Development and Implementation of an Adapted Evacuation Planning Methodology in the Framework of Emergency Management and Disaster Response: A Case Study Using TransCAD

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ABSTRACT

The nature of natural disasters is often unpredictable, so it is extremely important that sufficient planning be done to evaluate the preparedness, the system response, and the ability of transportation infrastructures to handle evacuation traffic. This paper presents an adapted evacuation planning methodology that essentially incorporates the traditional four-step planning model and dynamic traffic assignment. We utilize the transportation network in Western Massachusetts as an example to test the effectiveness of the proposed methodology using two with-notice hurricane evacuation scenarios. The analysis is performed by using the off-the-shelf computer-based planning software package, TransCAD to assist the four-step transportation planning process. By altering inputs and using dynamic traffic assignment, TransCAD can be used to predict how the transportation system behaves during an evacuation. Two scenarios are used as the basis of the evacuation modeling. A production-attraction model is presented to replicate the behavior of evacuees. The production-attraction model results are compared with a series of reports, and the model falls within the recommendations of these reports. Several different evacuation speeds are examined for two different study areas. The results section shows the outputs that can be garnered from the program such as the clearance time, critical locations, V/C ratios, and location-to-location travel times. Finally, recommendations are made on how these results can be used to aid planners. It is worth mentioning that the proposed evacuation modeling methodology can be extended and implemented in other places with minor modifications of network topology and localized travel behavior data.

Keywords: Emergency Management, Hurricane Evacuation Planning, Four-step Planning Model

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1. INTRODUCTION

Emergency evacuation planning plays a central role in the decision-making process to determine what proper responses should be activated during disasters. Researchers in the field of emergency management have classified disasters into four categories: natural, technological, civil, and ecological (1). This paper is concerned with natural disasters: specifically, hurricanes. The nature of natural disasters is often less predictable and its causes are sizable in terms of lives taken and property loss. Thus, emergency planning and management in advance is critical to ensure a safe and efficient evacuation during natural disasters.

The four-step planning model utilized in this study is not normally used to model evacuations. However, by modifying the initial inputs of the model, reasonable results and recommendations can be made that can improve the evacuation efforts. This paper examines how this model can be altered to replicate the system in the event of a hurricane evacuation. Generally, macroscopic transportation planning models consider the system as a whole and estimate routing and link flows through a network over a certain time period. It is being used for strategic planning, which usually covers a big area. This is, in many cases, completed by using the four-step transportation planning model. This model consists of trip generation, trip distribution, mode choice, and traffic assignment. The process can become computationally intensive, and therefore transportation planners have turned to computer-based software to help facilitate the development and implementation of the models. One such software package, TransCAD, made by Caliper Corporation, provides planners a set of tools that enables them to display, manage, and analyze travel behavior data.

Every area in the world can face some types of disasters (1). For this reason, it is important for planning agencies and emergency managers to be prepared to make decisions regarding what to do if a disaster were to happen. Emergency managers use a four-step cycle, which includes mitigation, preparation, response, and recovery (1). The transportation system is a major component of all of these steps. In the mitigation step, planners want to make sure citizens endure minimal delays; this could relate to the transportation system through the addition of roads leaving town if the risk of a disaster is high. Preparedness relates to the implementation of variable message signs that inform drivers of road conditions. Response relates to the use of the roadway to evacuate, along with the use of the network for emergency responders heading into harm's way. During the recovery phase there is need for reconstruction of the infrastructure itself along with the use of the network to help construction and maintenance crews to assist in the rebuilding of the affected communities.

Over the past decades of emergency management and recent disaster impacts, researchers and emergency professionals have sought to understand and predict the evacuation behavior characteristics (2, 3). These efforts have led to the development of evacuation model and computer-based software packages that are listed in Table 1 (2). More detailed discussion of the computer-based software packages regarding its requirements and capabilities can be found in "Appendix F: Hurricane Evacuation Models and Tools" within the U.S. DOT's "Report on Congress on Catastrophic Hurricane Evacuation Plan Evaluation"(2). Table 1 lists most of the hurricane evacuation models and operational tools. This table is not intended to be complete in any sense.

Baker (3) studied the hurricane evacuation behavior characteristics through twelve hurricane cases ranging from 1961 to 1989 from Texas through Massachusetts in terms of risk level, actions by public authorities, housing, and storm specific threat factor. Pielke (4) completed a comprehensive review of the normalized hurricane damages within the United States from 1900 to 2005. Lindell and Prater (5) described the major challenges confronting the local authorities and the behavior of a hurricane in order to be modeled in an evacuation management decision support system (EMDSS). Wilmot (6) provided a set of criteria to delineate hurricane evacuation zones based on geographic information system platform. Fu and Wilmot (7) developed a hurricane evacuation response curve using two past hurricanes (Floyd and Andrew) for model development and testing. Wolshon and Urbina et al. (8)(9)(10)(11)(12) reviewed hurricane evacuation plans and policies for transportation planning, operation, management, control, preparedness, and response purposes.

Table 1: Hurricane Evacuation Models and Tools

Software	Name	Developer
ETIS (2)	Evacuation Traffic Information System	FHWA/U.S. DOT
NETVAC (2)	Network Emergency Evacuation	Dr. Yossi Sheffi, Dr. Hani S. Mahmassani, and Dr. W.B. Powell at MIT in 1982
OREMS (13)	Oak Ridge Evacuation Modeling System	Center for Transportation Analysis at the Oak Ridge National Laboratory (ORNL)
MASSVAC (14)	MASS Evacuation	Hobeika et al (1985a)
HURREVAC (2)	Hurricane Evacuation	U.S. Army Corps of Engineers (USACE)
SLOSH (16)	Sea, Lake, Overland Surges from Hurricanes	National Weather Service (NWS)
CATS/JACE (2)	Consequence Assessment Tool Set/Joint Assessment of Catastrophic Events	FEMA and the Defense Threat Reduction Agency
HAZUS-MH (2)	Hazards US Multi-Hazards	Federal Emergency Management Agency
DYNEV (15)	Dynamic Network Evacuation	KLD Associates, Inc.

The objective of this study is to develop and implement a methodology that allows for the creation of an adapted evacuation planning strategy in the event of a hurricane. This project demonstrates how computer-based software can be implemented into the emergency planning process. In order to accomplish this objective, this project completes two scenario-based hurricane evacuations in Western Massachusetts. In this specific study, the results (such as, severely congested locations and the time it takes to clear the county of evacuees) show some of the relevant results that can be obtained from the software package. Using these results, planners can have more information to make decisions regarding emergencies.

2. METHODOLOGY

The specific algorithms and processes used in the four-step model have not been changed. However, the inputs into several of the steps (and sub-steps) are modified in order to model a hurricane evacuation. Steps that are not significantly altered are not discussed here.

2.1 Trip Generation

2.1.1 Productions and Attractions

There are two components of trip generation: trip productions and trip attractions. Normally, in this step planners can use guides, such as the ITE Trip Generation Manual, and employment data to derive the production and attraction rates. In this case, however, the productions are not typical of the land use data found in manuals, and people are no longer attracted to work locations.

Several studies completed by the Hurricane Study Program, a joint venture of the U.S. Army Corps of Engineers (USACE) and the Federal Emergency Management Agency (FEMA), provide some guidance on production rates. These studies provide recommended values to use for evacuation rates based on the trips taken per household and/or the percentage of the vehicles used to evacuate. Some of the entities gave one set of values or the other; some entities gave both values. Here, a model is created that may be more apt at predicting each TAZ's production rate than using the average production rate from the studies. Several assumptions are made to model this. First, in order to keep their family units together, families prefer to fit in the fewest possible number of vehicles during an evacuation. Second, if the number of cars required is greater than the available cars then the residents take all of the vehicles in the TAZ. Third, every household makes at least one trip. This implies the evacuation rate across the entire county is 100%. The average capacity of a vehicle is assumed to be four seats per vehicle. This method is shown below:

$$\mathbf{T_i = min\left(ceiling\left[\frac{HH\ Size_i}{N_{Veh}}\right], \frac{auto_i}{HH_i}\right)} \qquad (1)$$

Where:

$\mathbf{HH_i}$ **= Households in TAZ i**

$\mathbf{HH\ Size_i}$ **= Average number of residents per HH in TAZ i**

$\mathbf{N_{veh}}$ **= Average number of seats in a vehicle**

$\mathbf{{auto_i}/{HH_i}}$ **= Average number of vehicles per HH in TAZ i**

$\mathbf{T_i}$ **= Number of trips producted for each HH in TAZ i**

In order to ensure each household makes at least one trip, the minimum number of trips must be greater than or equal to one trip per household or,

$$\mathbf{T_i \geq 1.0} \qquad (2)$$

The final number of productions made for each TAZ is obtained by multiplying the number of households by the production rate:

$$\mathbf{P_i = HH_i * T_i} \qquad (3)$$

This method could also take into account certain percentages of people choosing to remain home by multiplying the production of each TAZ by the expected percentage of non-participating citizens.

It is more difficult to determine the destination of evacuees. If shelters are available then certainly people are able to go there. In the absence of shelters, the evacuees are able to go to hotels or friends' and relatives' homes. If this information is available, or if the shelters in county locations are full or unavailable, then another method is needed to determine where all of the excess trips go to seek shelter.

In the case of the excess trips leaving the county, another system is established. To do this, the model assumes people use the external TAZs they have been using during a normal day in the different proportion they use them to evacuate. This is multiplied by the total productions in order to balance the productions and attractions.

$$A_{i,evac} = P_{tot} * \frac{A_{i,norm}}{\sum_{i=1}^{n} A_{i,norm}} \quad (4)$$

Where:

$A_{i,evac}$ = Total attractions fot TAZ i

$A_{i,norm}$ = Total of HBW, HBNW, NHB trips for TAZ i

P_{tot} = Total productions leaving the county

2.2 Trip Distribution

The trip distribution process has three main steps: finding the shortest path between all of the centroids, obtaining the production-attraction (PA) matrices, and converting the PA matrices into origin-destination (OD) matrices. All three of these parts are mostly left unaltered in this methodology. One of the sub-parts of the conversion process is changed to reflect the timing of the evacuation.

2.2.1 Obtaining the PA Matrices

The number of trips produced by and attracted from each zone is discussed in an earlier section. Using these values along with the travel times estimated from the shortest path matrix, the PA matrices are obtained by implementing the gravity model. The gravity model is commonly used in transportation planning. This model takes the form of:

$$T_{ij} = \frac{P_i * A_j * f(C_{ij})}{\sum_{j=1}^{n} A_j * f(C_{ij})} \quad (5)$$

Where:

P_i = Productions of zone i

A_j = Attractions of zone j

C_{ij} = Travel cost from zone i to j (in this case travel time)

$f(C_{ij})$ = friction factor from zone i to j as a function of C_{ij}

2.2.2 Time of Day Analysis

In either a multi- or single- day evacuation people can leave slowly, quickly, or somewhere in between. A single-day evacuation example is shown in Figure 1. This figure depicts three evacuation rates adapted from the suggested planning values from the same series of reports mentioned earlier (17; 18; 19). In a multi-day evacuation, each day can be modeled separately. One of the Hurricane Study Program reports gives some guidance on multiday evacuations recommending seventy-five percent of the evacuees leave on the first day, while the balance leave on the second day (19).The results from this section are used in the PA to OD conversion process.

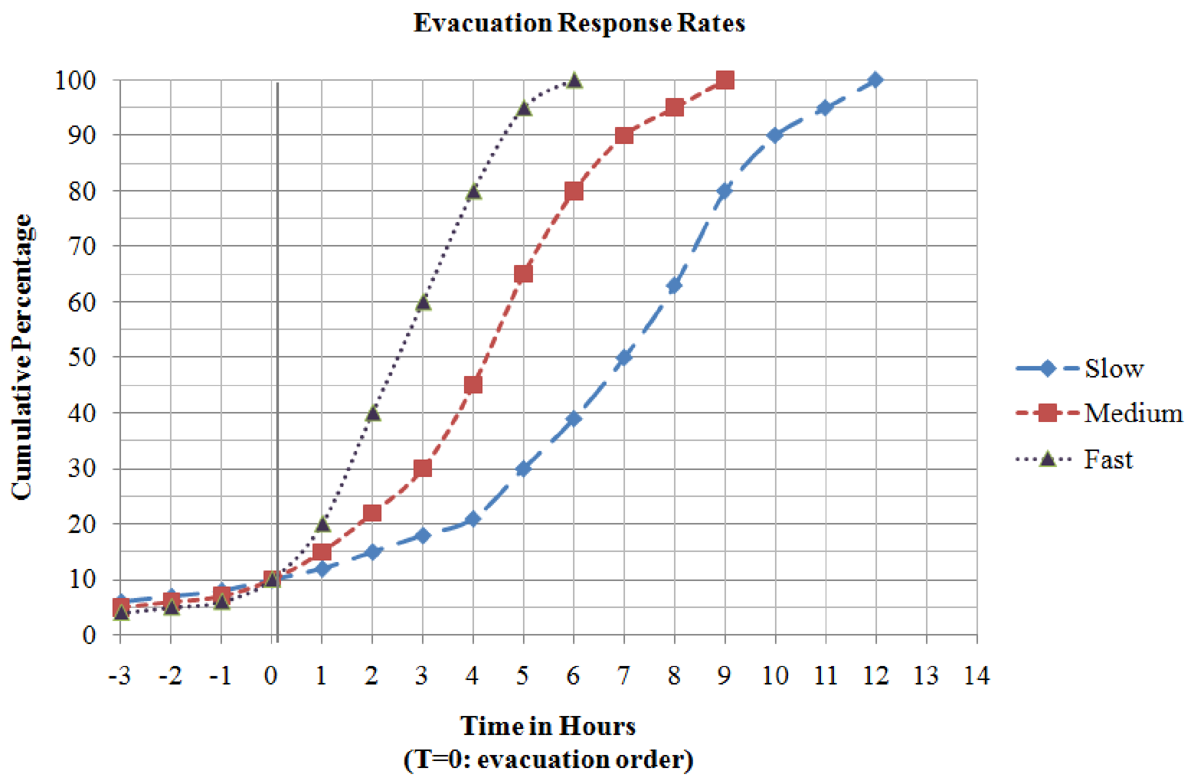

Figure 1 Evacuation response rates of three different evacuation speeds.

Naturally, the slower evacuation assumes people evacuate over a longer period; for each hour, the slow evacuation releases less people than the medium and fast speeds. The fast speed finishes first, but it releases more people for each hour. Each of these storms implies the perception of the danger of the hurricane. For example, the slow evacuation could be the situation if there is a weaker hurricane (Category 1), while the fast speed could be representative of a strong hurricane (Category 4 or 5). Since it is a mandatory evacuation, 100% of the population is evacuated regardless of the severity of the hurricane. In this sense, this study estimates the longest time for each evacuation speed because the maximum volume of people are evacuating. It is important to note that according to the Mississippi study in all of the examined situations people tended to evacuate before the evacuation is ordered, but this value is not over twenty percent of the population (19). This group may contain people who are more cautious or dislike congestion more than the rest of the population.

The hourly lookup table that contains the release rates for the TAZs needs to be populated with the hourly departure values of each of the evacuation speeds. It is also adapted to include the release of people from work back to their homes.

2.2.3 Obtaining the OD Matrices

An algorithm in TransCAD has the ability to turn PA matrices to OD matrices. This algorithm accounts for the mismatches between productions and attractions and origins and destinations. During this algorithm, the occupancy of the vehicles taking each type of trip is taken into account. In this step, the hourly lookup table described above is also taken into account.

2.3 Traffic Assignment

The final step is to run the traffic assignment algorithm. Normally, planners use a static traffic assignment (STA) procedure. However, to model the evacuation a dynamic traffic assignment

(DTA) procedure is used. Andem found in his thesis that DTA is more apt to capture the effects of a hurricane evacuation (20). STA treats the demands and capacities of the network as fixed and constant over the course of a day or several hours. DTA allows the demands and capacities to be variable and non-fixed values over the course of the day. This allows trips that are longer than the assignment period to be made successfully. That is, DTA tracks a vehicle through multiple time segments if the trip length is longer than the time segment. The data required is nearly identical to the data needed for the static assignment algorithm. The deterministic user equilibrium method is used during the traffic assignment. This closely follows Wardrop's first principle, which states, "the journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route. Each user non-cooperatively seeks to minimize their cost of transportation" (21). The Bureau of Public Roads volume delay function is used in the assignment (22). This function determines how the travel time on the links changes as the volume approaches (or surpasses) the capacity of the link. As α increases, the speed at which the link becomes congested increases. α varied for each link depending on the link's characteristics.

Spillbacks are required for the TransCAD DTA module. Spillbacks occur when the amount of vehicles trying to use a link is greater than the physical space available on the link. The amount of space available on a link is known as the link's storage capacity. This value can be taken as 210 vehicles per lane per mile of roadway (23).

3. SCENARIO ONE: BERKSHIRE COUNTY

3.1 Study Area

This methodology is used to model an evacuation of Berkshire County, Massachusetts. The scenario examined is as follows: hurricane force winds enter the county at 10 AM twenty-four hours after the evacuation order has been made. Everyone heads to the west because the hurricane tract may move to the east.

Berkshire County is the westernmost county in Massachusetts. Berkshire County is bounded by Vermont to the north, New York to the west, and Connecticut to the south. It is also neighbored to the east by three Massachusetts counties: Franklin County, Hampshire County, and Hampden County. There are 23,320 links and 11,508 nodes in the network. Berkshire County's regional model and the data associated with it show that the county has 143 internal zones and 37 external zones, for a total of 180 TAZs. The Massachusetts Turnpike, or I-90, is a major route used for trips passing through the county. The county and its relation to the rest of Western Massachusetts are found in Figure 2.

3.2 Trip Generation

Using Equations 1 and 3 in Berkshire County, the average production rate is 1.01 trips per household. This value is obtained by dividing the total number or trips by the total number of households in the county. In order to convert this rate into another metric for comparison, the number of trips made are added together and then divided by the total number of vehicles in the county. The result of this calculation is that the residents use 66% of the available vehicles during the evacuation. Table 2 shows how these results compare with the other studies produced by FEMA and USACE (17).

Table 2 Production By Veh. Trips per HH (LEFT) by Percentage of Vehicles (RIGHT)

Area	**Rate**	**Area**	**Rate**
Alabama	1.16–1.36	Apalachee Bay (FL)	65–75%
Apalachee Bay (FL)	1.20–1.30	NW Florida (FL)	65–75%
NW Florida (FL)	1.16–1.36	Tampa Bay (FL)	65–75%
Mississippi	1.15–1.49	Georgia	65–75%
		New York	70%
		North Carolina	60–70%
		South Carolina	65–75%
Berkshire County	**1.01**	**Berkshire County**	**66%**

These results are low when comparing the productions per household but are within the recommended range for the percentages of vehicles used during evacuations of other regions. As the average occupancy of the vehicles decreases, the amount of vehicles used increases. The rates are insensitive to an increase in the occupancy of the vehicles above about three people per vehicle.

Twelve zones along the western boarder of the state are used as the evacuation zones; Equation 4 is used to calculate the number of attractions to each of the twelve zones.

3.3 Trip Distribution

3.3.1 Obtaining the PA Matrices

Using Equation 5 with $f(C_{IJ}) = \exp(-c * C_{IJ})$, a PA matrix for each of the four trip types is obtained. The “c” value in the exponential friction factor function is a variable that determines how fast the roads become congested with a higher value indicating a road that becomes congested faster. For evacuation trip type, c is taken to be 0.15, which is a value in-between the original regional model’s HBW (0.16), HBNW (0.14), and NHB (0.13) trip types’ c values. This value is chosen to replicate the combination of the three trip types’ distributions. The normal-trip friction factors coefficients are left untouched in the evacuation model.

3.3.2 Time of Day Analysis

In the scenario provided by Berkshire County, the evacuation is a single-day evacuation. Since it is not going to be known at which speed the residents of the county will evacuate, all three scenarios presented in Figure 1 are examined. If the evacuation is monitored, then planners can decide which speed the citizens are evacuating and take the proper actions.

The time people are using the network before the evacuation is ordered is also considered. People leave their homes to evacuate while people are also returning home from work. The trip times are approximated by using data from national average hourly trip tables provided in NCHRP 187 (24). Whenever the evacuation is ordered (in this case, at 10 AM), all of the trips that have already been made are summed up and collapsed into one period and sent onto the roads. This is shown in Table 3. In this table, the "% Departing" column indicates what percentage of the trips leave during a given hour. Similarly, the "% Returning" column indicates what percentage of the trips return to the home during a given hour. In this case, no trips have returned home by the time of the evacuation; therefore, the trip percentages before then are zeros. For the other two trip types, it is assumed that a trip of those types take less than one hour. Therefore, all of the trips return by the time the evacuation order is called, and these trips did not need to be collapsed in the same way. Non-evacuation trips are not made after 10 AM.

3.3.3 Obtaining the OD Matrices

After using the PA→OD tool in TransCAD with the altered hourly trip table and each evacuation speed, twenty-four OD matrices are obtained. These matrices contain the number of vehicle trips originating and terminating in each TAZ for each hour. Each trip type is added together for each hour so twenty-four matrices are, again, obtained. These twenty-four hourly matrices are used in the DTA.

3.4 Traffic Assignment

Using DTA, the routes people might take to get to the evacuation TAZs are determined. The "Depart Periods" toolbox is set to the number of departure periods. This value depends on which evacuation rate is being examined. The values for the fast, medium, and slow cases respectively are 17, 20, and 23 hours. The "Total Periods" toolbox is set to one time step larger than the required amount of time to clear the network. The BPR function is used with α ranging from 0.15 to 0.70. The storage capacity of each link is also calculated using the spillback equation noted earlier.

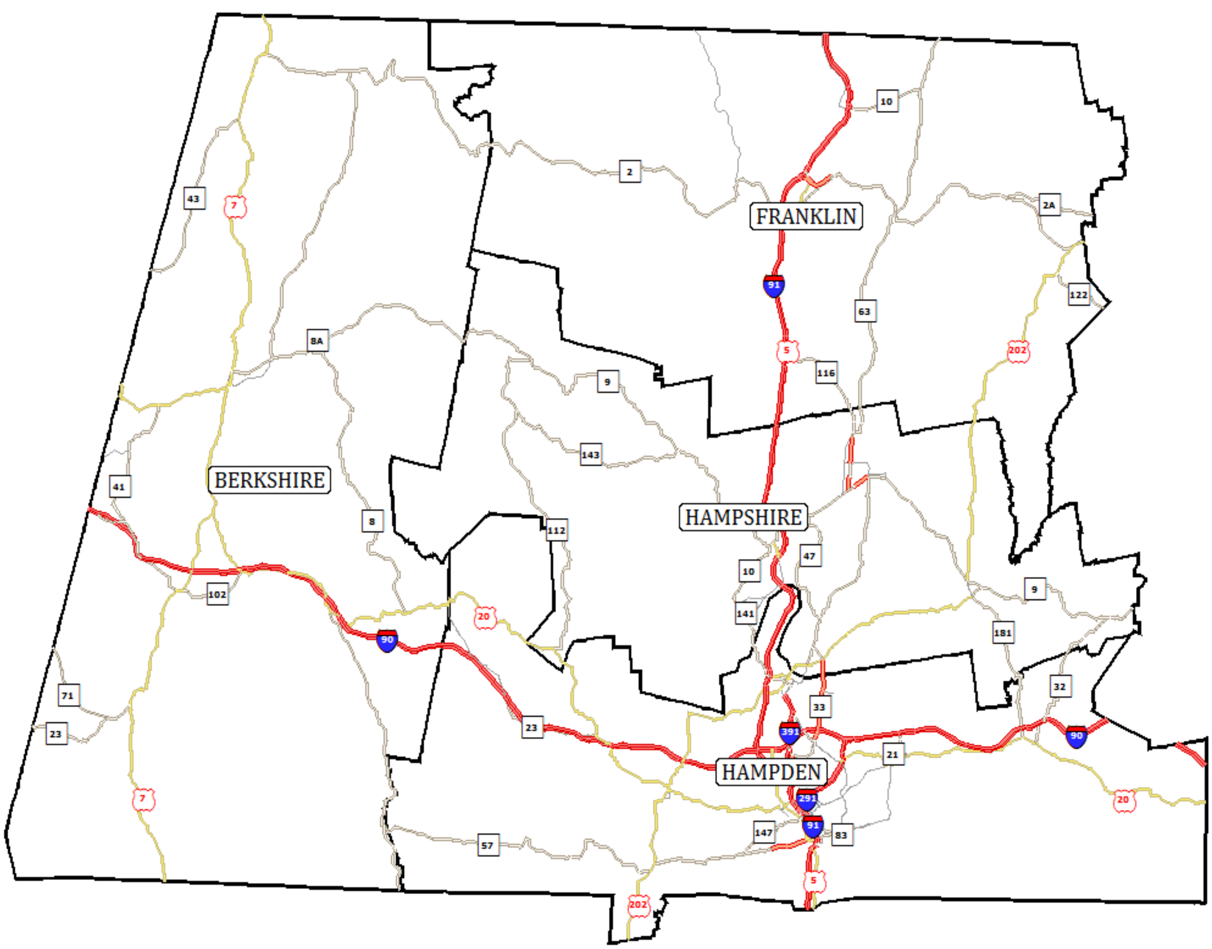

Figure 2 Major road system of Western Massachusetts.

Table 3 Hourly HBW Trips Made During Normal Day and a Hurricane Day

	HBW (Normal)		HBW (Hurricane)	
Hour	% Departing	% Returning	% Departing	% Returning
0	0.40	0.00	0.40	0.00
1	0.20	0.00	0.20	0.00
2	0.00	0.00	0.00	0.00
3	0.20	0.00	0.20	0.00
4	0.40	0.00	0.40	0.00
5	2.70	0.00	2.70	0.00
6	7.90	0.00	7.90	0.00
7	19.20	0.00	19.20	0.00
8	9.20	0.00	9.20	0.00
9	3.00	0.00	3.00	0.00
10	**0.70**	**0.00**	**0.00**	**43.20**
11	0.60	0.00	Forgone Trips (Evacuation begins at 10)	
12	0.70	1.40		
13	0.60	1.40		
14	0.60	3.20		
15	0.60	5.70		
16	0.60	13.10		
17	0.60	11.80		
18	0.60	3.10		
19	0.60	1.70		
20	0.60	1.00		
21	0.00	2.90		
22	0.00	2.80		
23	0.00	1.90		

During the trip generation step, the number of productions by each TAZ in the event of an evacuation is made. The productions per household are generally one, as most households fit in a single vehicle, but some TAZs produced multiple trips on average. After the productions for each zone are added together, 56,192 trips are made. 86% of the HBW trips, 15% of the HBNW trips, and 17% of the NHB trips are made. The total number of trips decreases to 51% of the original trips. Most of the HBNW trips are normally made after 10 AM. Since the hurricane forces people to forego making these trips, the total number of trips made significantly decreases. The total number of trips made during the day is highly affected by the number of forgone HBNW trips. Most of the HBW trips still are made, though the return portion of the trips is accelerated. Almost half of the HBW trips are made before the evacuation is ordered. In order to send those trips back to their home, that same percentage of trips returns home. If the evacuation is ordered earlier, around 5–6 AM, then almost no trips use the network and almost all of the trips made for the day are be induced by the evacuation order. The numbers of trips generated by the hurricane are not excessive when compared against a normal day. This leads to the notion that the problem with the hurricane is not volume based because the network can currently handle almost two times as many daily trips as the hurricane day produces, but rather is temporally based. Problems occur due to the small number of trips being produced all leaving at nearly the same time heading to the same places.

The PA matrices provide enough information to determine where people originate and where they are destined. In this case, the PA matrices are equivalent to twenty-four hour OD matrices. The trips are already in terms of vehicle trips and no one is making return trips. These can easily be graphed using utilities in TransCAD, but they are not shown here.

There are a small number of zones that may have problems regarding having enough vehicles to evacuate. The average number of vehicles per household is less than one for several of the TAZs. This implies some of the households have more than one car, but many houses have no cars. Either these residents must find a way to share a ride with nearby residents or they need some form of public transportation (e.g., buses) to assist in the evacuation. These TAZs are located in Pittsfield and North Adams. However, in these TAZs there is enough space in all of the vehicles (assuming four seats per vehicle) to evacuate. In another TAZ, there are simply not enough spaces in all of the vehicles to evacuate everyone. This TAZ has a large student population with very few cars.

3.5 Release Rate Based Results

In the previous section, the results that applied to all of the release rates are examined. This is because the results are obtained before the release rates are used in the analysis. They are results from the trip distribution portion of the four-step model. There are several important issues to look at when examining a hurricane evacuation. One of the more significant measures is the clearance time. Clearance time is the time it takes from when the evacuation is ordered until a significant number of people make it to a safe area, in this case the county border. Other measures are of value to different groups such as volume to capacity (V/C) ratios, which are valuable to engineers, or congested speeds, which are valuable to the planners and the public. Another metric of some value is the flows, or volume of vehicles passing in a given time. The clearance times are obtained by searching the output of the DTA report for the first hour with no volume on any links. The clearance time is the time from when the evacuation order is called until the end of the last hour with nontrivial traffic. The slow, medium, and fast evacuation speeds finished their evacuations by 2 AM, 11 PM, and 8 PM respectively. This gives clearance times of 16, 13, and 10 hours. It is evident from the results that the time it takes to evacuate fully is largely a function of the speed of the evacuation. It took about three hours after the last vehicle began its voyage for that vehicle to depart the county. All three of the rates satisfy the requirement of evacuating all of the people before the hurricane force winds enter the county.

Table provides the top three critical locations for each evacuation rate. These locations may exhibit a V/C ratio greater than equal to one. Travel times are important to the general public. They want to know how long it will take them to get out of harm’s way. The DTA reports the congested time taken to travel on each link. By using these values as the travel time to calculate the shortest path between any two centroids, the travel time between communities and evacuation TAZs can be found. Four of the larger communities’ travel times to the most utilized exit point are reported in Table 5.

The largest travel time in all of the cases is at Simonds Road where the highest rates of congestion are predicted. For the slow rate, these travel times are 1.0 to 2.5 hours. The medium rate has values ranging from 1.0 to 3.0 hours. The fast rate’s travel times are approximately 4.5–5.5 hours. This is due to the exceptionally high volume of vehicles using the road causing significant delays.

Table 4 Top Three Critical Locations for Each Evacuation Speed and Critical Hour

Slow	**Max V/C**	**Street**		**Street**		**Street**
1	2.17	Simonds Rd. (Rt. 7)	from	Main St.	to	State Line
2	1.66	West Housatonic (US 20)	from	Gale Ave.	to	Cen. Berkshire Blvd.
3	1.65	Richmond Rd.	from	Summit Rd.	to	Canaan Rd.
Medium	**Max V/C**	**Street**		**Street**		**Street**
1	2.52	Simonds Rd. (Rt. 7)	from	Main St.	to	State Line
2	1.73	State Line Road	from	Main St.	to	Albany Rd.
3	1.70	Richmond Rd.	from	Summit Rd.	to	Canaan Rd.
Fast	**Max V/C**	**Street**		**Street**		**Street**
1	2.78	Simonds Rd. (Rt. 7)	from	Main St.	to	State Line
2	1.87	State Line Road	from	Main St.	to	Albany Rd.
3	1.64	Massachusetts Ave.	from	Marshall St.	to	Simonds Rd.

Table 5 Congested Travel Time to Most Used Evacuation Zone

From	**To**	**Evacuation Rates (units in minutes) [hour examined]**			
		Free Flow	Slow [7—8 PM]	Medium [3–4 PM]	Fast [2–3 PM]
North Adams	Rt. 7	26.2	64.6	130.2	178.3
Pittsfield	US 20	31.8	49.2	47.0	51.2
	Rt. 295	34.5	43.5	51.3	52.4
Stockbridge	Rt. 23	34.8	36.5	38.4	39.3
Lenox	Rt. 295	29.1	31.3	37.8	39.0
	Rt. 102	27.8	28.8	34.7	36.2
Great Barrington	Rt. 23	28.3	30.1	31.8	32.8

4. SCENARIO TWO: FOUR-COUNTY EVACUATION

4.1 Study Area

This scenario extends the first study to the three counties that border Berkshire County to the east. These four counties are shown in Figure 2. The data for this region came from three independent data sources. This added many steps to prepare the data. These steps may not be applicable outside of this specific region, and therefore these steps are not discussed here.

This scenario is the same as the first scenario; an evacuation order is given at 10 AM, and people fully evacuate the four counties. In this case, the hurricane path is headed up through the center of the map causing people to evacuate to the east and west.

4.2 Trip Generation

The trip generation followed the same procedure as the first scenario. Using Equations 1 and 3, the trips per household and total trips as a percentage of vehicles used for the evacuation are about one trip per household and 64% of the available vehicles are used. Referencing Table , these values are low, but the trips taken as a percentage of vehicles are within or near the acceptable ranges.

4.3 Trip Distribution

4.3.1 Obtaining the PA Matrices

Using Equation 5 with $f(C_{ij}) = \exp(-c * C_{ij})$, where c is a constant, a PA matrix for each of the four trip types is calculated. For the evacuation trip type, c is taken to be 0.123 (the default value). More information from a similar event is needed to better calibrate this value.

4.3.2 Obtaining the OD Matrices

This step follows the same procedure as the Berkshire-only model.

4.4 Traffic Assignment

Significant changes are not made from this portion of the model from the Berkshire-only case. The first assigned period is the period from 5–6. The amount of departure periods varied from 18 for the slow speed and 12 for the fast speed.

4.5 General Results

As the majority of the process is the same for the isolated county as well as the full four-county area, the same sorts of results can be obtained.

Very similar results for the reduction in trips produced are found in the four-county evacuation. The percent decreases for HBW, HBNW, NHB, and the total number of trips are 86%, 16%, 17%, and 50% respectively. This again heavily corresponds with the time of the day that the hurricane evacuation order is given. The later in the day the evacuation is ordered the more these percentages drop (more regular trips are taken).

The TAZs that have less than one vehicle per household for Hampden County are shown in Figure 3. The other two counties also have several TAZs with a low number of vehicles per household, but these TAZs are not shown. The results for Berkshire County have already been shown in an earlier section. No additional TAZs have deficient vehicle space when taking into account the assumed capacity of the vehicles. The only TAZ in the region without enough space is shown in a previous section.

4.6 Release Rate Based Results

In this section, some of the results from the release rate based portion of the study are examined. The same results can be obtained from the single county scenario for the four-county scenario. One of the most important results for the hurricane evacuation is the clearance time. The fast evacuation clears by 1 AM for a clearance time of 16 hours, and the slow evacuation clears by 5 AM for a clearance time of 20 hours. The clearance times for Berkshire County can be isolated from the four-county model. These results line up well with the Berkshire County-only model, but a very small trickle of traffic is still on the network from 8 PM until the actual clearance time at 5 AM. If 8 PM is taken as the time when the vast majority of the vehicles are out of the county, then the clearance times agree. The amount of vehicles added to Berkshire County is not significant enough to explain a ten-hour extension of the clearance time in the county. The extra vehicles may be a result of the dynamic traffic assignment algorithm.

There are only about 850 centerline miles of modeled roadway in Berkshire County. There are about 3,200 centerline miles of modeled roadway in the four-county model. It should be expected that considerably more links are considered critical. Figure 4 presents the congested links during 2 to 3 PM of the fast evacuation rate, the hour with the most traffic on the network.

Grey links have a V/C ratio less than one, while the V/C ratios increase from yellow to orange to red and finally to pink with the highest V/C ratios. There is minor congestion of people using US 7 in the northwest corner of the state to evacuate. This is also seen in the Berkshire County model presented earlier. There is significant congestion in the northeast corner from the people using Rt. 2 and 2a to exit the county. The most congestion is seen in the southeast corner. These people are using I-90 to evacuate to the east towards Worcester and Boston. Some people from Springfield use I-90 to evacuate to the west. As is expected, the congestion is focused in the vicinity of the locations with the highest percentage of people using the routes to evacuate. There is a section in-between the people evacuating to the east and the people evacuation to the west that is not very congested. In addition, most of the east-west roads in the middle of the four-county region are mostly moving smoothly.

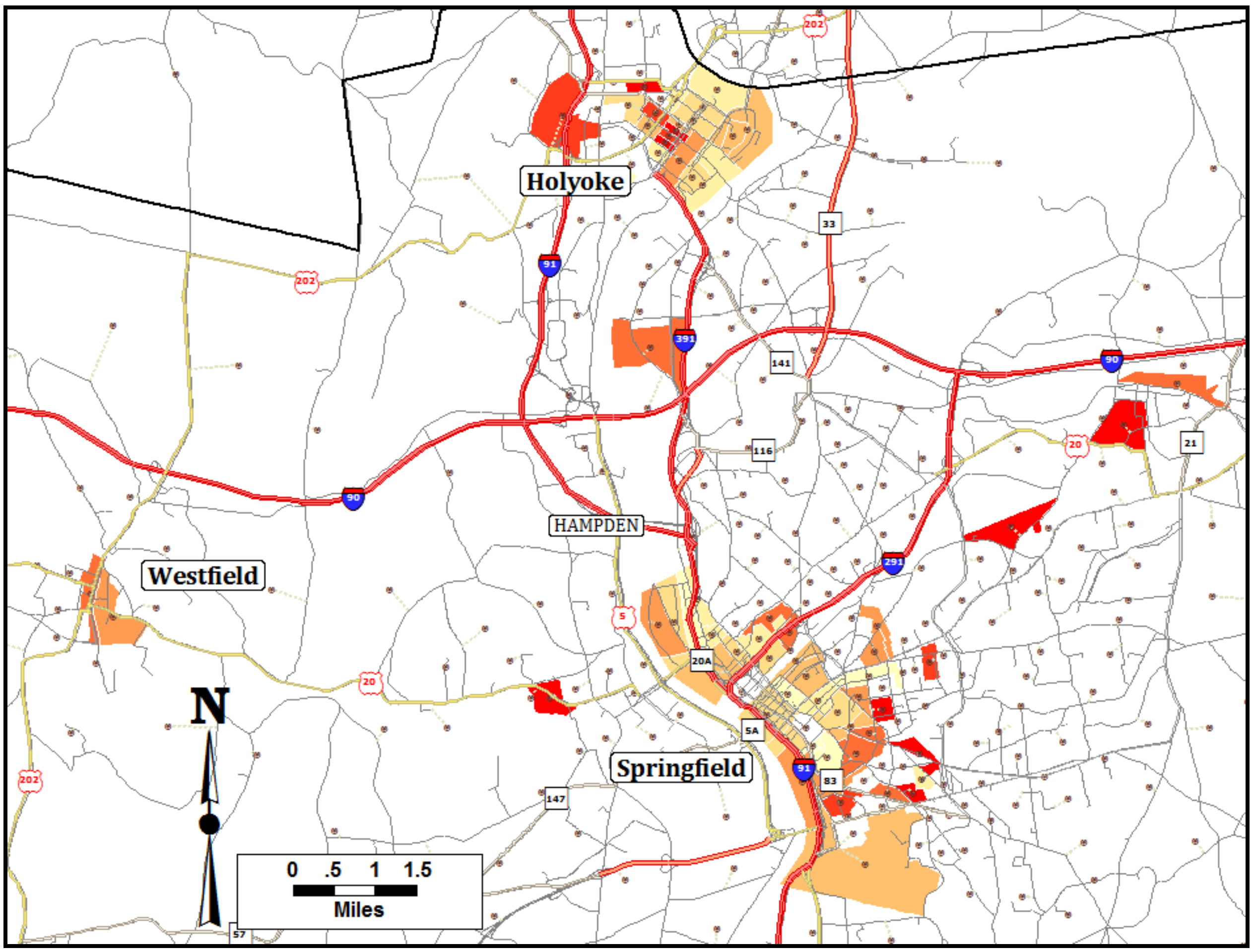

Figure 3 Hampden County TAZs with less than one vehicle per household.

The equilibrium travel times during the time with the most congestion are shown below in Table 1. These values represent the travel time an individual faces if they leave their TAZ at the beginning of the hour and headed to the listed exit. The travel time increases as the congestion increases. The travel time almost doubles under the slow case and more than triples in the fast case.

The results from Pittsfield to US 20 agree well with the results found for the Berkshire County only scenario. The travel time is nearly 54 minutes in this case and is 49 minutes in the

Berkshire-only case. The fast travel time is almost double the results from the Berkshire County only scenario.

Table 1 Congested Travel Time to Most Used Evacuation Zone (Four-County Case)

From	To	Evacuation Rate (units in minutes) [hour examined]		
		Free Flow	**Slow [8–9]**	**Fast [2–3]**
Pittsfield	US 20	31.8	53.9	97.2
Springfield	I-90	44.5	200.9	270.4
Amherst	Rt. 2	46.9	141.6	211.1
Greenfield	Rt. 2A	41.2	184.8	256.6

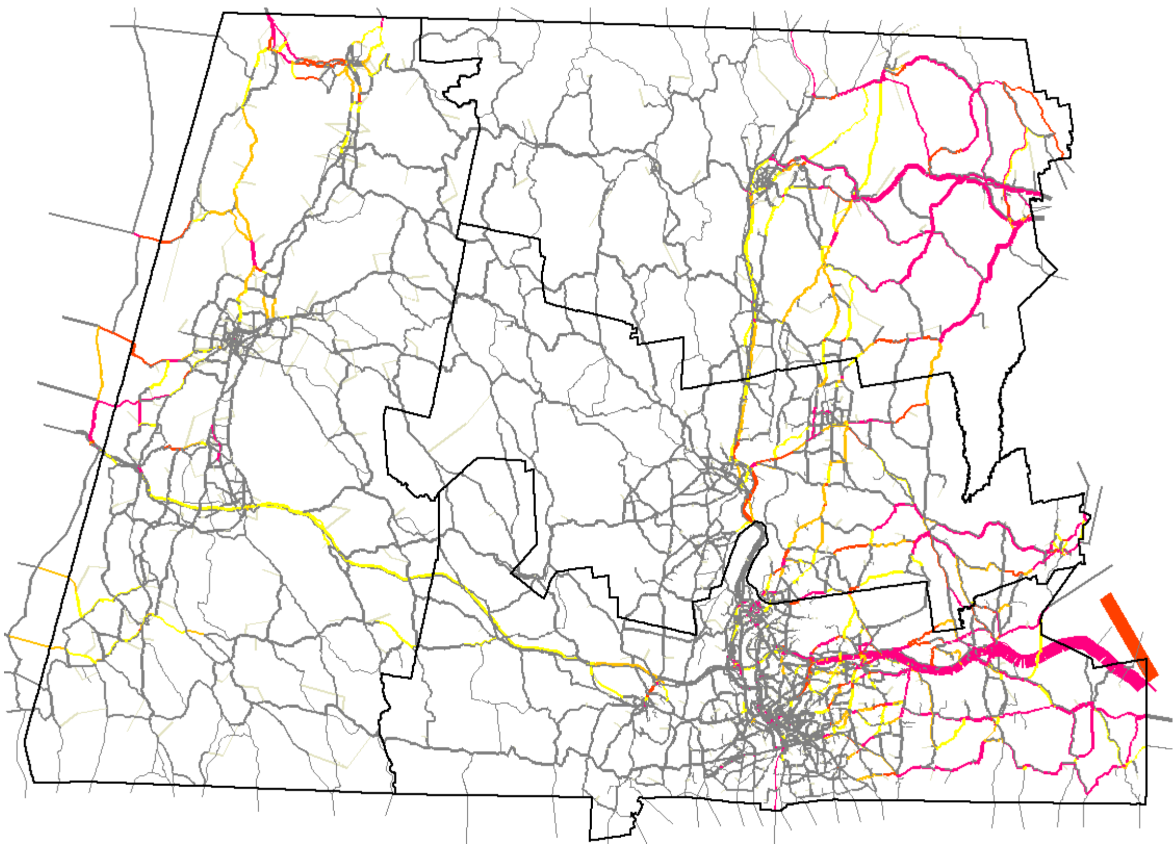

Figure 4 Flow and V/C ratio on the network during the hour of 2–3 PM.
Grey (Low V/C) → Yellow → Orange → Red → Pink (High V/C)

5. FINDINGS AND CONCLUSIONS

The results for both the Berkshire County as well as the four-county model are presented at the end of each scenario. These models are based on the four-step planning model, which is usually used in transportation planning, with some less than usual assumptions for some portions of the model. Similar results are provided for both scenarios. The specific solutions to these problems are not pertinent to an audience outside of Western Massachusetts; therefore, general solutions that can be made from this type of information are presented.

These results can be very valuable to the decision support system. Once the clearance times are known the decision arc, or the time the decision needs to be made to evacuate before the arrival of the hurricane, can be found. This allows officials to confer with the weather service, or similar groups, to determine the characteristics of the hurricane. The decision makers still need to determine what speed they think that their population will evacuate at, but this can be nudged by making stronger or weaker cases for evacuation. The citizens of a county so far away from the coast that are not used to hurricanes will react differently than residents of coastal states.

Potential travel times can be relayed to the public to inform them of what routes might be significantly delayed. Some routes in the network may be underutilized. Through this methodology, the routes can be discovered and then that information can be reported to the public. In this case, Route 2 to the west is underutilized, and it may be a good idea to tell that to the people living in the northern end of Berkshire County.

If certain areas inside of a county do not have enough vehicles to evacuate then shelters can be stocked with extra food, water, and beds. Buses can be diverted to take care of these areas as well. The citizens of these counties can be notified via radio or television about the availability of extra buses or shelter space.

Overall, TransCAD and the four-step transportation planning model are capable to use for evacuation modeling. The GIS mapping tools provided with the software allow for the stitching together of the network, and they also allow the information to be mapped in an efficient manner. The computation process turns out to be very efficient in this case considering the size of the evacuation network. The inclusion of the DTA module allows for a more realistic model of an evacuation. There are downsides to the deterministic user equilibrium method. An assumption of this model is that people have perfect information and perfect knowledge of the network. This may not be the case during a hurricane evacuation. If a system optimal (instead of user equilibrium) dynamic traffic assignment module were implemented, the software could be more useful in determining what the evacuation routes should be for the shortest network travel time. Further research must be completed to hone the friction factor in the trip distribution step. This model assumes reasonable values, but specific hurricane distributions would help improve the accuracy of the model.

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