Assessment of Post-disaster Re-entry in Megaregions: A Pilot Study

Brian Wolshon, Nelida Herrera, Zhao Zhang, and Scott Parr

February 2019

A publication of the USDOT Tier 1 Center:
Cooperative Mobility for Competitive Megaregions
At The University of Texas at Austin

Technical Report Documentation Page

1. Report No. CM2-8	2. Government Accession No.	3. Recipient's Catalog No. ORCID: 0000-0002-1703-2995
4. Title and Subtitle Assessment of Post-disaster Re-entry in Megaregions: A Pilot Study		5. Report Date February 2019 6. Performing Organization Code
7. Author(s) Brian Wolshon, Nelida Herrera, Zhao Zhang, and Scott Parr		8. Performing Organization Report No. CM2-8
9. Performing Organization Name and Address The University of Texas at Austin School of Architecture 310 Inner Campus Drive, B7500 Austin, TX 78712 Louisiana State University Department of Civil and Environmental Engineering 3255 Patrick F. Taylor Hall Baton Rouge, LA 70803		10. Work Unit No. (TRAIS) 11. Contract or Grant No. USDOT 69A3551747135
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Transit Administration Office of the Assistant Secretary for Research and Technology, UTC Program 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered Technical Report conducted June 2017 – January 2019 14. Sponsoring Agency Code
15. Supplementary Notes Project performed under a grant from the U.S. Department of Transportation's University Transportation Center's Program.		
16. Abstract This report summarizes the methods and results of the assessment of post-evacuation reentry and its impact on regional traffic operations. The work herein examined wider-ranging effects and focused specifically on mass evacuations in megaregions. Among the findings of this work was that, as expected, reentry traffic processes behavior was similar to evacuations, but in the reverse direction. Somewhat more unexpectedly, the results of this research suggest that network performance during the reentry process was consistently better than that of the evacuation. Another broad conclusion from the research was that the heterogeneity of the distribution of traffic is a primary factor that determines the network performance for any set of conditions.		
17. Key Words Megaregions, post-disaster, re-entry, simulation, TRANSIMS, emergencies	18. Distribution Statement No restrictions.	

19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 23	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

Chapter 1. Introduction

Transportation systems serve as vital lifelines to preserve health and safety during times of disaster and emergency. Among the most important ways that transportation systems, personnel, and infrastructure support emergency preparedness is through evacuations. The management of operation or infrastructure and transit assets during evacuation are one of the most visible and direct contributions of transportation before disasters and, undoubtedly, save the lives of thousands annually. However, just as important as the role that transportation plays *before* disasters is role that it plays *after*. Transportation is also a key component in recovery efforts that restore communities back to full function and minimize economic impacts for such events.

Opposite of evacuation, transportation networks are the primary conduits for the safe and rapid return of evacuees after disasters. It is thought that the faster that people can return to their homes, jobs, and schools, the faster communities will recovery and less adverse economic effects will be felt. Unfortunately, however, recent experiences suggest that the return of evacuees after hazard events can also be problematic. Traffic demand associated with reentry can severely congest road networks, delaying both residents and support personnel who need to assess and repair damage. Often, conditions also require careful control of repopulation and access to avoid safety risks from downed electrical lines, broken gas pipes, collapsed bridges, landslides, and flooded and washed-out roads.[1] Uncontrolled, rapid repopulation also have the potential to overwhelm still fragile community networks that are fundamental for commerce, health, education, sanitation, etc. but may not yet be ready to serve an entire population. Reentry can also negatively impact traffic conditions for those communities outside the affected area but within the path of the returning evacuees.

Despite importance and need for better understanding of these issues, research into the conditions and processes associated with post-event reentry and repopulation, as well as the development of better means and methods to support it, have been virtually non-existent. While the reasons for this are both numerous and diverse, the most obvious reason is the assumption that reentry does

---

[1] Wolshon, B. (2009). The Role of Transportation in Evacuation and Reentry: A Survey of Practice. *Journal of Transportation Safety & Security*.

not involve the same level of urgency as evacuation. A lack of a clear life-and-death need, coupled with an enormous number of other issues and problems that accompany disastrous events, means that attention has, historically, been focused elsewhere.

This report analyzes aspects of post-evacuation reentry and its impact on regional traffic operations. Focusing on the return of evacuees following regional hurricane mass evacuations, the research looked specifically at traffic conditions associated with extreme events in 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 often spread over hundreds of miles, can even cross national boundaries, and often share common economic, historical and social ties. From transportation and emergency planning perspectives, they can also share travel corridors and face similar threats from natural hazards. For all these reasons, a catastrophic natural disaster in such an area is regarded to be a worst case scenario from the perspective of regional evacuation and reentry.

In the sections that follow key aspects and findings from this study are highlighted. This starts with a review and summary of important prior work related to hurricane evacuations, traffic simulation, and post-disaster reentry of evacuees, especially as they relate to megaregions. Next, attention shifts to the key methods and assumptions of the work, including the data, means, and methods used to build the simulation models and run them. This is followed by the results and analysis of the simulation output. As the goal of the project was to assess traffic conditions that might be associated with reentry after a major megaregion disaster threat, performance measures like speed, and volume were used. Finally, these results were assessed to identify broader trends and key applicable results of the work. Although this work was theoretical, the model results can be used to illustrate important real-life trends and relationships between road capacity and reentry travel demand. This, in turn, could be used to better understand how to plan for such events and maintain efficient traffic flow for the development of effective post-disaster reentry plans across local, state, and megaregion levels.

Chapter 2. Literature Review

Different entry restrictions may be implemented in the reentry process to ensure the safety of returning evacuees and enhance the effectiveness of recovery/restoration processes.[1][2] [3] In general, a systematic process involving two to three levels of access in a process known as tiered reentry is typically followed. With this approach, entry to the most critically needed emergency services and personnel is granted first. This is then followed by a gradual opening of areas to residents and less critical workers.[1] [3] However, low compliance with official reentry plans have been observed in prior disaster events such as that after Hurricane Rita[4] and Hurricane Ike[5] which makes the recovery and reentry processes more challenging.

Post-disaster reentry in some cases may also be challenged by the large number of evacuees that are returning from distant communities across multiple regions or states.[5] This is particularly the case for hurricane evacuations where many crossed jurisdictional boundaries and often involving megaregions. For example, Hurricane Katrina in the Gulf Coast megaregion, and more recently Hurricane Irma in the Florida megaregion. As such, the transportation system could be significantly stressed due to high demand over relatively short time and in a potentially deteriorated transportation network. Some efforts towards traffic management during post-disaster reentries have been considered such as inbound contraflow.[1] However, there is a lack of traffic management plans as the primary role of transportation agencies in the reentry process has been related to debris removal, infrastructure inspection, traffic signal repair, etc.[1] In addition, relatively little is known about the post-disaster network performance in megaregions as it related to the reentry of the community to their homes, businesses, and properties.

Post-disaster reentries are often times overlooked and planned for, however it is an important component of disaster operations.[3] Amdal et al. (2010) assessed disaster planning and recovery efforts pre and post hurricane Katrina which flooded 80 percent of New Orleans in August, 2005.

---

[2] Texas Division of Emergency Management. Disaster Area Reentry. (2014). *Texas Department of Public Safety*.

[3] Federal Emergency Management Agency. (2014). Evacuation and Reentry Planning. *Emergency Management Institute*.

[4] Siebeneck LK, Cova TJ. An Assessment of the Return-Entry Process for Hurricane Rita 2005. (2008). *International Journal of Mass Emergencies and Disasters*.

[5] Lin, C.C., Siebeneck, L.K., Lindell, M.K., Prater, C.S., Wu, H.C., Huang, S.K.. (2013). Evacuees' Information Sources and Reentry Decision Making in the Aftermath of Hurricane Ike. *Natural Hazards*.

The study noted that communications across transportation modes and the different layers of government agencies at the federal, local and regional levels is crucial in all phases of a disaster.[6] A study is currently undergoing to investigate the reentry procedures and issues in more recent hurricanes such as hurricane Irma and other major events.

Post-disaster planning efforts require many assumptions as it is uncertain what the post-disaster conditions are as it relates to accessibility due to damaged roads and/or bridges, blocked lanes due to flooding or debris, area closures due to pipe leaks, etc. Similarly, traffic control devices may be malfunctioning or destroyed. It is also uncertain where people are coming from, when they plan to return, and whether they will be compliant to the reentry procedures. Moreover, different modes (i.e. air, passenger and freight rail, maritime) to transport evacuees or transport resources are typically needed to support recovery efforts; most of which are often vulnerable to these disasters.

Traffic simulation has been widely used for many applications including emergency planning.[7] [8] [9] [10] They are valuable tools that can provide various range of key performance indicators of the evacuation system, like congestion, delay, travel time, evacuation clearance times that can be used to assess different traffic management strategies such as contraflow,[11] [12] [13] manual traffic control,[14] and phased evacuation.[13] [15]

---

[6] Amdal, R. & Swigart, S. T. (2010). Resilient Transportation Systems in a Post-Disaster Environment: A Case Study of Opportunities Realized and Missed in the Greater New Orleans Region. *Gulf Coast Research for Evacuation and Transportation Resiliency, Final Report*.

[7] Jha, M; Moore, K; Pashaie, B. (2004). Emergency Evacuation Planning with Microscopic Traffic Simulation. *Transportation Research Record.*

[8] Sisiopiku, VP. (2007). Application of Traffic Simulation Modeling for Improved Emergency Preparedness Planning. *Journal of Urban Planning & Development*.

[9] Dixit, V. V., Montz T., and Wolshon, B. (2011). Validation Techniques for Region-Level Microscopic Mass Evacuation Traffic Simulations. *Transportation Research Record: Journal of the Transportation Research Board*

[10] Parr, S., Wolshon, B., Murray-Tuite, P. (2016). Unconventional Intersection Control Strategies for Urban Evacuation. *Transportation Research Record.*

[11] Theodoulou, G. (2003). Contraflow Evacuation on the Westbound I-10 out of the City of New Orleans. MS thesis. *Louisiana State University*, Baton Rouge.

[12] Lim, E., and Wolshon, B. (2005). Modeling and Performance Assessment of Contraflow Evacuation Termination Points. *Transportation Research Record: Journal of the Transportation Research Board*.

[13] Chiu, Y., H. Zheng, Villalobos, J. A., Peacock, W. and Henk, R. (2008). Evaluating Regional Contra-Flow and Phased Evacuation Strategies for Texas Using a Large-Scale Dynamic Traffic Simulation and Assignment Approach. *Journal of Homeland Security and Emergency Management.*

[14] Parr, S. and Wolshon, B. (2016). Methodology for Simulating Manual Traffic Control. *Transportation Research Record*

[15] Zhang, Z., Spansel, K., and Wolshon, B. (2014). Effect of Phased Evacuations in Megaregion Highway Networks. *Transportation Research Record*

Although there is wide range of research conducted considering emergency evacuations, the research on post-disaster reentry is limited, particularly at the megaregion-scale.

Chapter 3. Methodology

A range of different reentry scenarios were analyzed in this study using a traffic simulation model of the United States (US) Gulf Coast megaregion developed in TRANSIMS.[16] The Gulf Coast megaregion was selected as the area to analyze because of its history of frequent hurricanes. Six scenarios were modeled based on varying hurricane strength development and movement tracks as well as the evacuation travel demand they would generate. Each scenario was created to generate varying traffic conditions that might occur based on previous historical hurricane events in the Gulf of Mexico; some of which are recent and others that took place more than 100 years ago.[16] These included:

Scenario 1 (S1): Storm development and track of Hurricane Gustav in 2008;
Scenario 2 (S2): Hurricane Gustav, but increased to Category 4 strength;
Scenario 3 (S3): Hurricane Gustav, but increased to Category 5 strength;
Scenario 4 (S4): Category 4 storm based on an unnamed hurricane in 1867 with a forecast uncertainty that threatened the full southern Gulf Coast of the United States (US);
Scenario 5 (S5): Category 4 storm based on an unnamed hurricane in 1914, traveling east to west with a forecast uncertainty that threatened the full Gulf Coast study area; and
Scenario 6 (S6): Category 5 version of the Scenario 5 event.

The hurricane tracks and strength development conditions for storms in scenarios 3 and 6 are shown in Figure 3.1 and Figure 3.2. These two scenarios were analyzed in detailed because if large and/or variable enough, could require evacuations along the entire Gulf coast.

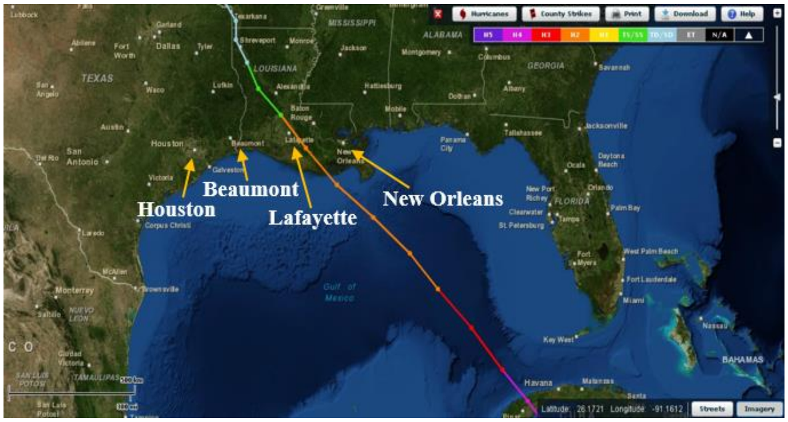

Figure 3.1 Hurricane track for S3

---

[16] Zhang, Z.; Spansel, K.; Wolshon, B. (2013). Megaregion Network Simulation for Evacuation Analysis. *Transportation Research Record.*

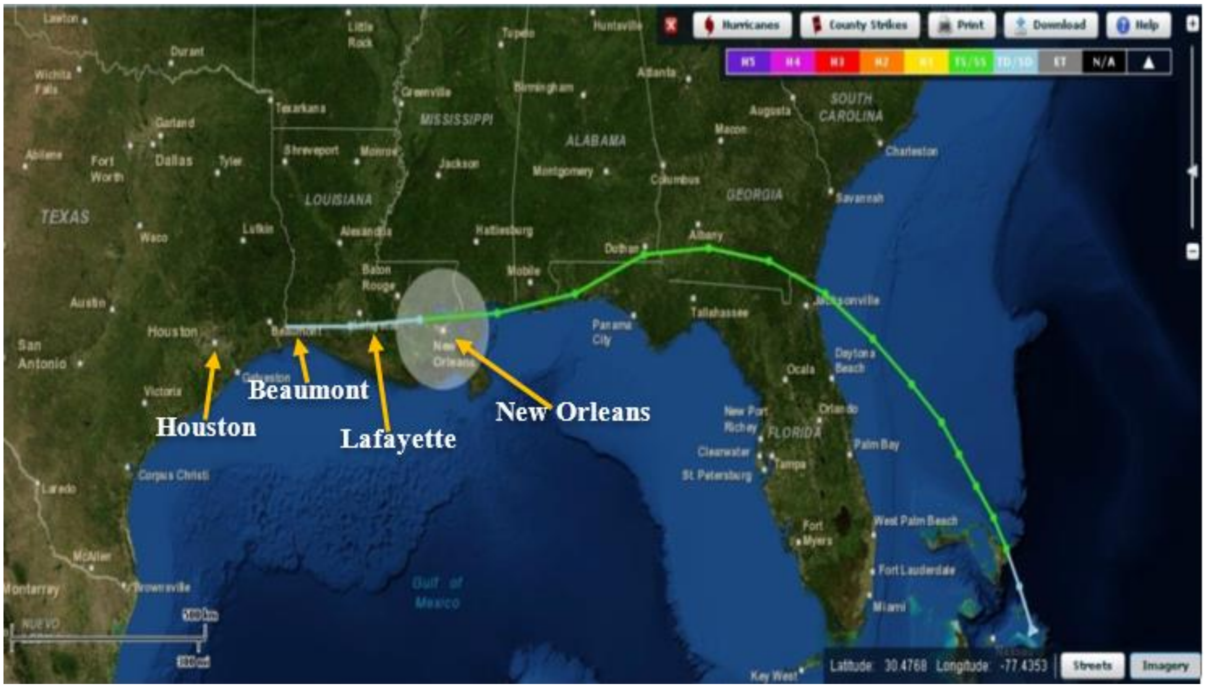

Figure 3.2 Hurricane track for S6

Departure curves for Scenario 3 and 6 are shown in Figure 3.3 and Figure 3.4, respectively. The figure includes the departure curves for the major cities that would evacuate under each scenario. The major cities were New Orleans (N.O), Baton Rouge (B.R), Lafayette, (L.F), Lake Charles (L.C), Beaumont (B.E), Coast 1, and Coast 2. Coast 1 and Coast 2 are the Gulf Coast areas in the State of Louisiana. It can be seen in Figure 3.3 that demand for the Coast areas in scenario 3 is the largest compared to the other regions. The departure for the coast is also the fastest with about 60-70 percent of the evacuees returning within the first 12 hours. Then, followed by New Orleans, Baton Rouge, Lafayette and Beaumont, and lastly Lake Charles. It can be seen in Figure 3.4 that demand for New Orleans in scenario 6 is the largest compared to the other regions. The departure for the coast is also the fastest with about 50 percent of the evacuees returning within the first 30 hours. Then, followed by Baton Rouge, Lafayette, the coast areas, Lake Charles, and lastly Beaumont.

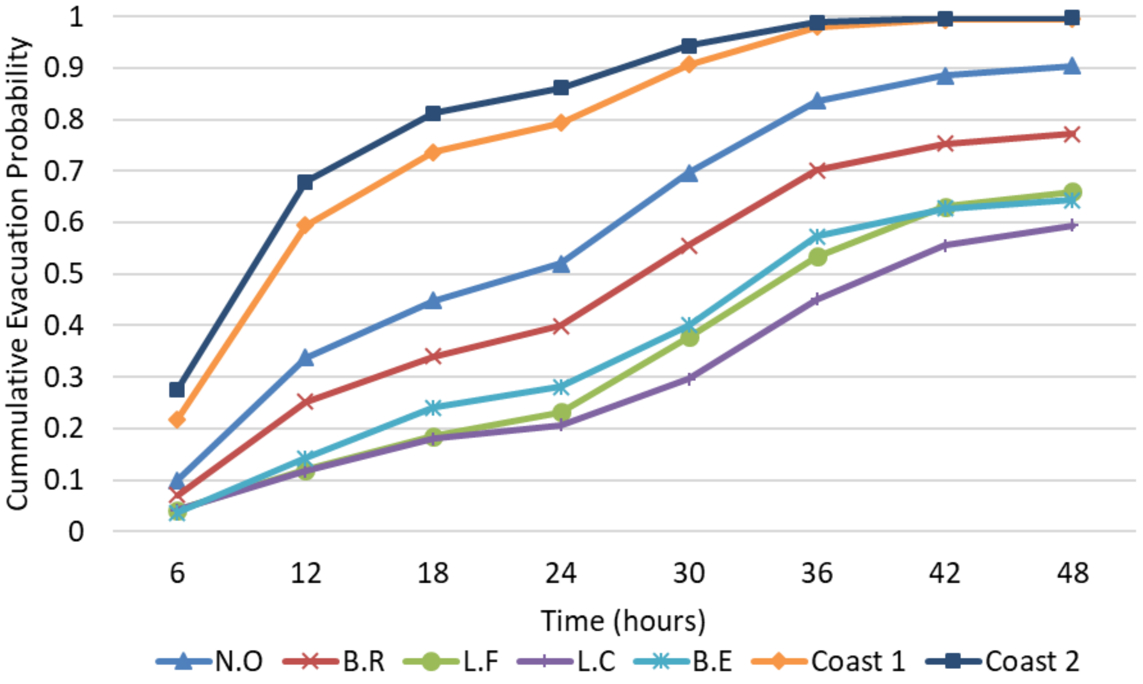

Figure 3.3 Departure curve for S3

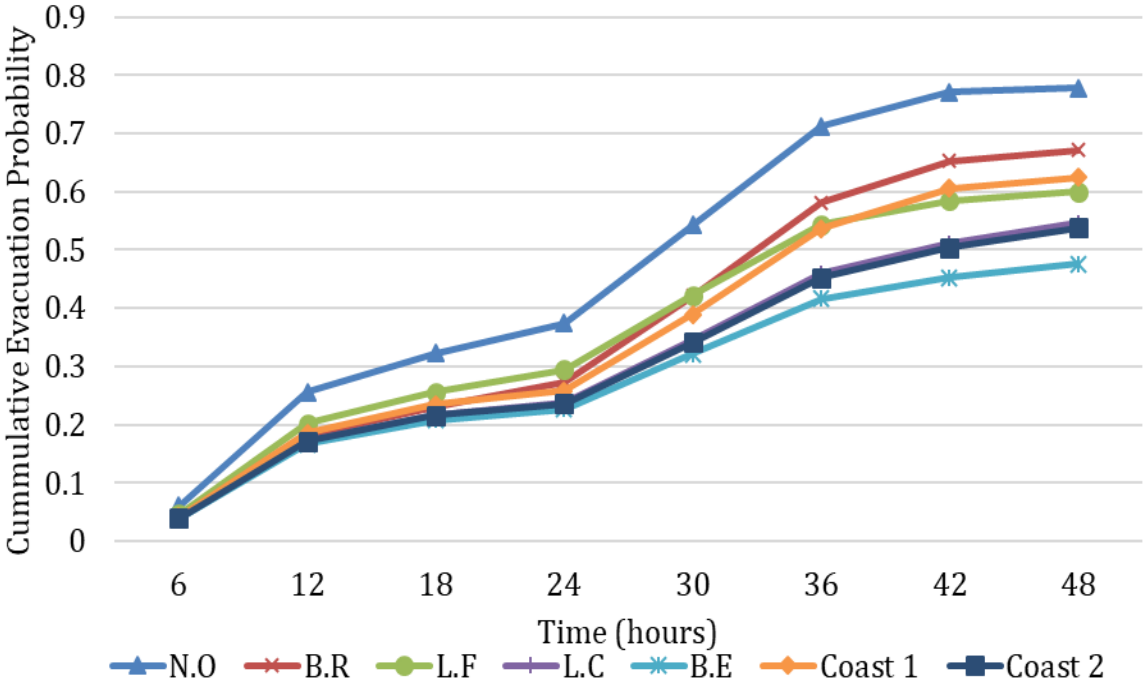

Figure 3.4 Departure curve for S6

Using the departure curves, the percentage of the total population from each of the major cities that would evacuate under each scenario was estimated next using the same TDSLM.[16] These percentages are shown in Table 1. The locations that were most threatened by the track and strength of the hurricane scenarios had the highest evacuation percentages. It is also worth noting in the table that Scenario 4 was the only condition that generated an evacuation in Houston. However, this particular storm track also generated the highest demand in every other city compared to the other cases. This demand was very large that could not be simulated in TRANSIMS without "crashing" it. Obviously, this demonstrated the limits of current processing capabilities relative to megaregion analyses.

Table 1 Reentry Demand under the Test Scenarios

Scenario	**New Orleans**	**Baton Rouge**	**Lafayette**	**Lake Charles**	**Beaumont**	**Houston**
S1	54.89%	42.95%	33.35%	31.04%	42.15%	0
S2	65.09%	54.91%	56.39%	41.97%	46.93%	0
S3	66.25%	63.75%	72.69%	52.31%	56.73%	0
S4	93.65%	90.75%	76.19%	93.83%	93.83%	95.50%
S5	63.23%	41.85%	48.99%	47.15%	38.75%	0
S6	63.23%	66.21%	55.12%	63.19%	60.44%	0

Chapter 4. Results

Several measure of performance were used to compare the traffic operation with the various test scenarios. The measures were selected based on their relevance to both to traffic managers and emergency planners. The primary measure was average travel speed. This was important because it gave a broad idea of the overall travel conditions within the network. Next, the percentage of vehicle miles of travel and vehicle hours of travel spent in a state of congestion (*PctVMT Congested* and *PctVHT Congested*) was used to show the relative amount of travel below free flow conditions.

Table 2 summarizes the network performance for Scenarios 1, 2, 3, 5, and 6. It should be noted that it was not possible to simulate Scenario 4. This was due to the enormous level of traffic demand that was generated in the Houston region by the storm track and strength under this condition. The traffic demand, more than four million vehicles,[16] effectively meant that it was not possible to include areas to the west of Beaumont Texas in this analysis.

Because the evacuation departure curve for Scenario 1 (S1) and Scenario 2 (S2) is similar, the network performance for Scenarios 1 through 3 (S1, S2, and S3) followed a similar trend. Likewise, the network performance for Scenario 5 and Scenario 6 followed a similar trend. Such similarity is mainly because the storm track for Scenario 1 to 3 is the same, i.e., Hurricane Gustav in 2008; and the storm tracks for Scenario 5 and 6 are the same as shown before.

Table 2 Network Performance Results

Scenario Number	Total Demand	Average Travel Speed	PctVMT Congested	PctVHT Congested
S1	919,535	61.9	1.1	12.0
S2	1,065,550	60.0	1.6	15.0
S3	1,210,214	57.7	2.4	18.7
S5	927,825	47.5	4.6	32.6
S6	1,231,933	43.4	5.6	35.1

As shown in Table 2, network performance under the reentry scenarios S5 and S6 are both worse than those in S1, S2 and S3. This is because the storm tracks for S5 and S6 required evacuees to move to the western side of the megaregion; while the storm track for S1, S2 and S3 required evacuees to move to multiple directions, including the north side, west side and east side of the megaregion. Therefore, the roads in the megaregion are more fully utilized under S1 to S3 than that under S5 to S6. After the evacuees get out of the megaregion, when they come back to their home from the shelter, the reentry traffic follows the "One to Multiple" form. Thus, the reentry model for S1, S2 and S3 has more roads utilized than the reentry model for S5 to S6. As the table shows, even S3 and S6 has almost equal traffic demand, the average speed of reentry traffic for S6 is about 25 percent lower than that for S3. The *PctVMT Congested* under S3 is 2.4 percent, much lower than that under S6, i.e., 5.6 percent. While the *PctVHT Congested* under S3 is 18.7 percent, much lower than that under S6, i.e., 35.1 percent.

4.1. Volume Distribution

Because the traffic volume distribution can reflect how the traffic evolve in space and time, the volume distribution was analyzed, in detail. The network flow, which is the average link flow rate for the whole network for a certain time, is analyzed to represents the average traffic flow in space. While the network flow stdv, which is the standard deviation of link flow rate for the network at a certain time, is calculated to represents how the traffic volume for the network differs to each other. The *h-index*, which is the *network flow* divided by *network flow standard deviation (stdv)*, is used to illustrate the heterogeneity of traffic flow distribution. All the three parameter were calculated to illustrate the flow changes for the whole megaregion. The formulas for *network flow*, *network flow stdv* and *h-index* are shown in Equation (1), (2) and (3), respectively.

$$network\ flow = \frac{\sum_{i=1}^{N} q_i}{N} \quad (1)$$

$$network\ flow\ stdv = \sqrt[2]{(q_i - \frac{\sum_{i=1}^{N} q_i}{N})/N} \quad (2)$$

$$h - index = \frac{network\ flow}{network\ flow\ stdv} \quad (3)$$

Where: q_i is the flow rate on link *i*, while N is the total number of links in the network.

4.1.1. Network Flow and Heterogeneity for Scenario 3 (S3)

Network flow and heterogeneity was investigated for S3. Figure 4.1 shows that the *network flow stdv* is much higher than the *network flow* in the megaregion. This indicates that the flow is heterogeneously distributed in space and time for S3. The network flow for the megaregion and the other six regions, i.e., NO for New Orleans, BR for Baton Rouge, LF for Lafayette, LC for Lake Charles, BE for Beaumont, and Coast for the Coast areas of the Gulf Coast Megaregion is shown in Figure 4.2. This figure shows how the traffic volumes were distributed in the megaregion. It can be seen that Baton Rouge had the highest rates of flow rate, exhibited by the red line in Figure 4.2. This occurred in large part because 1) reentry traffic back to New Orleans had to pass through Baton Rouge; and 2.) New Orleans and Baton Rouge are the most populated metropolitan areas within the megaregion analysis area.

The second highest average network flow was observed in Beaumont, Texas. This trend occurred for reasons similar to, but in the opposite direction of, Baton Rouge on the east side of the analysis area. Only here evacuees who sheltered in Houston had to return through Beaumont after the storm. It is interesting to note however, that flows through Beaumont were smaller than that in Baton Rouge. This suggests that some reentry traffic flow may not have passed through Beaumont. Instead returning evacuees may have opted for alternative routes to avoid the traffic congestion in east Texas and west Louisiana.

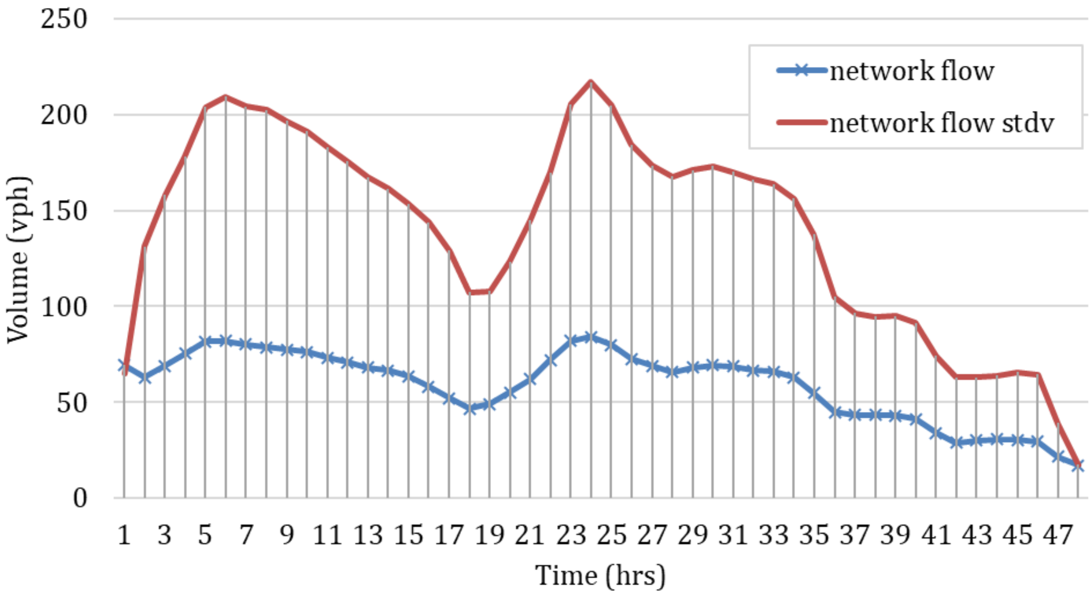

Figure 4.1 Network average flow rate and standard deviation for Reentry Scenario 3

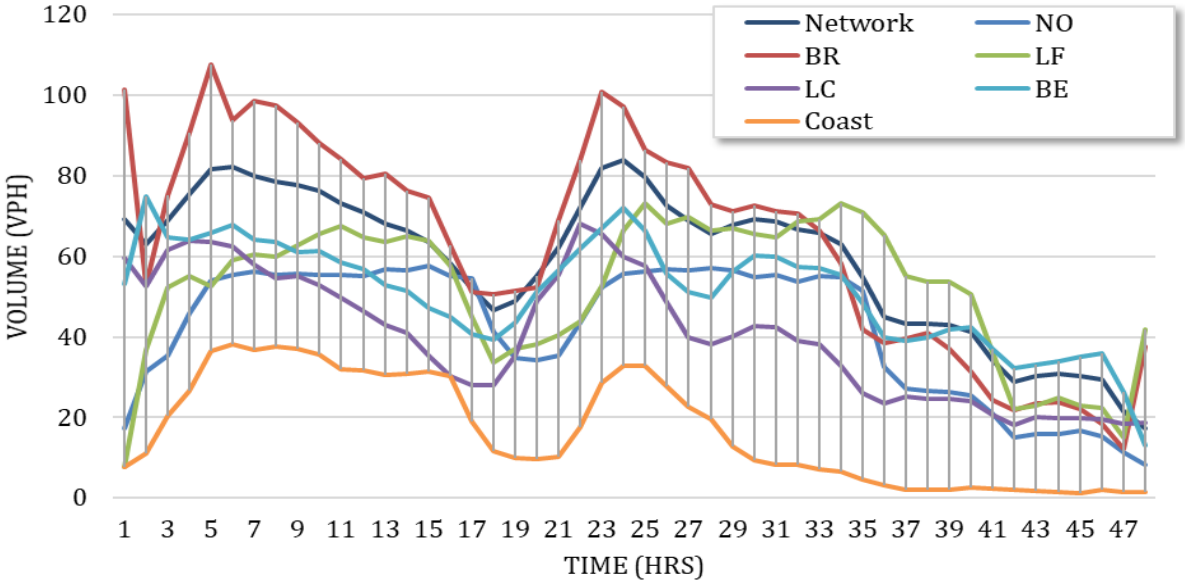

Figure 4.2 Megaregion network average flow rate and region average flow rate for Reentry Scenario 3

Figure 4.3 represents the heterogeneity in the megaregion and the six metropolitan areas. An h-index was used to demonstrate the heterogeneity of the network flow distribution. In the figure, it can be seen that all the six areas in the megaregion had h-indices higher than 1. Among these areas, Lake Charles had the highest h-index, and the coast area had the lowest. This was likely an indication of the direction of flow as drivers returned from the origins outside of the megaregion back to their homes.

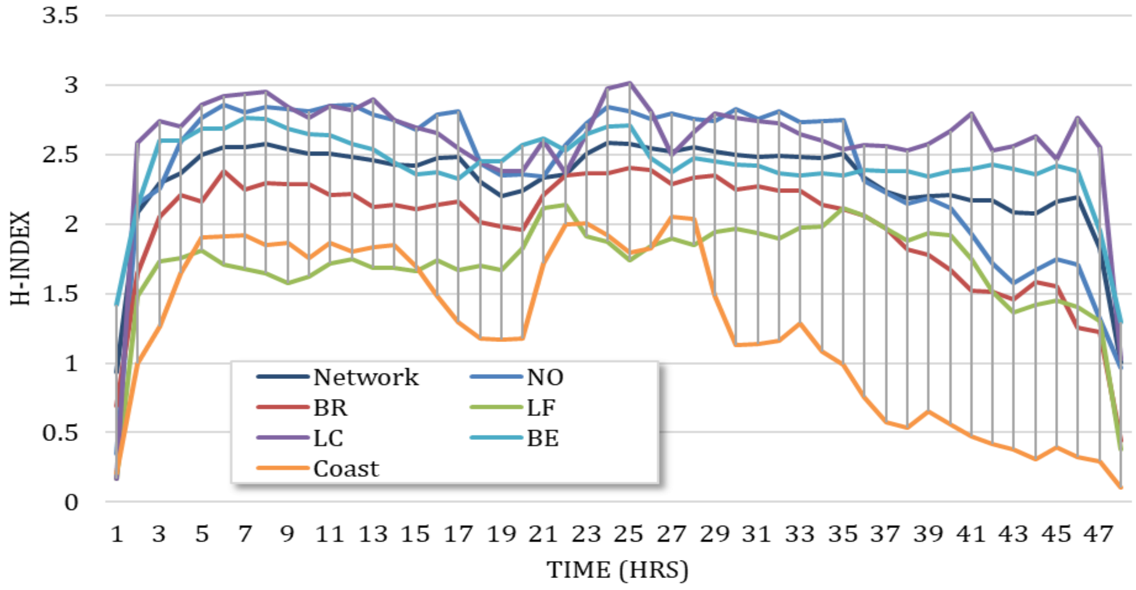

Figure 4.3 h-index for megaregion and each of the six regions for Reentry Scenario 3

The heterogeneity analysis also revealed that nearly half of the roads in each metropolitan area were not utilized during the reentry process. This suggests opportunities for better network utilization in reentry planning for this area.

4.1.2. Reentry Model Results for Scenario 6 (S6)

To understand the network performance in more detail, the volume distribution in Scenario 6 (S6) was also analyzed. The *network flow*, *network flow stdv*, and the *h-index* of S6 are shown in Figure 4.4, Figure 4.5 and Figure 4.6, respectively. It is clearly demonstrated in Figure 4.4. that *network flow* of S6 shows similar trend as in S3, i.e., the *network flow stdv* is much higher than *network flow*, meaning that network flow is heterogeneously distributed in space and time in S6.

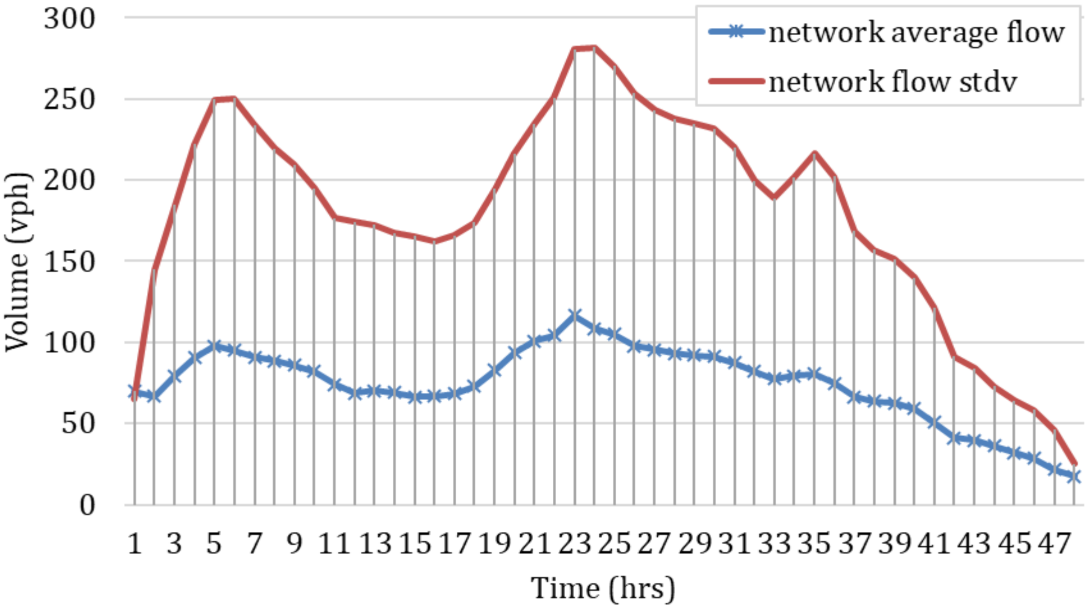

Figure 4.4 Network average flow rate and standard deviation for Reentry Scenario 6

The *network flow* for the megaregion as well as the other six regions are shown in Figure 4.5. This figure demonstrates how the average flow is distributed in the megaregion. Similar to S3, the flow distribution in the six metropolitan areas follows a trend that: 1) Baton Rouge has the highest average network flow rate; and 2) Beaumont had the second highest average flow rate. Such similarities indicate that the Baton Rouge and Beaumont both had high probabilities of becoming bottlenecks in the reentry scenarios. However, the flow distribution in time for S6 was different from that of S3. It is clear that traffic was distributed nearly equally in both days of S3, while more reentry traffic was distributed during the second day of S6. This suggests that the reentry traffic was better balanced over time in S3 than in S6.

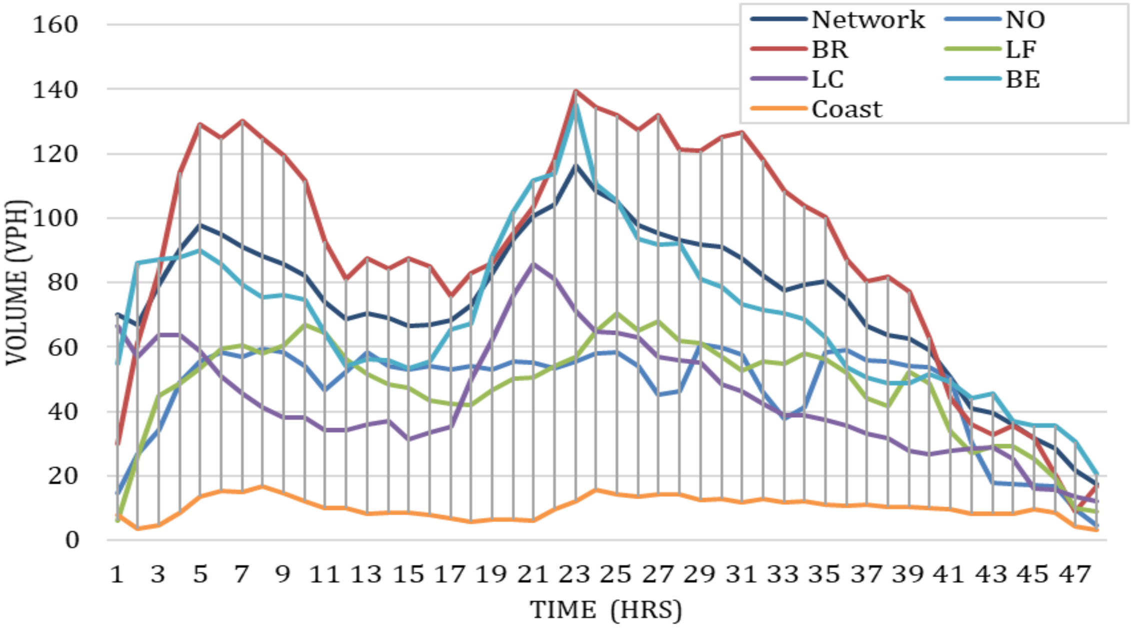

Figure 4.5 Megaregion network average flow rate and region network average flow rate for Reentry Scenario 6

Figure 4.6 also represents the heterogeneous status for the megaregion and its six metropolitan areas. It is shown that almost all the six regions in the megaregion had h-index higher than 1.5. The h-index values and its distribution in time is about 20% higher than that in S3. Because of that, S6 got worse network performance than S3.

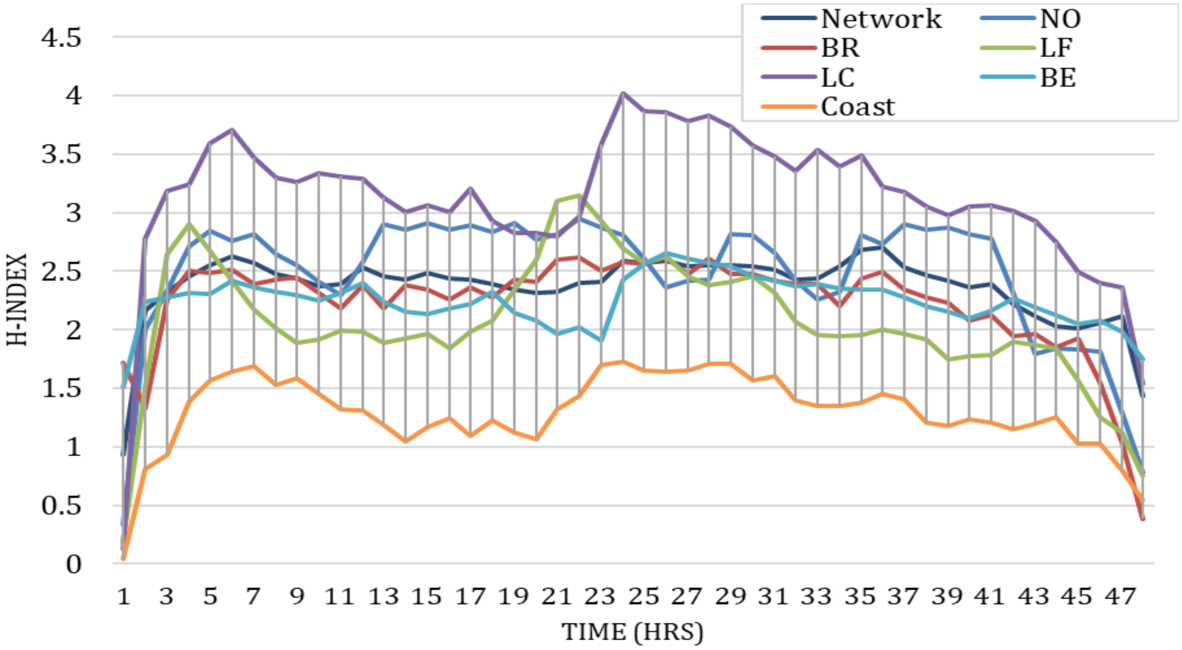

Figure 4.6 h-index for megaregion and the six regions for Reentry Scenario 6

Based on the overall results, the traffic flow was heterogeneously distributed in space and time for both S3 and S6. Because the traffic was heterogeneously distributed in space and time, both scenarios experienced network congestion. Ultimately, because S6 showed a higher heterogeneity than S3, the network performance for S3 was better than that for S6.

Chapter 5. Conclusion and Recommendations

Transportation systems are critical during emergencies. Among their most notable roles in disasters is to support evacuations. However, they are also important after a disasters when they facilitate the safe and rapid return of evacuees and support personnel who need to assess and repair damage. Despite importance of this latter role, ideas associated with transportation's role in reentry and repopulation has been relatively lightly researched topic. This report summarized the methods and results from recent research to analyze post-evacuation reentry and its impact on regional traffic operations. To examine wider-ranging effects and to look at extreme conditions, this work focused specifically on mass evacuations in megaregions.

Among the broad findings of this work was that, as expected, reentry traffic processes behavior similar to, but in the reverse direction of evacuations. The traffic distribution pattern between origins and destinations during evacuations are somewhat akin to water absorbed through the roots of a tree moving up its trunk then out to its branches. This was evident both in prior research[15] [16] and from examining actual statewide traffic count data.[17] The data herein suggest that traffic follows the reverse pattern when returning to their evacuation origins from their shelter locations. This was best illustrated by traffic moving through Baton Rouge and Beaumont in various scenarios.

Somewhat more unexpectedly, however, the results of this research suggested that network performance during the reentry process was consistently better than that of the evacuation. Although it is not completely clear why this was the case, the simulation results showed that the performance of the reentry model network was better than that of the same network that was modeled under evacuation conditions in the original research.[15] [16] Interestingly, this was evident throughout the whole network and not just in specific areas. Thus, in terms of a real-world post-hurricane reentry, it would be expected that the traffic flow would be expected to be relatively less congested than during the evacuation that precipitated it.

---

[17] Wolshon B. and McArdle, B. (2009). Temporospatial Analysis of Hurricane Katrina Regional Evacuation Traffic Patterns, ASCE *Journal of Infrastructure Systems.*

Another broad conclusion from the research was that the heterogeneity of the distribution of traffic is the primary factor that determines the network performance for any set of conditions. More specifically, this means that the more and the better that links are utilized in terms of traffic volume and even distribution, the more efficient that network will operate. While this is a logical finding, it was a condition that is not often observed during reentries or, more notably, during evacuations. Often, during major traffic events, both emergency and non-emergency (associated with planned major events), drivers have a tendency to more heavily utilize primary high volumes routes (like freeways) that they are most familiar with and where they may see most of the other traffic moving to. In the past, this has meant that many major route tended to go underutilized.[17] Perhaps this will change with a more extensive use of real-time travel guidance software than shows existing congestion and will suggest shortest-travel-time routes. However, from an emergency traffic management perspective, it suggests that travel time and congestion reduction gains may be realized through planning and guidance information that routes travelers to more traditionally underutilized routes.

In terms of the relationship of this work to other recent research in associated fields of traffic engineering, simulation, and emergency management, it is interesting to see an emerging pattern in simulation studies that compare scenarios and alternative conditions using traffic simulation modeling. Ongoing and, as yet, unpublished simulation studies of evacuations associated with nuclear power plant emergencies suggests that performance differences in evacuation networks are only readily apparent when some condition or set of conditions influences (positively or negatively) the capacity and demand relationship of an evacuation system. These could either result in increased or diminished congestion within corridors or at specific locations (ramps, intersections, etc.) that are then revealed in a simulation as a change in observable performance measures. This may occur from demand-related factors such as higher rates of participation, background/pass-through traffic, resident/transient population, etc. Conversely, they can relate to capacity-related factors such as added or reduced numbers of lanes, route closures, contraflow operations, and the like. This similar pattern can be useful in an application context because it can help planners better identify problems as assess ways to address them.

References

Wolshon, B. (2009). The Role of Transportation in Evacuation and Reentry: A Survey of Practice. *Journal of Transportation Safety & Security*, Volume 1, Issue 3, pp. 224 – 240.

Texas Division of Emergency Management. Disaster Area Reentry. (2014). *Texas Department of Public Safety.*

Federal Emergency Management Agency. (2014). Evacuation and Reentry Planning. *Emergency Management Institute.*

Siebeneck LK, Cova TJ. An Assessment of the Return-Entry Process for Hurricane Rita 2005. (2008). *International Journal of Mass Emergencies and Disasters.* 26(2), pp. 91-111.

Lin CC, Siebeneck LK, Lindell MK, Prater CS, Wu HC, Huang SK. (2013). Evacuees' Information Sources and Reentry Decision Making in the Aftermath of Hurricane Ike. *Natural Hazards,* Vol. 70, pp. 865-882.

Amdal, R. & Swigart, S. T. (2010). Resilient Transportation Systems in a Post-Disaster Environment: A Case Study of Opportunities Realized and Missed in the Greater New Orleans Region. *Gulf Coast Research for Evacuation and Transportation Resiliency, Final Report*. Project # 10-01.

Jha, M; Moore, K; Pashaie, B. (2004). Emergency Evacuation Planning with Microscopic Traffic Simulation. *Transportation Research Record.* 1886, 1, 40.

Sisiopiku, VP. (2007). Application of Traffic Simulation Modeling for Improved Emergency Preparedness Planning. *Journal of Urban Planning & Development*. 133, 1, pp. 51-60.

Dixit, V. V., Montz T., and Wolshon, B. (2011). Validation Techniques for Region-Level Microscopic Mass Evacuation Traffic Simulations. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2229, pp. 66–74.

Parr, S., Wolshon, B., Murray-Tuite, P. (2016). Unconventional Intersection Control Strategies for Urban Evacuation. *Transportation Research Record*. 2599, 1, 52.

Theodoulou, G. Contraflow Evacuation on the Westbound I-10 out of the City of New Orleans. MS thesis. *Louisiana State University*, Baton Rouge, 2003.

Lim, E., and Wolshon, B. (2005). Modeling and Performance Assessment of Contraflow Evacuation Termination Points. In Transportation Research Record: Journal of the Transportation Research Board, No. 1922, pp. 118–128.

Chiu, Y., H. Zheng, Villalobos, J. A., Peacock, W. and Henk, R. (2008). Evaluating Regional Contra-Flow and Phased Evacuation Strategies for Texas Using a Large-Scale Dynamic Traffic Simulation and Assignment Approach. *Journal of Homeland Security and Emergency Management*, Vol. 5, No. 1.

Parr, S. and Wolshon, B. (2016). Methodology for Simulating Manual Traffic Control. *Transportation Research Record*, 2562, 1, 9.

Zhang, Z., Spansel, K., and Wolshon, B. (2014). Effect of Phased Evacuations in Megaregion Highway Networks. *Transportation Research Record*, No. 2459, pp. 101-109.

Zhang, Z.; Spansel, K.; Wolshon, B. (2013). Megaregion Network Simulation for Evacuation Analysis. *Transportation Research Record.* 2397, pp. 161-170.

Wolshon B. and McArdle, B. (2009). Temporospatial Analysis of Hurricane Katrina Regional Evacuation Traffic Patterns, ASCE *Journal of Infrastructure Systems*, Vol. 15, No. 1, pp. 12 - 20.