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16. Abstract

This paper describes a project to develop a micro-level traffic simulation for a megaregion. To accomplish this, a mass evacuation event was modeled using a traffic demand generation process that created a spatial and temporal distribution of departure times, origins, and destinations based on past hurricane scenarios. A megaregion-scale simulation was required to assess this event because only at this level can traffic from multiple cities, over several days, with route assignments in multiple and overlapping directions be analyzed. Among the findings of the research was that it is possible to scale-up and adapt existing models to reflect a simultaneous multi-city evacuation covering a megaregion. The movements generated by the demand and operational models were both logical and meaningful and they were able to capture the key elements of the system, including the traffic progression over vast spaces and long time durations. They were also adequate to demonstrate benefits of proactive traffic management strategies and the effect of increased and decreased advanced warning times. The project also revealed numerous limitations of existing modeling and computational processing capabilities. The knowledge and results gained from this research can be adaptable and transferable for the evaluation of other locations with different road networks, populations, transportation resources, and hazard threats. Models such as this can be modified to represent anticipated growth and development within large regions and can be used to evaluate the interrelationships between behavioral response and regional transportation management strategies.

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GULF COAST MEGAREGION EVACUATION TRAFFIC SIMULATION MODELING AND ANALYSIS

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DISCLAIMER

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EXECUTIVE SUMMARY

This paper describes a project to develop a micro-level traffic simulation for a megaregion. To accomplish this, a mass evacuation event was modeled using a traffic demand generation process that created a spatial and temporal distribution of departure times, origins, and destinations based on past hurricane scenarios. A megaregion-scale simulation was required to assess this event because only at this level can traffic from multiple cities, over several days, with route assignments in multiple and overlapping directions be analyzed. Among the findings of the research was that it is possible to scale-up and adapt existing models to reflect a simultaneous multi-city evacuation covering a megaregion. The movements generated by the demand and operational models were both logical and meaningful and they were able to capture the key elements of the system, including the traffic progression over vast spaces and long time durations. They were also adequate to demonstrate benefits of proactive traffic management strategies and the effect of increased and decreased advanced warning times. The project also revealed numerous limitations of existing modeling and computational processing capabilities. The knowledge and results gained from this research can be adaptable and transferable for the evaluation of other locations with different road networks, populations, transportation resources, and hazard threats. Models such as this can also be modified to represent future anticipated growth and development within other large regions and can be used to evaluate the performance, varying conditions, and interrelationships between behavioral response and regional transportation management strategies.

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INTRODUCTION

Over the past several decades, the world has experienced enormous growth in the population of its coastal regions. While societies have always tended to concentrate in areas with water accessibility for trade and transportation, this recent growth has accelerated, leading to the emergence of megaregions. Megaregions are broadly defined as chains of once separate metropolitan areas that have grown together to form geographically extensive and continuously populated regions. They may spread over hundreds of miles and can even cross national boundaries. While the population sizes that make up megaregions vary by location, there are several areas of the United States (US) that are considered to be megaregions. These include the corridor from Boston, through New York, to Washington DC with a population of about 50 million as well as the Great Lakes region that includes Milwaukee, Chicago, Detroit, Cleveland and Toronto and Ontario, Canada. Worldwide, megaregion sizes are even larger, particularly in Asia. The Pearl and Yangtze River Delta regions of China are among the largest at 120 million and 88 million inhabitants, respectively, and the Taiheiyō Belt region of Japan incorporates a population of about 80 million.

Although they may be composed of separate local governmental jurisdictions, megaregions often share common historical, cultural, environmental, and topographic systems. Because of transportation linkages that connect the movements of people and freight, they also share close economic ties. These shared cultural and transportation ties also mean that they often share many similar problems. One of these, and the focus of this paper, is the issue that arises from the emergence of coastal megaregions and changing global climatology.

Over the past twenty or so years there has been a converging consensus among long-range climatological forecasters that the earth is experiencing significant changes to its climate. These climatological changes have the potential to result in rises in ocean sea level as well as the elevated risk for both the frequency and severity of tropical weather systems like hurricanes (1). This combination has also created a significant and growing potential for the occurrence of catastrophic natural disasters (flooding, tsunami, hurricane, and so on), the portions of which have never been imagined. Recent history has already demonstrated this threat potential. The hundreds of thousands of lives lost in the 2004 Indonesian Tsunami disaster and various floods and hurricanes throughout China and the United States suggest the potential for loss and destruction.

To better prepare for such threats and to more effectively plan, construct, and operate transportation systems within megaregions in general, research has been ongoing to examine megaregion mobility issues. One of these efforts has involved collaborative work between Chinese and American researchers to analyze megaregion evacuations using traffic simulation modeling. Among the unique aspects of these relationships and the models that have resulted from them has been the ability to model not only the evacuation processes of multiple interconnected metropolitan areas that span tens of thousands of square miles with populations exceeding many millions over multiple days, but with the ability to track and analyze individual vehicles and evacuees over several days and throughout these extensive networks.

To achieve modeling at this scale, special tools and techniques are necessary. In this paper, a research project is described that involved the construction of a megaregion model to simulate mass evacuation events along the Gulf Coast of the US from New Orleans, Louisiana west to Houston, Texas. Although this area is not the largest or most populated megaregion in the US, it is growing in population and economic importance, particularly as a hub for the development and transport of energy resources. From a modeling standpoint, it was also selected based on its extensive recent history of transportation modeling, simulation study, and analysis conducted on hurricane evacuation (2). With the ability to adjust the model to various conditions, the population can also be varied in this research to reflect potential future growth conditions that may exist in the area and to evaluate the general effects of additional population with no additional road infrastructure, a very commonly occurring condition.

The use of a megaregion-level model to simulate evacuations in this area was critical from several perspectives. The most important is that only a model at a megaregion scale was capable of reproducing the traffic processes associated with a full evacuation of the region. Currently, Houston and New Orleans have independent evacuation models in which traffic is assumed to follow historical outflow patterns. However, it has been theorized that all or parts of both regions could be evacuated simultaneously and traffic could move into overlapping areas concurrently. Prior corridor-level and even area-wide models have fallen well-short in their ability to simulate this condition and only a model similar to the scale presented here is capable of modeling such a coinciding evacuation condition. Another motivation for doing megaregion-scale modeling is that it can also be used for more than just evacuation. The model discussed here is also currently being adapted for the analysis of commercial freight movements as well as for the evaluation of a high speed rail line within the Interstate 10 corridor. From a research perspective, the incorporation of emerging knowledge to dynamically model travel demand generation is also a significant step forward in the modeling of evacuations and megaregion transportation issues.

BACKGROUND

Megaregions, Hazards and Evacuation

Megaregions are continuously populated areas that have grown together over time from distinctly separate individual cities or populated areas to form continuously densely populated areas that may span over many hundreds of miles. This concept was originally used by Jean Gottmann in 1961 (3), to describe the huge metropolitan area along the eastern seaboard of the U.S. Although there is no systematic method to define megaregion, Richard Florida used a global dataset of nighttime light emissions to produce an objectively consistent set of megaregions (4). These 40 megaregions had an economic output of more than $100 billion producing 66 percent of total world output of goods and 85 percent of global innovation.

Paralleling the growth of megaregions has been a growing consensus that the earth is experiencing significant climatologically changes. These changes are thought to be contributing to the melting of ice caps, raising of the sea levels, and increasing the frequency and intensity of hurricanes that threaten coastal regions throughout the world. When the trends of climate change and population growth are combined, it is inevitable that there will also be a significant increase in the number of catastrophic disasters that can threaten millions of people. The 2012 Hurricane Sandy event, for example, threatened 50 million people and killed more than 66 persons. In addition, the hurricane caused widespread power outages; air, rail, and bus transit shut downs; and the evacuation of 375,000 people from low-lying coastal areas (5).

Traffic Simulation for Evacuation

Traffic simulation modeling has grown steadily as a tool for evacuation traffic analysis since the 1979 Three Mile Island nuclear power plant emergency. Generally speaking, traffic models used for evacuation traffic analyses encompass three levels of scale and computational detail and output fidelity; macroscopic, mesoscopic and microscopic. The spectrum of currently available models, in terms of fidelity and detail, and evacuation traffic demand generation modeling are described in the following sections.

Macroscopic models are used primarily to represent traffic processes over large geographic areas. In macro-level models, traffic flow conditions are aggregated to represent average conditions over segments of road rather than as individual units (vehicle or people).

Although macroscopic models lack time sensitivity, they require the least amount of computing time and the low input requirements often make them useful tools for static planning and analysis, especially over large areas.

The earliest generations of evacuation traffic simulators like NETVAC (6) were based on macroscopic relationships. In the decades since, the application of these models has expanded to other large-scale disasters both natural and manmade (7, 8, and 9) and in particular, for hurricanes (10 and 11). They have also increased in both scalability and computational detail. Among these, Emme/2 (12), ETIS (13), the Oak Ridge Evacuation Modeling System (OREMS) (14) and TransCAD (15 and 16) have been used to estimate evacuation clearance times and support the development of evacuation plans for different events and scenarios, including traffic management strategies and operational traffic characteristics.

Microscopic models differ from macro models in that they simulate the movement of individual vehicles, including specific driver and vehicle performance characteristics and behavior as well as road geometry. They have been useful for operational-level analysis as well as for mass evacuation analyses, particularly for contraflow and intersection control. Among the micro models identified by Hardy (15) for emergency evacuation planning, were AIMSUN II, CORSIM/TSIS, Paramics, SimTraffic, VISSIM and DynaMIT (17). CORSIM, a widely used general simulation system, has been used to model and evaluate contraflow segments out of New Orleans (18) (19) and VISSIM for the analysis of the Hampton-Roads, Virginia Hurricane Evacuation Traffic Control Plan (TCP) (20).

Mesoscopic models have aspects of both micro and macro systems. They work by disaggregating segments of macro models into smaller segments to create near-micro systems. Within such a framework, these models can produce detailed traffic performance indicators including traffic congestion and queuing. Several models, including Cube Avenue (21), DYNSMART-P, TRANSIMS (2) and TransModeler DYNASMART (22 and 23) have been used to support local emergency evacuation management, planning, and decision making.

Evacuation Travel Demand Models

In the past, researchers have used evacuation response or departure curves to predict when people will evacuate (24). These response curves have been assumed to follow various distributions, including Weibull, Uniform, Sigmoid and Poisson as shown by Liu, Lai and Chang (25), Yuan et al (26) Cova and Johnson (27), Lindell (28), Kalafatas and Peeta (29), and Xie, Lin and Waller (30). However, most of the research predicts travel demand and departure time separately. Static evacuation demand models may predict the number of households that will evacuate but not *when* they will evacuate. Work by Fu, Wilmot and Baker (31) showed that traditional (non-emergency) static urban transportation modeling techniques do not adequately model hurricane evacuation travel demand because they ignore the dynamic variation in conditions and travel behavior that occurs during the evacuation process. In a more recent study, Fu and Wilmot (24) developed a sequential logit dynamic travel demand model to predict the evacuation demand and time of departure using Hurricane Andrew data that included evacuee socio-demographic characteristics, distance to the hurricane, the storm path, forward speed, and intensity. Later, in an improved version, Fu, Wilmot and Baker (31) created an updated model with a data set from Hurricane Floyd, which provided insights to understand household evacuation behavior under different evacuation order conditions. Then, a sequential logit model by Gudishala and Wilmot (32) used a video based survey and time dependent storm data from Hurricane Gustav in 2008 to build a time dependent sequential logit model (TDSLM) of evacuation demand. In their most recent effort, Gudishala and Wilmot (25) built a time-dependent nested logit model (TDNLM) and compared its performance to data from 2008 Hurricane Gustav.

RESEARCH GOALS, APPROACH AND CONTRIBUTIONS

The goal of the project was to develop a megaregion evacuation model capable of incorporating the transportation process of the Gulf region from New Orleans to Houston. The motivation for this work was based originally on requests from police, transportation, and emergency preparedness officials in the State of Louisiana charged with the planning and management of evacuations. They sought information that could show clearance times for evacuees departing from specific locations at certain times and estimate travel times between threatened areas and safer shelter. This has been achieved in earlier versions of the model, but only for the immediate southeastern coastal area of the State.

Later, after it became apparent that Louisiana evacuees commonly travel to Texas and vice versa, travel time estimates and congestion information was needed for a much wider area. It was also suggested that in the future it might be necessary to evacuate large areas of central Gulf Coast, including New Orleans and Houston simultaneously. This would be problematic given that long segments of Interstate 10 are planned to be used in a unidirectional contraflow operation in one direction or the other. From a modeling standpoint, it was not possible since simulation can only be conducted at a megaregion scale.

The megaregion model developed for the project has been constructed over several years using an iterative process during which additional areas were added to the original New Orleans metropolitan area model developed prior to Hurricane Katrina. The expansion was made to the west to add Baton Rouge, then further to incorporate Lafayette and Lake Charles, Louisiana and the Beaumont/Port Arthur region of southeast Texas. Ultimately, it included the Houston-Galveston region, home to over 6 million people. In addition to the road network description, two other key aspects of the model were created. These included the characteristics and locations of the region's inhabitants as well as the temporal and spatial hurricane threat scenarios (stimulus) in combination with evacuation orders and evacuee decision-making behavior (response) to determine how such combinations translate into evacuation travel demand, specifically their origins, departure times/locations, destinations, and route selection. The integration of the evacuation travel demand modeling, in particular, was an innovative feature of this megaregion model. Ultimately, the megaregion network was used to assess clearance times and forecast travel times, speeds, congestion, and delay.

This paper describes the processes and assumptions used to construct and execute this model as well as the results that were gained. Perhaps more importantly, this paper provides a rationale and basis for the assumptions used here and the application to future megaregion models.   This work also summarizes lessons learned during its development; techniques that were found to be particularly effective and/or useful; and other limitations and difficulties that were not able to be overcome or which limited the effectiveness of the overall effort.

MODEL DEVELOPMENT

The development of the mega region traffic simulation model in this project was accomplished within a framework of three primary tasks. The first was the creation of a “base model” which included the link, node, and control features of the regional road network, then its calibration and validation based on the 2005 Hurricane Katrina and 2008 Hurricane Gustav evacuations. The second step was to build a series of evacuation scenarios based on theoretical hazards and response conditions. Then, the last step was to run the scenario model for each of these scenarios, extract the pertinent performance measures and analyze them. Each of these steps, as well as their component subtasks, is described in the following sections.

Base Model Development

The TRAMSIMS system was used to construct the megaregion model. Although there are other models which may be capable of achieving similar results, TRANSIMS was selected because of its proven capability to effectively model the traffic processes associated with regional evacuations in the Gulf region as well as the existing data that has been established for use in the area. TRANSIMS is an agent-based travel simulation system originally developed to aid in the development of travel forecasts for transportation planning and emissions analysis. Because it incorporates capabilities for the creation and simulation of synthetic populations based on actual census data and spatial and temporal traffic patterns of these populations, it was also thought to be uniquely suited for the purpose of large scale evacuation traffic analysis.

To code the road network, a geographic information system (GIS) software was used to convert existing Metropolitan Planning Organization (MPO) road network models from the six major metropolitan areas in the region, including New Orleans, Baton Rouge, Lafayette, Lake Charles, Beaumont and Houston-Galveston. Each of these separate networks was merged into a single mega-network and the “empty spaces” between them were filled by manually connecting the roads based on various online and printed maps. Each road was coded as a link connecting two nodes, A and B. Each of these links also had attributes such as a direction; one or two way operation; a speed limit; and a functional classification such as interstate highway, arterial, major road, local road, etc. The resulting mega road network is depicted in Figure 1.

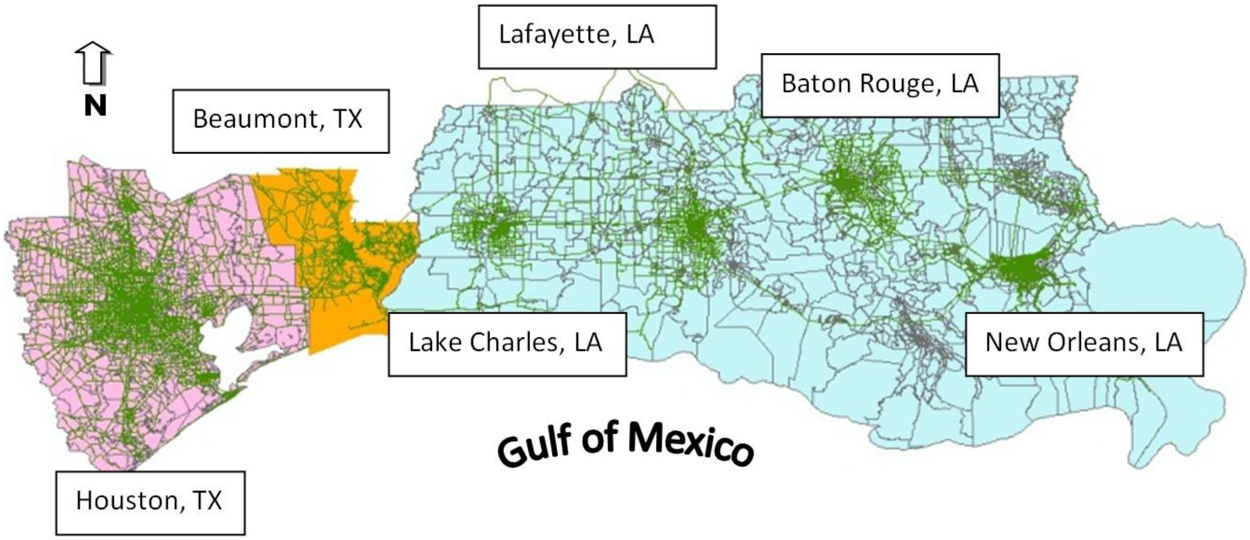

Figure 1: Gulf Coast Megaregion Road Network

Evacuation Demand Forecast

Another critical component of the simulation was the generation of the evacuation travel demand, specifically when the evacuees departed, where they departed from, and the location of their shelter destinations. Prior to combining the TDSLM and evacuation destination choice models, it was first necessary to create a synthetic population. This mathematical representation was statistically representative of recent US Census data for all the travel analysis zones (TAZs) for each area within the megaregion. The TAZ data set for each area came from 2010 US Census data. The “blank” or “missing” areas between each of the metropolitan subareas were specified using Cheng’s method (33), in which voting districts (VT) from 2010 US Census were used. The 2010 Census Summary File 1 (SF1) data was then used to assign households and population to each TAZ.

To simulate departure times, a binary logit model (for 2008 Hurricane Gustav) developed by Gudashala and Wilmot (25) was used. In this model, household evacuation decision making is represented as a series of sequential binary choices over discrete time periods until either the household evacuates or not. The equation for TDSLM and the method used to estimate TDSLM is explained in the above referenced publications. Then, a multinomial logit destination choice model (MLM) developed by Cheng, Wilmot, and Baker (33) was used to model evacuee shelter destination locations. This model assigns a probability to each destination based on its distance from an origin, the level of hazard threat at the destination, the population of the destination and the destination’s racial make-up. Since the evacuation demand was estimated, evacuation OD tables and departure curves were used to assign travel demand at each time interval. The concept of user equilibrium (UE) was then used to build routes (travel plan) at the household-level. TRANSIMS, with its separate modules, Router and Simulator, has the capability to perform static UE and dynamic UE.

The simulations also reflected the current lane-reversal or “contraflow” plans that have been used in the area during several recent regional evacuations. Under these traffic management plans, flow in the inbound lanes of several key segments in the region is reversed to carry traffic in the outbound direction (LA DOTD, 34). These include both northbound and westbound freeways out of New Orleans and eastbound Interstate 10 between the Texas border and Lafayette, Louisiana to facilitate cross-state and west Louisiana evacuations. In the simulations, the timing of these reversals was set to start at various times and locations on the first day and end on the second day of the evacuation based on the Louisiana Department of Transportation and Development plans and the issuance of evacuation orders to accommodate the anticipated demand. A detailed description of these specific times and locations can be found in the full project report (34).

Finally, it should also be mentioned that the simulations assumed a single travel activity (evacuation) and did not take into the likelihood of local work, shopping, and family visitation/coordination trips that would take place in and around the origins, particularly by the non-evacuees on the first day of the event. While this assumption was less than ideal, it was thought that the preparation and localized traffic movements in the evacuation area would affect loading onto the network, but its impact on routes further away from these areas would be comparatively less.

SCENARIO DEVELOPMENT AND TESTING

Once the base model was calibrated and validated (this is detailed in a related paper currently under development), a series of threat-response scenarios was created to evaluate the regional traffic conditions that might occur under various hurricane events. These scenarios, listed below and shown graphically in Figure 2, were based to varying degrees on several prior hurricane events in the Gulf, some recent and others that took place more than 100 years ago.

- Scenario 1: The storm development and track of Hurricane Gustav in 2008
- Scenario 2: Hurricane Gustav increased to Category 4 strength
- Scenario 3: Hurricane Gustav increased to Category 5 strength
- Scenario 4: A Category 4 storm based on an 1867 unnamed hurricane with a forecast uncertainty that threatened the full Gulf Coast study area.
- Scenario 5: A Category 4 storm based on a 1914 unnamed hurricane, traveling east to west with a forecast uncertainty that threatens the full Gulf Coast study area.
- Scenarios 6: A Category 5 version of the Scenario 5 event.

Using these six hurricane scenarios, the time dependent sequential logit model (22) was applied to predict the evacuation participation rate and departure times for each of the metropolitan areas as well as the immediate coastline areas in Louisiana and Texas. The total evacuation generated by these areas is in Table 1 as a percentage of the total population. As apparent in the table, the evacuation participation percentage varied for each scenario; largely as a function of the level of perceived threat from each storm. For example, only Scenario 4, which made an initial direct track toward the Houston-Galveston area, precipitated an evacuation response from the Houston region.

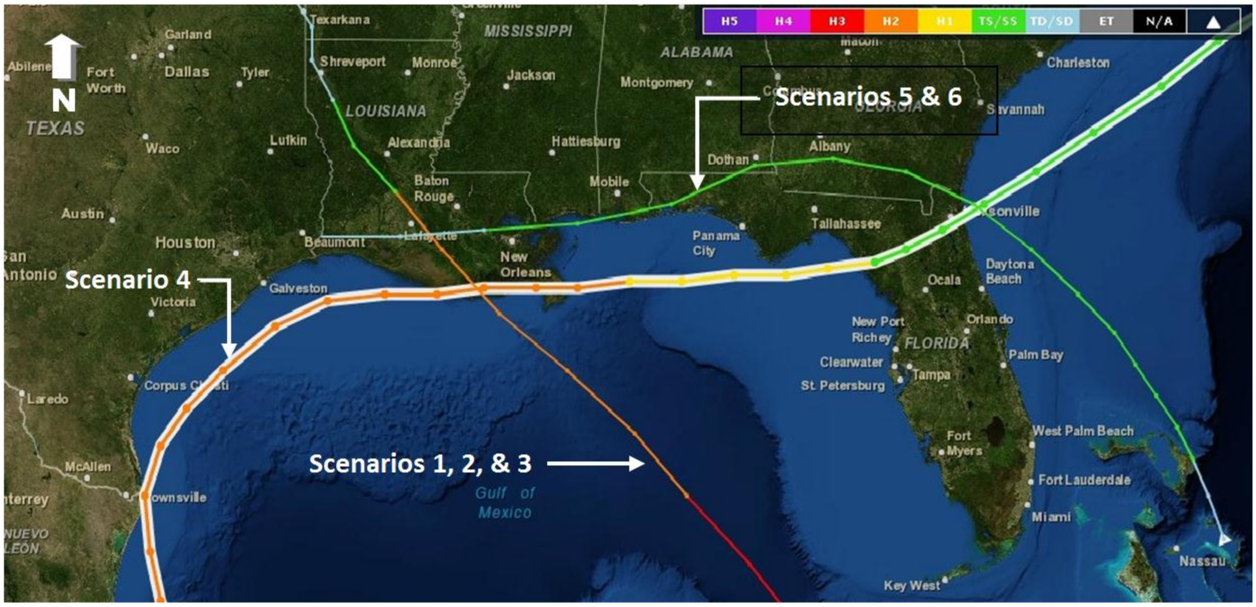

Figure 2: Hurricane Track Scenarios

Table 1: Evacuation Percentage

Scenario	New Orleans	Baton Rouge	Lafayette	Lake Charles	Beaumont	Coast1	Coast2	Houston
1	65.2%	50.2%	41.0%	38.3%	51.5%	96.7%	99.9%	0.0%
2	82.9%	66.2%	56.4%	53.3%	58.2%	100.0%	100.0%	0.0%
3	93.0%	81.2%	72.7%	67.0%	70.5%	97.6%	97.9%	0.0%
4	93.6%	90.7%	76.1%	93.8%	93.8%	86.6%	86.4%	95.5%
5	70.9%	58.1%	50.0%	47.1%	38.7%	56.1%	46.6%	0.0%
6	77.7%	67.2%	60.0%	54.6%	47.6%	62.4%	53.8%	0.0%

Next, departure times for the evacuees for each area under each storm scenario were developed. This process yielded cumulative temporal response curves that reflected the cumulative percentage of evacuee departures over the duration of the evacuation. An illustrative example of the cumulative response curve for each location under Scenario 1 is shown in Figure 3. In the figure, it is apparent that the coastal areas showed the most urgent response and the areas further to the west, with the lowest rates of participation, showed the least urgent responses.

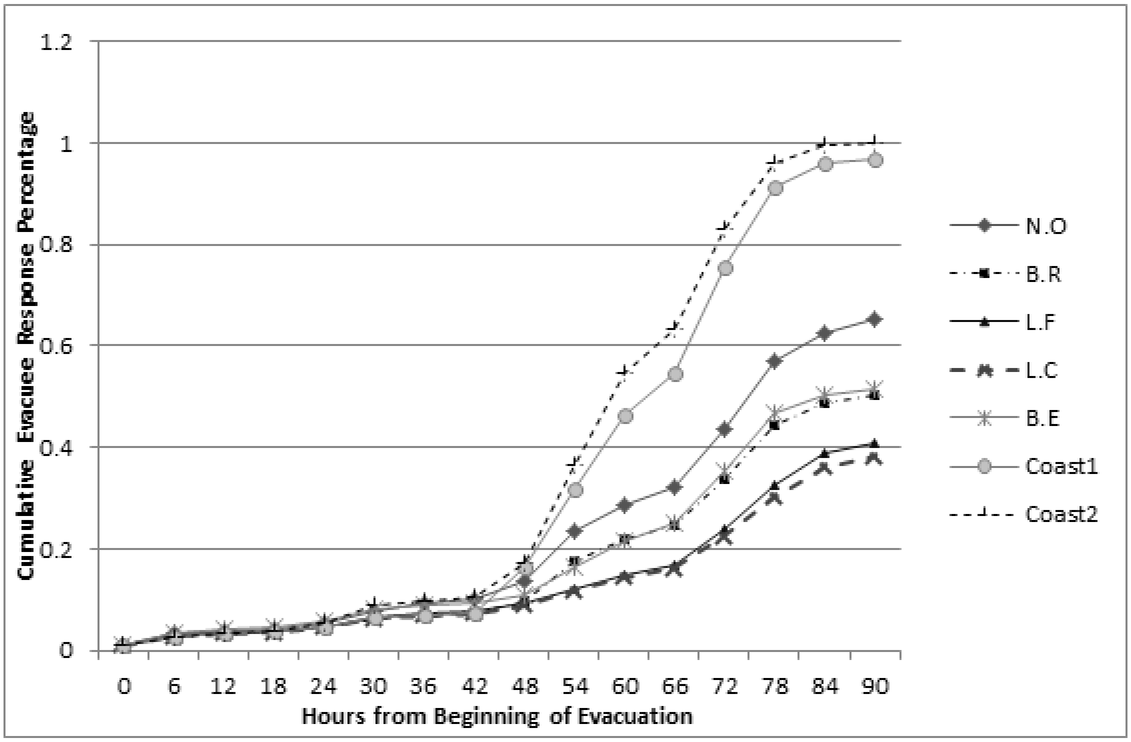

Figure 3: Cumulative Response Curve for Scenario 1

In the final step of the evacuation demand generation process, the destination choice model was applied to estimate the ultimate location for each area under each scenario. As described previously, the selection of a final shelter destination was based on a number of factors identified in prior research. To illustrate the results of the destination analyses, directional probabilities for New Orleans evacuees under Scenario 1 are shown in Table 2. As is typical, evacuees tended to be drawn to the closest large cities which are also the most distant from danger. In the case of Scenario 1, New Orleans evacuees showed a preference for Baton Rouge, Louisiana, Houston, Texas, and Mobile, Alabama.

Using this demand generation, the TRANSIMS model was executed using 40 to 60 iterative runs to assign the evacuation traffic to the regional road network based on its equilibrium-process. After the first several attempts at simulation, it became apparent that the 12 core high-performance desktop computer was limited in its ability to fully execute the model in its complete form. Unfortunately, the memory and computational time required to track and store the movement characteristics of every individual vehicle agent was more than the capability currently easily attainable. As a result, it was necessary to separate the evacuation simulation into two runs, each encompassing one of the two days of the evacuation. From a real-world standpoint in the simulation, this separation had a negligible impact because the greatly diminished demand in the overnight hours permitted the road network to recover and restore a state of free flow operations on all roads.

Table 2: Destination Choice for New Orleans, Scenario 1

Travel Direction	Destination	Distance (mi)	Population (2000)	Danger Level	Metro Area	Racial Pct.	Utility	Prob.
WEST	Btn Rge, LA	85	227,818	1	1	0.46	0.9899	0.1603
	Houston, TX	350	1,953,631	0	1	0.49	0.5801	0.1064
	Shrvprt, LA	315	200,145	1	1	0.47	-0.0786	0.0551
	Monroe, LA	270	53,107	1	1	0.37	0.0394	0.0619
	Dallas, TX	500	1,188,580	0	1	0.57	-0.1915	0.0492
NORTH	Jackson, MS	190	184,256	1	1	0.3	0.3866	0.0877
	Mmphs, TN	400	650,100	0	1	0.34	0.0303	0.0614
	Lttl Rck, AR	420	183,133	0	1	0.55	0.0006	0.0596
NORTH EAST	Httsbrg, MS	110	51,993	1	0	0.5	-0.6850	0.0300
	Mrdian, MS	198	39,968	1	0	0.44	-1.1369	0.0191
	B’mghm, AL	340	242,820	0	1	0.24	0.1749	0.0709
EAST	Mobile, AL	145	198,915	1	1	0.48	0.7193	0.1223
	Atlanta, GA	470	416,474	0	1	0.33	-0.3411	0.0423
	Tallhssee, FL	380	150,624	0	1	0.6	0.2150	0.0738

(note: Utility calculated from the multinomial logit model by Cheng et al. (30))

RESULTS

The performance of the network was evaluated using several different quantitative parameters produced by the TRANSIMS system. These were selected based on their interest from transportation system performance perspective and an emergency management point of view and they include:

- Total number of trips - for vehicles engaging in the evacuation event.
- Total vehicle hours - the sum of travel time for all evacuating vehicles. This parameter also indicates the general level of congestion in network because the more time spent by vehicles on the road, the larger the value of travel time.
- Total distance traveled by all vehicles - this measure implies the efficiency of travel within the network in that this value indicates whether vehicles were traveling most directly from the origins to the destinations in each scenario.
- Average travel time –broadly indicates the average time taken from origin to the theoretical destination.
- Average travel speed - shows how efficiently vehicles were moving through the network.
- Clearance time – the duration of time required for all vehicles from the threat zone. It is influenced by the time at which evacuation order is issued, the amount of demand on the roads, network capacity, and level of congestion. This parameter is of particular interest to emergency managers.

The performance measure values for each scenario are presented in Table 3. As described previously, each scenario reflected the two separate days of simulation as well as an additive total that included both day simulations. The general findings of these runs are also briefly summarized in the sections that follow.

It should also be noted that the shelter location destinations in the simulations were located at the termination points of each road in the network and not in the actual cities where evacuees would shelter. Thus, measures such as travel time and travel distance are considerably shorter than what would occur in reality. However, these numbers were helpful to illustrate the conditions occurring within the immediate threat zone. To capture full travel conditions, future versions of this model will be coded to include complete networks as well as the full populations in the destination and intermediate pass-through cities. However, that will require significantly greater computer processing capability not currently available for the program as it is presently coded.

Table 3 also includes another parameter that was used to assess the computational performance of the TRANSIMS program. The second column from the right shows the number of vehicles that were "removed" from the system by the program. TRANSIMS removes vehicles with a travel time three hours longer than under normal conditions. While this would never occur in the real world, it is a helpful measure from a coding and error-checking perspective because it indicates where routes may not be connected properly or where signals have been mis-timed. Since vehicle removal may also be indicative of the excessive congestion in the network the location and timing of vehicle removals can also be used to identify bottleneck locations that could be improved through the implementation of traffic management techniques such as contraflow and signalization optimization.

Table 3: Simulation Results

Scenario	Time	Total Trips	Tot Vehicle Hours	Tot Vehicle Miles	Ave Travel Time (min)	Ave. Travel Speed (m/h)	Ave. Trip Length (m)	Vehicles Removed	Contraflow Plan
1	**Day1**	417,808	1,287,164	52,916,443	3:04	51.6	126.7	13,765	Plan1
	Day2	548,878	1,714,707	61,970,935	3:07	48.1	112.8	9,193	
	Total	966,686	3,001,871	114,887,378	3:06	49.9	119.7	22,958	
2a	**Day1**	580,370	2,385,837	74,755,968	4:06	43.1	128.8	103,673	Plan1
	Day2	549,154	1,261,835	56,460,951	2:19	49.0	104.0	10,672	
	Total	1,129,524	3,647,672	131,216,919	3:13	46.1	116.4	114,345	
2b	**Day1**	580,370	2,176,945	74,540,040	3:45	44.7	128.4	77,841	Plan2
	Day2	549,154	1,093,388	57,285,191	2:00	53.7	105.6	21,735	
	Total	1,129,524	3,270,332	131,825,230	2:52	49.2	117.0	99,576	
2c	**Day1**	580,370	2,155,501	75,136,114	3:42	45.7	129.5	60,526	Plan3
	Day2	542,714	1,093,388	57,285,191	2:00	53.7	105.6	21,735	
	Total	1,123,084	3,248,888	132,421,305	2:51	49.7	117.5	82,261	
3a	**Day1**	715,991	2,819,686	87,345,490	4:03	40.6	125.7	97,377	Plan2
	Day2	499,919	945,549	50,033,944	1:54	54.8	100.9	14,289	
	Total	1,215,910	3,765,235	137,379,434	2:58	47.7	113.3	111,666	
3b	**Day1**	715,991	2,853,408	88,190,921	4:06	39.0	126.9	84,895	Plan3
	Day2	499,919	945,549	50,033,944	1:54	54.8	100.9	14,289	
	Total	1,215,910	3,798,957	138,224,865	3:00	46.9	113.9	99,184	
4*	**Day1**	3,178,238		0	0:00	0.0	0.0		Plan3
	Day2	1,009,552	2,102,544	75,831,492	2:04	48.0	75.1	211,754	
	Total	1,009,552	2,102,544	75,831,492	1:02	48.0	75.1	211,754	
5	**Day1**	344,280	999,179	48,919,898	2:54	53.2	142.1	22,306	Plan3
	Day2	559,037	1,753,492	77,686,720	3:08	50.7	139.0	125,558	
	Total	903,317	2,752,672	126,606,618	3:01	52.0	140.5	147,864	
6	**Day1**	551,807	1,696,479	75,854,501	3:04	51.6	137.5	113,855	Plan3
	Day2	660,000	2,174,490	89,863,937	3:19	50	137	237,304	
	Total	1,211,807	3,870,968	165,718,438	3:11	50.7	137.4	351,159	

(*Note: Scenario 4 would never fully execute the full simulation prior to failure.)

Scenario 1

In Scenario 1, a total demand of 992,280 vehicles was generated by the threat conditions. Demand was about 30 percent higher on the second day of the evacuation compared to the first. This is a common condition as evacuees tend to depart in greater numbers as the level of threat increases. Despite this, average travel time only increased by about one percent and speeds dropped by about four miles per hour (6.8 percent) and average trip lengths decreased by about 13 miles (about 10 percent) on the second day. Combined, these statistics suggest that the implementation of contraflow on the second day significantly improved traffic flow.

Scenario 2

With the storm track of Scenario 2 being the same as Scenario 1, the only change in threat was the increased strength from a Category 3 to a Category 4. As a result the destination choices were the same as in Scenario 1, however, the departure urgency and level of evacuation participation were larger. To accommodate the additional demand, the LA DOTD contraflow plans were applied in three different ways. In the first analysis (Scenario 2a) the duration of contraflow was the same as Scenario 1. In Scenario 2b, it was extended from 14.5 hours, to 40 hours (Plan2), then up to 48 hours of the simulation in Scenario 2c (Plan3).

The performance statistics indicated an interesting result, particularly related to contraflow. By extending the length of time that contraflow was active, the average travel time under contraflow Plan2 was shortened by 10.4 percent compared to Plan1. However, extending contraflow eight additional hours from Plan2 to Plan3 incrementally decreased travel time by only an additional 0.4 percent. Similarly, the average speed increased by about 7 percent in Plans 2 and 3 over Plan1 and the average trip length showed nearly no change (less than one percent). The number of vehicles removed from the system by the program due to excessive delay decreased by 13 and 28 percent, respectively, by further extending contraflow.

Thus, it was apparent that the use of contraflow on a region-wide basis significantly improved the progression of traffic. However, the incremental benefit of its use diminishes as time extended later into the evacuation and the overall evacuation traffic demand dropped.

Scenario 3

Scenario 3 used the same track as Scenarios 2 and 1, but the strength category was increased yet again. And, as expected, the destination choice results were unchanged from the previous two scenarios although the participation and departure urgency both increased. To accommodate this increased level of demand, only the two longer contraflow plans (40 hours in Plan2 and 48 hours in Plan3) were tested.

Similar to earlier analyses, the results showed that the additional eight hours of contraflow use resulted in only marginal improvements in system performance. The average travel time, average speed, and trip length each showed improvements of less than one percent. The only significant area of improvement was in the number of vehicles “removed” by the TRANSIMS program. Under contraflow Plan3 there was an approximate 12 percent improvement over Plan2 suggesting that, at least computationally, the extension of contraflow resulted in improved travel conditions.

Scenario 4

The Hurricane track used for the evacuation in Scenario 4 was based on an unnamed Hurricane which impacted the Gulf Coast from Texas to southern Louisiana in 1867. For modeling purposes the storm strength was assumed to be a Category 4. Because of the track and strength, a very large number of evacuees were generated. Due to the track, evacuees could only move to the north, northwest and northeast. This was quite different from all other scenarios.

On the first day of evacuation, the TDSLM model forecasted that about 3 million vehicles would evacuate with an additional 1.1 million joining on the second day. It was assumed that because of this enormous volume, TRANSIMS was never able to fully execute the model. From the data that was produced, however, it was evident that even though the demand was 102 percent more than the same day in Scenario 3, the average travel time was only 8.8 percent longer, the average travel speed was 12.7 percent lower, and the average trip length was 33.5 percent shorter than Scenario 3. This result likely was related to the fact that the majority of Houston evacuees traveled to destinations north, northwest, and northeast of the city, a much shorter distance than for the other scenarios.

Scenario 5

The storm track used to feed the evacuation in Scenario 5 and 6 was based on an unnamed hurricane which struck the area in 1914. Uniquely for storms in this area, it moved across Louisiana from east to west and on to Beaumont, Texas. Although specific strength data was not available, the strength of this hurricane was assumed to be a Category 3 for modeling purposes.

The destination modeling results showed that because the track of this storm was from west to east, no people evacuated to the east or northeast. Rather, all the evacuees traveled west, northwest, or north. What is most interesting about this scenario from a transportation perspective is that the overall capacity of the road network actually decreased because the routes to the east were effectively unused as evacuees moved into alternate directions. This resulted in a reduced overall system performance as evidenced by the much higher percentage of vehicles "removed" from the system as compared to Scenarios 1, 2, and 3. To illustrate this effect, the demand in Scenario 5 was about 25 percent less than that of Scenario 3, however, the number of vehicles "removed" due to excessive delay was nearly 50 percent higher under the same contraflow plan.

Scenario 6

The same storm conditions and contraflow plans were used in both Scenario 5 and Scenario 6. However, the maximum storm strength was increased to a Category 4. As a result, the destination choices were the same as in Scenario 5, but the departure urgency and level of evacuee participation were larger. The total demand for Scenario 6 was 1.2 million, 34.2 percent more than in Scenario 5. However, the average travel time was only 6 percent longer, the average speed was 2.4 percent lower and the average trip length was 2.2 percent shorter than in Scenario 5. Additionally, as the demand increased by 34.2 percent, the number of vehicles removed was 351,159, or nearly 29% of the total demand. This was an interesting result because while these key operational parameters changed minimally from Scenario 5, the number of vehicles removed was 200,000 greater. Based on this, there appears to be a threshold for the number of vehicles, ranging from 750,000 to 860,000, that can be evacuated in Scenarios 5 and 6.

ANALYSIS AND CONCLUSION

The project described in this paper was undertaken to develop a micro-level traffic simulation for a megaregion. To accomplish the task, a region-wide evacuation event was modeled using a traffic demand generation process that resulted in a spatial and temporal distribution of departure times, origins, and destinations reflective of a hurricane threat scenario. Using these travel patterns, traffic flows were assigned to the regional primary road network and operational performance measures like speed, travel time, and the formation and recovery of congestion were computed.

A key issue underlying this entire effort was the need to create a model at the megaregion level to be able to assess the simultaneous evacuation of multiple cities. Over the past decade or so, the scale of transportation models has been expanding steadily. Initially, only intersections and short sections of roads were able to be modeled effectively. Over the past two decades, evolving technology permitted modeling at the level of corridors and small networks incorporating tens of thousands of vehicles, over hundreds of square miles, and durations approaching 20 hours. With today’s technology, micro-level traffic simulation can be undertaken at scales of millions of vehicles, over hundreds of thousands of square miles, and durations of several days. Only at this scale was it possible to assess events like mass evacuations for hurricane that impact regions encompassing multiple cities over periods of several days, in which traffic goes in multiple directions – including in opposite directions on the same route. In this research, directional traffic interference phenomena were examined between the population centers along the Gulf Coast. In the simulations, the primary cases were observed between New Orleans and Baton Rouge with some between Baton Rouge and Lake Charles, affecting movements out of Lafayette. More pronounced overlapping traffic from the Houston area was likely lessened by the modeling assumptions and computation processing results, which suggested that evacuees from Houston preferred to move north and west toward Dallas, Austin, and San Antonio depending on the specific storm track.

Among the findings from this effort was the ability to model megaregion-level traffic patterns on a microscopic level. The project results showed that the demand models can be scaled up and adapted to reflect simultaneous multi-city travel activities. The movements generated and traffic operational models were suggestive of processes which are both logical and meaningful. While it may be premature to base detailed operational-level planning decisions on the results of this model, the model does capture the key elements of the system and realistically simulate the traffic progression through time and space well enough to demonstrate, for example, the benefits of contraflow and the effect of increased and decreased advanced warning times.

As the threat of major catastrophic disasters in coastal megaregions continues to grow, the need to better plan and prepare for them increases. With limited sheltering options in most locations, the need to conduct regional mass evacuations grows relative to other options. This research has taken the initial steps toward investigating the megaregion evacuation issue. With more work and the incorporation of additional details to describe the physical system (control conditions, design features, and threat situations) and behavioral responses (individual/group evacuation decision making, vehicle and driver behavior, etc.) along with greater computational speed and power, models such as this will continue to evolve and improve and will lead to more effective planning for both emergency and routine, non-emergency traffic conditions. However, to accomplish this, a considerable amount of work remains. Not every aspect of an event of this scale can be modeled precisely. Thus, the need to balance the requirements of representative details, computational speed, and ease of use must be attained. Presently, there are several simulation systems that can support mirco-level megaregion traffic simulation; however each of them needs to be assessed for their relative strengths and weaknesses to accomplish the objectives of any particular simulation.

It is expected that the knowledge and results gained from this research are also readily adaptable to evaluate other locations with different road networks, populations, transportation assets, and hazard threats. Models such as this can also be modified to represent future growth and development within megaregions. They can also be used to evaluate varying conditions and interrelationships between behavioral response and regional transportation management strategies to examine the performance of and methods to improve transportation system performance.

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