-65 will be evacuated southward. The accuracy of this new approach is demonstrated by the resolution of the population data. For the case study, GIS provides population data in the form of census block groups with an area as small as 0.24063 square miles for Baldwin county and 0.03032 square miles for Mobile county. These population data are represented in the form of points, with population sizes ranging from 1 to 785 persons. In the fourth step, population data (point theme) were associated with feeder roads (line theme) by a spatial join. Next, in the fifth step hurricane evacuation zones were digitized and stored as polygons, based on the intensity of hurricanes, as seen in Figure 2. The five evacuation zones were obtained from the Technical Data Report on hurricane evacuation study conducted...
by the AEMA. Finally the population data within a hurricane evacuation zone were associated to feeder roads in the same manner as explained in the third step.

The GIS output for Mobile and Baldwin counties in the form of maps and tables provides information such as the number of vehicles entering the model, roadway links, roadway intersection, roadway link lengths, lane counts, speed limits, and grades of the road. This information is required for simulation modeling, which is presented in the following section.

**Traffic Simulation Model**

OREMS was used to develop traffic simulation models during extreme events for Baldwin and Mobile counties in Alabama. ArcView GIS produces input data for the simulation model. The model developed for Mobile and Baldwin counties considers all vehicles to be northbound. A reverse-laning method is adopted in the simulation model to represent the actual reverse-laning of I-65, which involves the use of one or more southbound traffic lanes to be used for traffic movement in the northbound direction. Interstate I-65 and I-10 are main routes used for evacuation. I-65 can be used for reverse-laning, whereas I-10 cannot be used for reverse-laning due to various traffic congestion problems. United States Routes 331, 231, and 431 are the other north and south running routes that may be used for reverse-laning (12).

The following assumptions were made to develop the model:
- 1.25 persons travel in each vehicle.
- The maximum speed limit on urban streets ranges from 30 mph to 40 mph.
- The maximum speed limit on freeways ranges from 50 mph to 65 mph.
- 20% of all vehicles are trucks.
- Lane counts for all urban streets are 2 lanes.
- Lane counts for interstate I-65 are 4 lanes and for interstate I-10 are 4 lanes.
- Traffic flow on interstate I-65 is unidirectional and northbound. Whereas the traffic flow on interstate I-10 is on both directions.
- Signal timing for the network are assumed according to the flow of traffic.
- Prior knowledge of the percentage of vehicles turning at each intersection.

The traffic simulation models were produced for Mobile and Baldwin Counties using the five tasks as explained in the above Simulation Methodology Section. In the first step internal and external nodes were created. In the second step links were created, which connects the nodes. These links store information such as the speed limit, grades of road, and length of road segment, which are derived from the GIS. The maximum free flow speeds of vehicles were assumed to be between 50 to 65 mph on interstates and 30 to 40 mph on urban streets. The grades of the roads were not available; therefore 0% grade was assumed throughout the road network. It was also assumed that the user has prior knowledge of the percentage of vehicles turning at each intersection. Hence, the turning movements of vehicles are entered for each internal node. In the third step the traffic controls are designed for signal timings and traffic control devices on all internal nodes. The nodes and links developed for the OREMS simulation for Baldwin County are shown in Figure 3. In this figure internal nodes are shown as circles while external nodes are shown as hexagons. In the fourth step, traffic flow data are entered into the model. The population data provided by GIS are from 1990 and was projected to 2000 by assuming a 4% growth rate per year. For this case study, a vehicle-occupancy of 1.25 person per vehicle was used to calculate the total number of vehicles entering the traffic network. The vehicles are entered in the network with respect to time and they are normally distributed. The final step was to calibrate and run the simulation model to determine optimum parameters.

Output data were produced in both the static and dynamic form. An example summary of details from an evacuation of Mobile County is shown in Figure 4. On the left side of Figure 4, data associated with a simulated evacuation are presented. Evacuation time is typically the most important information. On the right side of Figure 4 is a cumulative distribution function graphically showing the percentage of population evacuated verse time. The results show that the total evacuation time for Mobile County is 7 hours 13 minutes. The evacuation started at 08:00 hours and ended at 15:13 hours. Fifty percent of the population was evacuated at 09:55 hours, 75% of the population was evacuated at 11:25 hours, and 95% of the population was evacuated at 13:55 hours. This information is also shown graphically in the same figure.

The results from the model created for Mobile and Baldwin County show that the clearance time for Baldwin County is approximately 21 hours and for Mobile County is approximately 8 hours. This difference in time is attributed to the fact that 1) the population in Mobile county is at the northern end of the county and 2) mobile
county has multiple interstates, which lead from the population center. The Alabama hurricane evacuation study shows that the clearance time for each county generally falls between 6 – 28 hours depending on the severity of hurricane (9). The maximum allowable speed was changed for the model and it was observed that to evacuate Baldwin and Mobile County, vehicles traveling with a maximum of 60 mph on interstates and 40 mph on urban streets had the least traffic congestion and best results. Small variations in speed do not seem to affect the model. The worst case was reached when traffic speed fell to 10 mph. A summary of the results for evacuation of Baldwin and Mobile County are shown in Table 2. The top half of Table 2 is for Baldwin County while the bottom half is for Mobile. Six model runs are shown with varying maximum speeds producing different evacuation times. These different simulations are producing evacuation time with very little difference because each model was run with the same trip generation rates.

CONCLUSION

ArcView GIS 3.2 and traffic simulation software OREMS 2.5 were used to develop evacuation models, which can be used to develop emergency evacuation plans. ArcView GIS database was used to organize input data such as roadway links, roadway intersection, lane counts, and population data for OREMS. The high resolution of population data, with respect to location, number of people, and area, produced accurate input data when compared to a complete city or county evacuation with an evenly distributed population. OREMS was then used to estimate the evacuation time and to develop an evacuation plan for emergency events within user defined spatial boundaries. Simulation models were developed for Baldwin and Mobile counties of Alabama to test this methodology. Models were developed, calibrated, and simulated for optimum results. The model outputs produced by OREMS were in the form of animation (graphic files), tabular reports, and raw data files. The “measures of effectiveness” were displayed for each roadway segment. The results from the models created for Mobile and Baldwin County show that Baldwin takes approximately 21 hours to evacuate and Mobile takes approximately 8 hours to evacuate. Vehicles traveling at 60 mph on interstates and 40 mph on urban streets had the least traffic congestion and best evacuation results.

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### TABLE 2 Results Summary of Simulation

**BALDWIN**

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<th>Model Number</th>
<th>Model # 1</th>
<th>Model # 2</th>
<th>Model # 3</th>
<th>Model # 4</th>
<th>Model # 5</th>
<th>Model # 6</th>
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<tbody>
<tr>
<td>Evacuation Time</td>
<td>21 hrs 8 min</td>
<td>21 hrs 7 min</td>
<td>21 hrs 8 min</td>
<td>21 hrs 7 min</td>
<td>21 hrs 1 min</td>
<td>21 hrs 7 min</td>
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<tr>
<td>Average Speed (mph)</td>
<td>23.6</td>
<td>23.4</td>
<td>23.8</td>
<td>23.5</td>
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</table>

**MOBILE**

<table>
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<tr>
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<th>Model # 1</th>
<th>Model # 2</th>
<th>Model # 3</th>
<th>Model # 4</th>
<th>Model # 5</th>
<th>Model # 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuation Time</td>
<td>7 hrs 13 min</td>
<td>7 hrs 1 min</td>
<td>7 hrs 13 min</td>
<td>7 hrs 1 min</td>
<td>7 hrs 13 min</td>
<td>7 hrs 1 min</td>
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<tr>
<td>Average Speed (mph)</td>
<td>27.9</td>
<td>33.6</td>
<td>27.9</td>
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Note: I- Interstate, US- United States Highway, SH- State Highway and CH- County Highway