Hurricane Evacuation in Delaware

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Abstract

This paper discusses the plan outlined for an evacuation in Delaware due to a hurricane. The paper draws on the plans, research, and lessons learned from hurricane prone states and those states less likely to experience a hurricane. It also discusses the engineering and sociological issues associated with an evacuation. It culminates with the gaps between Delaware's plans and the aforementioned research.

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1. Introduction

Delaware is located on the Delmarva Peninsula, bordered on the east by the Atlantic Ocean and on the west by the Chesapeake Bay (see Fig. 1). Because of this location Delaware is a state vulnerable to many natural hazards. Sussex County, the southernmost county in Delaware, is at risk for seventeen of the twenty-one hazards defined by the federal government, the most threatening of these being floods and hurricanes (Edwards and Kelcey, 2006). Over 95% of the state has an elevation less than 150 feet (geology.com/state-map/Delaware.shtml). Although hurricanes do not pass through this area often, they do occasionally, and the state is in a very vulnerable position when it happens. Delaware is also very dependent on tourism as an economic base. One of Delaware's beaches, Dewey Beach, has a population of 350 in the winter, and it swells to 30,000 on a summer weekend (Cormier, 2008). Seventeen percent of all of Delaware's non-hotel or motel housing could be impacted by some kind of tidal inundation from a category 4 hurricane (Edwards and Kelcey, 2007b). The threat from a storm of this magnitude would likely result in a large evacuation being ordered. The 2005 Delaware Hurricane Evacuation Study completed by the U.S. Army Corps of Engineers, estimated anywhere from 90,000 to 115,000 vehicles would leave statewide. Since this study, development has continued along the Delaware coast and tourism is booming, causing even more people to vacation in the area and then need to vacate the area if a hurricane threatens.

Figure 1: Map of Delmarva Peninsula

Evacuation plans exist, but with limited experience we do not know how effective or efficient these plans are. Since Delaware is located on a peninsula, getting all of these people out safely before a hurricane is a tricky situation. In general, the only evacuation direction is to the north into Pennsylvania

and Maryland, directly into the I-95 corridor, which is congested in normal times. Evacuating to the west is toward the Chesapeake Bay, which would also be subject to storm surge and subsequent flooding. These limited evacuation routes could get congested very quickly. Another large problem the state encounters is how to educate the public on the plans it has formulated, including warning messages, planned evacuation routes, and the meaning of relevant signing. The most comprehensive and detailed plan serves no purpose if the public is not aware of its existence.

2. Literature Review

This research draws on two areas of the literature: (1) Engineering studies and models relating to evacuation and (2) the sociological perspective of evacuation. This section reviews each of these areas.

2.1 Engineering Studies Related to evacuation

Engineers have traditionally had little involvement in planning and managing hurricane evacuation. Hurricanes are rather rare events and are localized to certain geographical locations in the United States. Historically, the thought was moving smaller coastal populations through road networks was no problem (Wolshon et al. 2005a). Now, however, huge growth along the coastal regions of the U.S. has occurred. The population of the 22 most vulnerable and populated coastal counties are expected to grow from 36 million in 1993 to 76 million in 2010 (Wolshon et al. 2005a). This is an increase of 111% in 17 years. The number of new roadway lane miles in these counties, however, will only increase by about 1% during the same time (Wolshon et al. 2005a). In order to tackle this problem in a systematic way, Hurricane Evacuation Studies (HES) are undertaken. The studies vary in sophistication from elaborate modeling efforts that recognize growing population, limited roadway capacity, and the role of new technologies such as variable message signs, to relatively simple maps.

2.1.1. Hurricane Evacuation Studies and Relevant Engineering Models

A Hurricane Evacuation Study (HES) consists of five analyses – (1) a hazard analysis identifies areas that will need to be evacuated, (2) a vulnerability analysis estimates the number of people in the threatened area and which structures should be evacuated, (3) a behavioral analysis predicts how the

public with react to the imminent hurricane, (4) a shelter analysis identifies the number and locations of structures safe to house evacuees, and (5) a transportation analysis assesses street and road capacities to determine clearance times and identify critical links in the road networks (Wolshon et al. 2005a). There are several models that are used in practice today to help with these analyses and to assess the need for evacuation and then model the evacuation. These models can come up with evacuation arcs. This is a circle or arc whose radius is the distance an approaching hurricane will travel during the time an area is evacuated. If officials order an evacuation as soon as tropical storm force winds hit the outside of the evacuation arc, a full evacuation of the area can be completed before winds reach tropical storm intensity in the vulnerable area (Lindell and Prater 2007). The time of the arrival of the storm is found by the following equation (Lindell and Prater, 2007):

$$\frac{d-r}{FMS}$$

d: distance from eye of the hurricane to coastline

r: radius of tropical storm winds

FMS: hurricane's forward movement speed

One of these models is the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, which maps the storm surge and helps distinguish the safe areas from at-risk areas (NOAA 1999). There is also simulation evacuation modeling. Several models are used to simulate evacuation and estimate clearance times. These include NETVAC (NETwork emergency eVACuation), MASSVAC (MASS eVACuation), and CORSIM(CORidor SIMulation). These models simulate the evacuation and let officials see problem areas and peak flow times. NETVAC (Sinuany-Stern and Stern, 1993), which is designed to get a population from point A to point B by assessing the road networks, and MASSVAC (Hobeika and Kim, 1998), which is used to describe vehicle flow, both use Evacuation Simulations (ESIM) as the core traffic flow model. NETVAC estimates flow on the macro, or vehicle-group level. It allows for dynamic route selection and lane and intersection management (Wolshon et al. 2005a). MASSVAC allows for much broader evacuation situations, not just routes radiating away from one point

like NETVAC (Wolshon et al. 2005a). The final model is CORSIM (USDOT 1996) which is a general traffic simulation model, but also simulates the termination of contraflow lanes.

Hurricane evacuation modeling is also used. Two examples of this type of model are HURREVAC and EMBLEM (Lindell and Prater, 2007; Wolshon 2005a). These models help officials in the decision making process to order an evacuation. They use SLOSH to visualize the projected tidal inundation and are also able to produce evacuation time estimates (ETE's). According to Lindell and Prater (2007) HURREVAC is limited because it can only provide ETE's for a few situations, and treats the time to make a decision to evacuate as a deterministic value.

2.1.2 Challenges in modeling hurricane evacuation

For a category one hurricane, most states along the entire east coast would take 12-24 hours to evacuate the vulnerable area (Wolshon et al. 2005a). There are several factors that planning engineers need to keep in consideration when they are developing those time estimates. One of these is compliance of the evacuee. They might have their own preference in route choices, and may not follow instructions, thereby potentially increasing the total travel time (Han et al. 2007). Another factor that can increase evacuation times is "shadow evacuation." This is a spontaneous evacuation of those who are not at risk, but believe they are (Wolshon et al. 2005a). Evacuation route designers also need to find a way to incorporate the evacuation of special needs populations. This includes those who cannot physically evacuate themselves and those who do not have a means of transportation. One would need to specify pick up points for individuals without personal vehicles and elderly (Wolshon et al. 2005a). One of the best ways to transport this population is by contracting buses to take these people to shelters (Wolshon et al. 2005a). Finally, transportation engineers need to monitor the warnings to see who is being advised/ordered to evacuate. An over extensive evacuation could be ordered and overstress the transportation system, reducing access to those who are really at risk (Wolshon et al. 2005a).

A big challenge in major evacuations is that the evacuation routes are limited in number and may not be able to handle the capacity of vehicles trying to enter the roads (Han et al. 2007). This coupled

with the risks of evacuation which can increase with hazard type, meteorological and geographical conditions of the evacuation area, and time of evacuation can cause an inefficient evacuation. Traffic accidents, deaths, those refusing to evacuate, and those who evacuate and do not need to, or before they need to can all occur because of the associated risks and limit the effectiveness of an evacuation (Han et al. 2007).

2.1.3. Measures of evacuation effectiveness

An effective evacuation optimizes the time and space a person travels to evacuate an at-risk area (Han et al. 2007). One way to quantify this is by examining clearance times. This is the time it takes to configure traffic control, start the evacuation, and get all evacuees outside an evacuation area once deteriorating conditions signal the end of the evacuation (Wolshon et al. 2005a);(Han et al. 2007). Han et al. (2007) have developed several equations to measure the effectiveness of an evacuation:

$$\text{Min} \int_0^{t*} Q(t)\ \mathrm{d}t$$

Where Q(t) is the percentage of total evacuees on the road in an Emergency Protection Zone (EPZ) at time t. t* is a selected time to complete the efficiency assessment. This function minimizes the area under the Q(t) curve. Another equation Han et al. (2007) developed to measure the efficiency is:

$$\text{Min} \int_0^{t*} \sum_a x_a(t)\ R_a(t)\ \mathrm{d}t$$

Where $x_a(t)$ is the number of vehicles within the EPZ on route *a* at time t, $R_a(t)$ is the risk index for evacuees remaining on route *a* at time t, and t* is a time selected for the efficiency assessment. This equation considers time, space, and risk, and minimizes them all (Han at al. 2007).

2.1.4. Recent innovations in hurricane evacuation

Several new ideas and practices have been introduced recently into the field. Two of these are contraflow lanes and Intelligent Transportation Systems(ITS) (Wolshon et al. 2005b). Contraflow is defined as "the reversal of traffic flow in one or more of the inbound lanes (or shoulders) of a divided highway for use in the outbound direction, with the goal of increasing capacity (Wolshon et al. 2005b)." Contraflow can be completed in several different ways: both inbound lanes can be reversed, or one inbound lane can be reversed, and the other left normally, and the last formation is the use of shoulders for extra lanes (Wolshon et al. 2005b). A study estimates that by reversing two lanes and essentially being able to evacuate with four lanes of traffic, capacity can increase by 70% (Wolshon et al. 2005b). Single-lane contraflow operations can increase outbound road capacity by 30% (Wolshon et al. 2005b). And finally, by opening a shoulder for outbound traffic, one will see an 8% increase in capacity (Wolshon et al. 2005b). This is due to shoulders generally being narrower than normal lanes, causing motorists to drive slower than other moving lanes. This increased capacity can substantially reduce clearance times, but also has some downfalls (Wolshon et al. 2005b). To set up the configurations is extremely time consuming, with single-lane contraflow accidents are common, and having the correct signs facing the "wrong" direction has been a problem (Wolshon et al. 2005b).

Access to timely and accurate data during an evacuation is necessary to have an effective evacuation (Wolshon et al. 2005b). Intelligent Transportation Systems (ITS) help out here. Volume and speed are the most important quantitative data for evacuations (Wolshon et al. 2005b). They tell you what the flow of the road is and if you are about to hit capacity and need to divert some traffic to other routes. This data can be collected from recorders most states have set up in random locations (Wolshon et al. 2005b). Also, cameras have now been mounted throughout states along highways and at intersections. This gives direct visual confirmation of

traffic and weather at remote areas along evacuation routes (Wolshon et al. 2005b). One example of this type of camera is a closed circuit television (CCTV) (Wolshon et al. 2005b). Another use of ITS systems is to disseminate traffic information to motorists on the road. Two examples are Highway Advisory Radios (HAR) and Dynamic Message Signs (DMS). States are starting to put these in advance of exits and intersections where alternate routes are available (Wolshon et al. 2005b). Some states also have their own radio stations devoted to telling the public about current travel information (Wolshon et al. 2005b). One problem with ITS systems is that most of the locations of these devices are in urban areas, but many evacuation routes are in rural, remote areas. Therefore portable HAR and DMS systems would be used which can be costly to purchase (Wolshon et al. 2005b).

2.2 Sociology Literature

A warning is defined as a "means of getting information about an emergency, communicating that information to those who need it, and facilitating good decisions and timely response by people in danger" (Mileti and Sorensen 1990). A poorly constructed warning message can cause a lot of unexpected social behavior. To avoid this Mileti and Sorensen (1990) stress the need to craft an objective warning that everyone in an endangered area sees in the same way. One of the best ways to accomplish this is through the content of the message. It should contain what the hazard is and the risk associated with it, guidance on what someone should do to stay safe, what areas are at risk (in an easily understood non technical manner - no longitude and latitudes, etc.), the time the hazard is expected to strike and how long it will last, and finally the source issuing the warning so the receiver will know if it is credible (Mileti and Sorensen 1990). Once the warning is written, the message must be disseminated. Mileti (1999) found the best way to do this was by alerting and notifying the public. The alerting phase gets the public's attention with a sound or other sensory stimulus. Then, the message is communicated in the notification stage. One thing to keep in mind is to make sure the warning does not infringe on civil

liberties (Mileti 1999). It must guide public behavior and advise and recommend, but cannot force anyone to stay or leave if they do not want to. Most states will not forcibly evacuate those who wish to stay with their property (Wolshon et al. 2005a).

Warnings for hurricanes are especially important to study. Hurricanes give rather large lead times compared to other hazards, but they can unpredictably, rapidly change course, speed up or stall randomly, and grow in intensity in hours. Hurricanes watches are issued by the National Weather Service (NWS) 72 hours before expected landfall for enormous areas of the coast (Mileti and Sorenson 1990). At only 24 hours before expected arrival, the NWS narrows the watch down to a warning for about 250 miles of coast. The NWS is still only a maximum of 35-45% sure that any single area on that region of the coast will actually be hit by the hurricane (Mileti and Sorenson 1990). This is where a good warning is important. Those who will not be affected do not need to evacuate or take protective measures, but there is still a small chance that these people could be affected and the storm could veer in a direction that was not predicted. Those who did not evacuate might have needed to, and those that did evacuate might have been able to stay home. These types of situations can affect future experiences and impact evacuation routes.

One can engineer evacuation routes following traffic engineering theories perfectly, but if you do not allow for people's decision making processes and priorities, this plan will not work. Society is not made of robots, but free thinking individuals. When a warning message is given, it has no real meaning. The meaning comes from the manner in which the receiver perceives the warning message (Quarantelli 1990);(Mileti and Sorensen 1990). Mileti and O'Brien (1992) say "public response to communicated risk information is a direct consequence of perceived risk, the warning information received, and personal characteristics of the warning recipient; and perceived risk is a direct function of both the warning information received and personal characteristics of the warning recipient." People do not just hear a warning and then leave. They go through a process of questions to come up with their decision to evacuate or not. Lindell and Perry (1992) say there are four general steps the public go through:

(1) Risk identification: Does a threat exist?

(2) Risk assessment: Is protection needed?

(3) Risk reduction: Is protection feasible?

(4) Protective response: What action should be taken?

Mileti (1999) built on this model with the following series of perceptions:

(1) Hear the warning

(2) Believe the warning is credible

(3) Confirm the threat does exist

(4) Personalize the warning to oneself and confirm that others are heeding the warning

(5) Determine whether protective action is needed

(6) Determine whether protective action is feasible

(7) Determine what action to take and take that course

The public goes through these steps each time a warning is given and ultimately decides to evacuate or shelter in place.

The manner in which a person receives the warning is also very important. People are more likely to rely on local news sources than national news sources, are more likely to rely on local authorities than peers, and are likely to rely somewhat but not greatly on the internet (Lindell 2005). Once one receives a warning they try to confirm with other people. If the warning is reported on the news and then a public official follows up and also disseminates the warning saying evacuation might be a good idea, the public is much more willing to evacuate (Baker 1991). Quarantelli (1990) also stresses the importance of personalization of the message. The public wants to feel like it is addressed to them and not a large population of people (1990). Baker (1991) seconds this saying that watches and warnings alone do not motivate people to evacuate an area. If someone walks around knocking on doors, targeting a specific population, they are more likely to listen. They have to believe the storm will hit and believe damage to themselves, their loved ones, or property is imminent to want to evacuate . It is also important for people

not at risk to be informed. One needs to know whether they are safe from an impending threat (Mileti and Sorensen 1990).

Historically, 90% of people who die in a hurricane drown in storm surge (Mileti 1999). This shows the importance of evacuation as a life saving strategy. Once one decides to evacuate it takes the public on average three hours between deciding to evacuate and reaching the main evacuation route, but it can take up to six hours for some people. This estimate includes time to prepare to leave work, travel from work to home, gather family and friends, pack essential items, protect their property, secure their home, and reach the primary evacuation road (Lindell et al. 2005). Another problem that can cause evacuation delay is waiting for missing family members. A family wants to make sure their entire "group" is safe. The best way for them to do this is to move as a whole unit. So people will wait for members to get home, or go into vulnerable areas to retrieve loved ones who do not have transportation (Quarantelli 1990). It has been found in several studies (Sorenson 2000, Lindell et al. 2005) that people do not like to leave during the night. The peak evacuation time is the morning and then the evacuation rate falls off as the day progresses.

3. Hurricane evacuation plans from other states

3.1. North Carolina hurricane plans

All information in this section is taken from the North Carolina Coastal Region Evacuation and Sheltering Standard Operating Guide (2007).

North Carolina is set up so that the Counties are ultimately responsible for preparation, and evacuation and sheltering efforts prior to and after the impact of a hurricane. They have distinguished between risk and host counties. Risk counties are those that are vulnerable to the hazard and would need to be evacuated. Host counties are the counties expected to receive the evacuees from the risk counties. They may have shelters available, or just support the evacuees on their roadways. If there is widespread devastation that becomes multijurisdictional, the state EOC and Emergency Management will intercede

and help run things smoothly. North Carolina has a timeline set up in its plans that assigns different organizations tasks and exactly what hours before a storm hits they are to be completed by. There are six phases that divide the pre-disaster, disaster, and post-disaster periods. They are preparedness (120 hours +), stand-by (120-96 hours), decision (96-72 hours), implementation (72-12 hours), storm effects (12-0 hours), and re-entry (0+ hours). The state plan divides the North Carolina Coast into three sections: Northern Coastal Plain, Central Coastal Plain, and Southern Coastal Plain. This section will focus on the Northern Coastal Plain plans. This area includes the vulnerable counties of Currituck, Camden, Pasquotank, Perquimans, Chowan, Bertie, Washington, Martin, Tyrrell, Hyde, and Dare. The Outer Banks are included in these counties. The key roadways in this area are US 158 west and US 64 west. These counties have a year round total population of about 204,000 and a summer population that quadruples mostly because of Dare and Currituck counties. Each county plans its own evacuation, coordinating its activities with neighboring risk and host counties and the North Carolina Emergency Management's Eastern Branch Regional Coordination Center. The state uses the model HURREVAC to make evacuation decisions.

For a Category 1-3 hurricane, those who live in storm surge vulnerable areas and those who live in mobile homes would be the only ones evacuated. In the event of a Category 4 or 5 hurricane a mandatory evacuation will be ordered for all of the at-risk areas. The North Carolina State Highway Patrol is the coordinating agency for all traffic related hurricane issues, including coordinating traffic control points and maintaining traffic flow from the risk counties. There is a possibility written into the plans for the reversal of Interstate 40 from Wilmington to I-95. This will help get people out faster but will only be implemented in extreme circumstances.

On a peak season day in Dare and Currituck Counties (the counties that include the Outer Banks), the time it would take to clear the entire roadway in the vulnerable areas in a Category 1 or 2 storm is found to be about 28 hours 30 minutes. But the worst household commute time, the

time it takes for a single car to clear the road network ranges from 5 hours 15 minutes to 13 hours. For a Category 3, 4, or 5 hurricane, the clearance time is about 33 hours, and worst household commute time ranges from 6 hours 15 minutes to 15 hours 15 minutes. Another way the area tries to keep traffic moving is by utilizing ferries to transport people off of the Outer Banks barrier islands. Also, there is an entire section written into the state evacuation operating guide about coordination with Virginia. Virginia shares the northern border of North Carolina so several of their planned evacuation routes eventually lead into Virginia and will effect Virginia's evacuation planning. The converse of this could also be true. Therefore the two states have border control plans known as the Barco Plan.

There is a large section devoted to the evacuation of those who do not have personal vehicles to evacuate, and those who are ill or frail, for whom evacuation is difficult. County school buses and ambulances will be used to get special needs populations to safety in shelters. They will make trips up until 12 hours before the hurricane makes landfall. To complete this time consuming process, a tiered evacuation would be ordered. The plans require four days to arrange and implement the evacuation of this population. Shelters in host counties will open two days prior to landfall and evacuation will continue until the arrival of tropical storm force winds. The most vulnerable areas essentially have all the buses and ambulances needed to complete this part of the evacuation. The shortage for most of these counties is only at most 10 buses or ambulances. Each risk county has appropriate host counties to evacuate to. In the event of a tiered evacuation, each tier has its own host county to go to as well.

After Hurricane Floyd hit North Carolina and caused huge amounts of damage, the North Carolina Department of Transportation put together a detailed report on lessons learned from the evacuation from this hurricane. They found that major congestion developed on I-40 when many

residents decided to evacuate Wilmington in a short period of time. As the storm grew closer and traffic got worse, discussions began about the implementation of contraflow on I-40, but there was never a traffic management plan to complete all the preparations. As these discussions continued traffic started to ease up. Luckily no one was stuck on the road when the hurricane hit, but if they had thousands could have lost their lives. A good lane reversal plan can help prevent this and the state realized they needed to develop criteria that dictates when the reversal of lanes would best be executed (North Carolina Department of Transportation 2000).

3.2. Texas Hurricane Evacuation Plans

The information from this section comes from the State of Texas Hurricane and Mass Care Plan (2007).

The threat of hurricanes to the State of Texas has the potential to cause catastrophic damage, mass casualties, and mass fatalities. Twenty-two counties are vulnerable to hurricane generated storm surge and coastal wind. It is important for the state to have a good evacuation plan to prevent harm on their citizens. The primary responsibility for evacuation in Texas belongs to local governments. The state assumes that local governments will develop emergency management plans to address all hazards and contain the phases of disasters: mitigation, preparedness, response, and recovery. In the instance of a catastrophic hurricane, response and recovery capabilities will also be supplemented by the State of Texas and other surrounding states through mutual aid agreements. Risk area boundaries, evacuation routes, and destination shelters do not respect jurisdictional boundaries and therefore it is essential for local governments to coordinate regionally and state-wide.

The evacuation plans of Texas are in accordance to the National Incident Management System and follow requirements in the National Response Plan. The state looks at evacuation in

four phases: (1) collection and analysis of data in order to understand the potential impact and threat, (2) Preparedness activities to make sure government officials and the public understand what actions to take and how and when to accomplish those actions, (3) implementation of evacuation operations to move people and equipment out of harms way, and (4) sheltering of evacuees in facilities.

The initial phase of evacuation is data collection and analysis. In this phase information is gathered by the Governor's Division of Emergency Management on the category of the storm threatening the coast, population characteristics to determine the number of people endangered by the storm, the local geography to locate possible shelters in the area, the infrastructure available to support evacuation operations, and the potential damage impacts of the storm. The Texas Department of Transportation collects and analyzes data to map the state-wide highway system to determine routes and traffic capacities.

Once the necessary data is compiled, preparedness actions commence. The Department of Public Safety is responsible for coordinating the direction and control of emergency evacuation traffic. These plans would establish specific evacuation routes, additional hurricane lane usage, contraflow plans along certain roads, law enforcement assignments, and traffic signal controls to ensure the most efficient movement of traffic. In this time the Department of State Health Services will develop means to identify, transport, treat, and shelter special needs populations. The Salvation Army, Texas Voluntary Organizations Active in Disaster, and the American Red Cross are agencies to help shelter and treat evacuees. The Texas Military Forces will also provide personnel to help in the evacuation of special needs populations. They will manage evacuation hubs in coastal regions and help in sheltering operations. The Texas Animal

Health Commission develops and implements plans to evacuate and shelter those individuals or families with pets.

The third phase is implementation. To implement an evacuation effectively, Texas says they must not only have low clearance times, but also coordination of evacuation information and instructions between organizations, agencies, and the public. The state mandates local jurisdictions to have working warning systems in vulnerable areas and at least a plan for a warning system to alert the special needs population. An agency called the Regional Unified Command Structure (RUCS) typically coordinates evacuation flow with other jurisdictions and states. In this phase the Department of Public Safety will make sure all at-risk areas are warned of evacuation decisions. They will also determine if more law enforcement or traffic control personnel is needed, and provide status reports with traffic counts, road closures, traffic flow problems, etc.

Texas Department of Public Safety and Texas Department of Transportation identified major evacuation routes and choke points with in vulnerable areas. Specific assignments for law enforcement control at those areas have been written into the state plan. TxDOT developed routes to control traffic so that there is a northerly evacuation flow and restrict eastern and western flow. The Department of Transportation developed contraflow plans for five of its highways: IH-45, US 290, IH-37, US 59, and IH-10. On the TxDOT website brochures on how the contraflow will be implemented can be found for each of these roadways. They can also be found translated into Spanish. They have detailed plans set up describing how to “flush” the highways that will be used for contraflow and how many troopers will be needed in each case. The activation of these steps is estimated to take no less than 12 hours to effectively pre-position resources.

Texas has a thorough and comprehensive plan for the evacuation of special needs populations. They have a Texas Radio Communications Interoperability Plan. In the event of a hurricane, or any hazard, this plan warrants the use of pre-existing public radio stations rather than trying to replace the aging public safety radio infrastructure. The state will use public school district and contracted buses, local transient systems, rail assets, aircraft, helicopters, and Emergency Services resources to make sure the movement of special needs populations is swift and efficient. If transportation resources in Texas alone are not enough to evacuate this population, Texas is part of a multi-state Emergency Management Assistance Compact (EMAC) that acquires transportation means from other states. Evacuation hubs have also been established in vulnerable areas for those that need assistance. The population would congregate at these hubs and then have some sort of transportation means come and pick them up and take them to shelters. An interesting aspect to Texas' plan to evacuate special needs people are that they will give everyone who comes to the evacuation hubs a tracking device. These will be used to ensure control of evacuees, to help locate family members who may have been split up, and to make sure there are enough shelters open for the demand of people requesting shelter. The plan includes a detailed list of items that should be available at shelters, and in particular special needs shelters.

For those who are evacuating using their personal vehicles, several measures have been made to make sure their evacuation can be as smooth as expected. Periodically along evacuation routes will be evacuation comfort stations. The public will find food, water, shelter information, and medical assistance. Also, the issue of refueling is paid special attention to. The state even developed a fuel coordination team to ensure fuel is available and able to be distributed in a crisis. Public service announcements will play five days prior to the landfall of a hurricane to

encourage both the public and private sector to fill up prior to the event while there is still time to replenish the fuel system. Air surveillance will be used to pinpoint congested areas and have fuel brought to those areas. Up to 500 law enforcement officers can be delegated to escort and accelerate the delivery of fuel.

3.3. Florida Hurricane Evacuation Plans

The content of this section was taken from the Lower Southeast Florida Hurricane Evacuation Study's Transportation Appendix (1991).

The HES identifies five traffic movements associated with evacuating for a hurricane: in county origins to in county destinations, out of county origins to in county destinations, in county origins to out of county destinations, out of county origins to out of county destinations (passing through the county), and background traffic (traffic that is not evacuating, but running errands to prepare for the storm). The planners used these movements, along with assumed conditions and behavioral responses to develop clearance times. They realized that an actual storm will differ greatly from a simulated storm developed to do the analysis. The plan outlines the variables found to have the greatest impact on clearance times and then varies them to give a wide range of data so that it could include the actual storm. To make for an easier time to evacuate the huge populations in this area of the state, the HES developed evacuation zones. These zones are based on an area's storm surge vulnerability to the different category hurricanes, as well as areas vulnerable to the wind. For example, the first zones encompass the areas that would be affected by a Category 1 hurricane. The next zones cover the areas that would be impacted by a Category 2 or 3 storm, and so on.

The plan also deals with behavioral assumptions dealing with evacuation. These include occupancy of hotel and motels, participation rates, evacuation rates, destination desires, and

vehicle uses. The study assumed 100% participation rates of those in mobile homes and surge vulnerable residents and it would take between three and nine hours for residents to prepare and then enter the evacuation route network (evacuation rate). The study chose roadways to be included in the evacuation network that had a higher road elevation, little to no tree coverage, shoulders that were structurally sound and wide, and roads that were already contained in existing evacuation routes. The evacuation will be completed upon the arrival of tropical storm force winds.

After developing all of these assumptions, the team then ran a model and found results. They ran two scenarios for each category hurricane; one scenario for a summer hurricane, and one scenario for a late fall hurricane. For a summer hurricane it is found to take anywhere from 15 hours to 37 hours to clear Palm Beach County. This includes all the traffic from Monroe, Dade, Broward, and Palm Beach Counties trying to evacuate using I-95 and the Florida Turnpike. For a late fall storm it can take anywhere from 19 hours to 42 hours to clear the same area. The study recommends lane reversal on the Florida Turnpike and I-95.

3.4. Virginia's Plans after Hurricane Isabel (2003)

Hurricane Isabel hit near Drum Inlet, North Carolina as a Category 2 hurricane on September 18, 2003. It then weakened to a tropical storm over southeastern Virginia but not without dumping huge amounts of rain and high-speed wind gusts (National Hurricane Center 2004). This hurricane was the costliest natural disaster in state history causing $925 million to $1.685 billion dollars in damage (National Hurricane Center 2004). Ten people died in Virginia as a result of the storm (National Hurricane Center 2004). In an effort to better prepare for hurricanes, Virginia has completed Hurricane Evacuation Studies.

The 2008 Virginia Hurricane Evacuation Study preliminary findings developed draft storm surge maps that told how many people would be affected by different category hurricanes. They found 176,000 people would be impacted by water alone during a Category 1 storm. A Category 2 hurricane would impact 451,000 people, a Category 3 would affect 900,000 people, and a Category 4 storm will impact just under 1.2 million residents (Virginia Emergency Management Agency 2008). The study found that only 5.8% to 7% of the vulnerable region would evacuate for a Category 1 storm whereas a Category 4 storm would cause 54.5% to 57% of the region to evacuate (Virginia Emergency Management Agency 2008). The state plans to use contraflow on the main road segment from the coast (Norfolk) inland through Richmond (I-64 to I-295). This is an 85 mile drive that usually takes around two hours. The implementation of contraflow is expected to reduce evacuation times of worst household commute times from 5 hours 15 min to 1 hour 30 minutes in a Category 1 storm and 53 hours 10 minutes to 31 hours 45 minutes in a Category 4 storm (Virginia Emergency Management Agency 2008). They have designated a few exits where evacuees will have access to gas stations, restrooms, and food (Virginia Department of Transportation 2008). One thing Virginia does to help get information out to the public is make a hurricane guide that gives advice on how to prepare for a hurricane, making kits, finding shelters, and making your own evacuation routes. It gives a map of all the preplanned routes and the vulnerable areas (Virginia Department of Transportation 2008).

3.5. Massachusetts' Plans after Hurricane Bob (1991)

The information from this section comes from the Commonwealth of Massachusetts Comprehensive Emergency Management Plan (2007) and the Cape Cod Emergency Traffic Plan (2008).

In Massachusetts, the decision to evacuate is made by the local governing body. It is assumed that municipalities will establish mutual aid agreements with neighboring jurisdictions. In the event of an evacuation covering several communities, a region, or more than one region, state assistance and support will be administered. The State Emergency Operations Center (SEOC) will be the lead agency in this type of evacuation. Some of the measures that will be made to expedite the evacuation process will be to lift tolls, coordinate regional, inter-regional, and statewide emergency communication, coordinate evacuation by identifying regional, inter-regional, and/or statewide evacuation routes; mobilizing, deploying, and placing personnel to direct traffic flow, and providing personnel and vehicles to evacuate the special needs population. They will monitor the availability of fuel, and lock down drawbridges. The SEOC will also ensure that stranded motorists on evacuation routes will be brought to shelters, and coordinate emergency medical evacuation issues with local government in the vulnerable area.

The primary agency dealing with transportation issues is the Massachusetts Highway Department. They have prioritized their allocations of resources so that the evacuation of people in immediate peril comes first, then to maintain the movement of traffic for evacuees and transportation of emergency resources, and finally transporting personnel, materials, equipment, and other resources to assist local governments.

Massachusetts has a special traffic plan for evacuating Cape Cod. This is an area that has limited roadways and is also very vulnerable to hurricanes and floods. It is imperative to keep traffic moving in this area. The best way to accomplish this is to keep traffic moving near the Sagamore and Bourne Bridge areas. The main roads along the Cape are US 6 and SR 28. Traffic control will be set up to restrict off-Cape access to these roads near the bridges. Law enforcement will also control access to exits for “Cross Cape” scenic highway and create

flexibility in opening and closing of exits in order to quickly usher off-Cape traffic across the bridges. There are set secondary evacuation roads for those planning on leaving the Cape, and those that are sheltering locally. These new traffic patterns will be accomplished through the control of Massachusetts State Police, prepositioned information signs, and periodic media announcements. At 70 mph wind gusts, the Army Corps of Engineers will shut down the Sagamore and Bourne Bridges. Motorists still on the road will be directed to appropriate detours and shelters. One of the main shelters will be the Mass Military Reservation Shelter. A table top exercise of this plan is completed each year and revisions are made.

4. Delaware' s Evacuation Plans

Delaware's evacuation plans can be taken from the All Hazards Evacuation Annex (2005-2006) for each of the three counties. All of the counties in Delaware are potentially vulnerable to some level of tidal inundation from a hurricane or a storm. In this section I discuss the plans developed by each of the three counties in Delaware.

The state of Delaware has established levels of response, 1 through 4, that relate to the "level" of impact an event has on the transportation system. One is the lowest impact and four has the greatest impact. These levels allow the counties to assign their various resources (people, equipment, vehicles, machines) and how many of each will be needed. This can reduce the time associated with delegating roles and mobilization. Hurricanes fall under level four, therefore that is the only level that will be discussed in this paper. The agencies that are expected to participate in some way during an evacuation are generally the same across all three counties. They are outlined in the chart below.

Agency/Organization	New Castle	Kent	Sussex
DelDOT	X	X	X
DEMA	X	X	X
County EOC	X	X	X
County Communications Center	X	X	
DE State Police	X	X	X
Local Law Enforcement	X	X	X
DNREC	X	X	X
Emergency Support Agencies	X		X
Department of Health and Social Services	X	X	
Public Utilities	X	X	X
DE National Guard	X	X	X
Fire Departments	X	X	X
Local Emergency Management Agencies	X	X	X

DelDOT, DEMA, and the state police will be the most active participants in the event of an evacuation. DelDOT is responsible for activating traffic control plans and placing resources such as Dynamic Message Signs, detour signs, cones, and barricades into position at critical locations. They must clear any maintenance operations or roadwork along evacuation routes. One of the biggest tasks is to activate the evacuation routes and set up traffic control measures to provide maximum flow. They must also impose mandatory traffic control to direct vehicles to designated evacuation routes. DelDOT will coordinate with state and county EOC's and emergency managers to disseminate instructions, warnings, and advice to the public. DelDOT developed an Evacuation Model that is used alongside the Statewide Travel Demand Model. These two models will allow DelDOT to evaluate traffic patterns, impacts of instituting contraflow, impacts of changes to intersection operations, impacts of evacuation start times and populations, and many other "what if" scenarios.

DEMA will ensure evacuation decisions will be able to be completed before the arrival of gale force winds (39 mph). They will use the Emergency Alert System and Delaware Emergency Notification System to get needed information out to the public. They will emphasize the immediate evacuation of all

campers and mobile homes, as well as have some members of their team go door-to-door recommending evacuation to residents who live in beach or coastal areas who refuse to leave.

Delaware State Police and Local Law Enforcement will limit all incoming traffic on evacuation routes to emergency vehicles and personnel. Their last job is to block all access to evacuation routes once evacuation is completed, and also to setup patrols to guard the property of evacuated residents.

4.1. New Castle County

New Castle County is the northern-most county in Delaware. Based on the 2000 census, it is the home to approximately 500,265 people or 188,935 households. Although, this county is not located next to the ocean, is does have a coast along the Delaware Bay and numerous freshwater river, lakes, and streams. The US Army Corps of Engineers determined that New Castle County is potentially vulnerable to some level of tidal inundation from a hurricane. Three percent of New Castle County's housing units are mobile homes and are susceptible to damage cause by severe winds, and would need to be evacuated. It is estimated that 8,508 housing units, 82 mobile homes, and 24 seasonal houses in New Castle County would be vulnerable to some level of tidal inundation or storm surge due to a category 1-4 hurricane. The 2005 Delaware Hurricane Evacuation Study estimated that a total of 26,000 to 27,000 vehicles could potentially evacuate. Since New Castle County is the northern-most county, it will also have to sustain the traffic coming northward from the rest of the peninsula. This includes 46,000-69,000 vehicles exiting from Sussex County and 18,000-19,000 vehicles from Kent County.

County emergency efforts will be coordinated and directed from the New Castle County Emergency Operations Center (NCCEOC). The county also developed the New Castle County Emergency Communications Center (NCCECC). This center dispatches fire and emergency medical services, and county and state police. This is the central coordinating station until the NCCEOC is activated. At a level of impact 4, the New Castle County and state Emergency Operations Centers (EOC) will be activated.

The evacuation routes in New Castle County are outlined in this section. They are broken up into three categories: primary, secondary, and local routes. Primary routes are the main highway arteries that can sustain a high traffic demand. It is also assumed that traffic flow will continue normally along these routes. It is expected that evacuees will use the outbound lanes and emergency vehicles using the inbound lanes. All of these routes should be signed. The New Castle County Transportation Management Team developed 5 different evacuation scenarios that could affect the county and routes for each. These scenarios evacuate the County if a hurricane hits the southern Delmarva peninsula and directs evacuees through New Castle County to major interstates, if a hurricane hits southern New Castle County directly, and then plans that evacuate three of the county's more populated areas of Wilmington, Newark, and Middletown. The tables below outline these routes.

Table 1. Primary Evacuation Routes for a Hurricane Affecting Southern Delmarva Peninsula

ROUTE	FROM	TO
SR 1	New Castle/Kent County border	I-95
US 13	New Castle/Kent County border	I-295
US 301/SR 896	DE/MD border	I-95

Table 2. Primary Evacuation Routes for a Hurricane Affecting Southern New Castle County Directly

ROUTE	FROM	TO
SR 72	Delaware City	US 13
SR 273	City of New Castle	I-95
SR 141	City of New Castle	I-95
Pennsylvania Ave.	Delaware Ave.	DE/PA border
South Heald St./ 4th St.	South Market St.	I-495
Concord Ave.	North Market St.	DE/PA border
North East Blvd.	11th St.	US 13
Maryland Ave.	Lancaster Ave./ MLK Blvd.	SR 141
South Market St.	4th St.	I-495
North Market St.	12th St.	I-95
Lancaster Ave.	Union St.	DE/PA border
South Union St.	Pennsylvania Ave.	SR 141
SR 141	SR 2	I-95

Table 3. Primary Evacuation Routes for Emergency Evacuation of New Castle County Cities

ROUTE	FROM	TO	EVACUATING…
Pennsylvania Ave.	Delaware Ave.	DE/PA border	Wilmington
South Heald St. 4th St.	South Market St.	I-495	Wilmington
Concord Ave.	North Market St.	DE/PA border	Wilmington
North East Blvd.	11th St.	US 13	Wilmington
Maryland Ave.	Lancaster Ave./ MLK Blvd.	SR 141	Wilmington
South Market St.	4th St.	I-495	Wilmington
North Market St.	12th St.	I-95	Wilmington
Lancaster Ave.	Union St.	DE/PA border	Wilmington
South Union St.	Pennsylvania Ave.	SR 141	Wilmington
SR 141	SR 2	I-95	Wilmington
SR 896	SR 273	DE/MD border	Newark
SR 896	SR 4	I-95	Newark
SR 273	SR 72	DE/MD border	Newark
SR 273	SR 72	I-95	Newark
SR 2	SR 273	DE/MD border	Newark
SR 2	SR 273	SR 141	Newark
SR 141	SR 2	I-95	Newark
SR 72	SR 273	US 13	Newark
SR 4	SR 2	SR 273	Newark
US 301	Middletown border	SR 896	Middletown
SR 896	US 301	I-95	Middletown
SR 896	US 301	SR 1	Middletown
SR 71	SR 299	SR1	Middletown

Secondary evacuation routes direct local traffic to the primary evacuation routes and can reroute traffic if the primary routes reach their capacity. All secondary evacuation routes should be signed.

Table 4. Secondary Evacuation Routes for a Hurricane Affecting Southern Delmarva Peninsula

ROUTE	FROM	TO
SR 9	New Castle/Kent County border	SR 299
SR 299	SR 9	

Table 5. Secondary Evacuation Routes for Emergency Evacuation of Middletown

ROUTE	FROM	TO
SR 299	SR 71	SR1

Local routes are roads that are not primary or secondary routes. They are generally smaller and will get evacuees to the other routes. Local municipalities will perform traffic control along these roads.

4.2. Kent County

Kent County is the middle county of Delaware's three counties. According to the 2000 census it has a population of about 126,697 people or 47,224 households. The state capital of Dover is located in this county. The U.S. Army Corps of Engineers declared that Kent County is potentially vulnerable to tidal inundation from a hurricane. The coastal areas in Kent County are becoming more common tourist destinations, a population that would need to be evacuated in the event of a hurricane. All of the 9,400 mobile homes would also have to be evacuated. These comprise 19% of the county's housing units. Also, 4,180 homes, 740 mobile homes, and 172 seasonal houses are vulnerable to water or wind damage from a Category 1-4 hurricane, and 54 hotel or motel units are vulnerable to some level of tidal inundation from a Category 4 hurricane. The 2005 Hurricane Evacuation Study estimated 18,000 to 19,000 vehicles would evacuate from Kent County. This county also has to account for the 46,000 to 69,000 vehicles passing through Kent County from Sussex County.

County emergency efforts will be coordinated and directed from the Kent Emergency Operations Center (KEOC). The county also developed the Kent County Emergency Dispatch Center (E911). This center dispatches fire and emergency medical services (KENT CENTER), and state police (KENT COM). Kent County also has their own levels of impact on the transportation system (A:ALPHA, B:BRAVO, C:CHARLIE, D:DELTA) that correspond to the state's numbered system. Level A is the same as a level 1 and level D is the same as a level 4. A level D or 4 corresponds to a hurricane threat and the Kent County and state Emergency Operations Centers (EOC) will be activated. Each organization knows what they are supposed to do and who to report to. DEMA will consider the relocation of the county EOC if conditions force relocation.

The DelDOT Transportation Management Center and the Kent County Transportation Management Team will maintain 24-hour operations from the beginning of an evacuation through the execution of a recovery plan. They also have to notify Delmarva Emergency Task Force (DETF) and adjacent states of their traffic plans and road status. A subsection of DelDOT is the Delaware Transit Corporation (DTC) which is charged to pick up those who need transportation to get to shelters.

The evacuation routes in Kent County will be outlined in this section. They are broken up into three categories: primary, secondary, and local routes. Primary routes are those that have unlimited access. They have many entrances and exits and is hard to limit who gets on the roadway. It is also assumed that traffic flow will continue normally along these routes. It is expected that evacuees will use the outbound lanes and emergency vehicles using the inbound lanes. All of these routes should be signed. Kent County is set up to have evacuation routes running North and South which are the main highways, and then to have East/West running routes to get vehicles to these North/South running routes.

Table 6. Primary Evacuation Routes (North/South)

ROUTE	FROM	TO
SR 1	Kent/Sussex County border	Kent/New Castle County border
US 13	Kent/Sussex County border	Kent/New Castle County border
US 113	Kent/Sussex County border	US 13

Table 7. Primary Evacuation Routes (East/West)

ROUTE	FROM	TO
Woodland Beach Road	Delaware Bay	SR 9
Port Mahon Road	Delaware Bay	SR 9
Pickering Beach Road	Delaware Bay	SR 9
Kitts Hummock Road	Delaware Bay	SR 9
Bowers Beach Road	Delaware Bay	SR 1
Milford Neck Road	Delaware Bay	SR 1
Thompsonville Road	Delaware Bay	SR 1
Big Stone Beach Road	Delaware Bay	SR 1

Secondary evacuation routes direct local traffic to the primary evacuation routes and can reroute traffic if the primary routes reach their capacity. All secondary evacuation routes should be signed.

Table 8. Secondary Evacuation Routes (North/South)

ROUTE	FROM	TO
SR 9	SR 1	Kent/New Castle County border

Table 9. Secondary Evacuation Routes (East/West)

ROUTE	FROM	TO
SR 300	US 13	DE/MD border
SR 42	SR 9	SR 1
SR 8	SR 9	DE/MD border
SR 15	SR 14	US 13
SR 12	SR 1	US 13
SR 14	SR1	DE/MD border

Local routes are roads that are not primary or secondary routes. They are generally smaller and will get evacuees to the other routes. Local municipalities will perform traffic control along these roads.

4.3. Sussex County

Sussex County is the southern-most county in Delaware. It has a long shoreline that has barrier islands, inlets, and small bays. This makes for a very vulnerable area for floods and hurricanes. About 90% of Delaware's housing that is vulnerable to coastal flooding (a Category 2 hurricane) is located in Sussex County. What makes the coast even more vulnerable is the touristy nature of the at-risk areas. A large amount of hotel or motel units are located in or near Sussex County storm surge and flooding areas. In addition, 92% of the Category 2 flood vulnerable housing and 59% of Category 4 flood vulnerable housing in Delaware is located in Sussex County. This will cause a huge number of people to evacuate the area, especially with such a large tourist industry. The 2005 HES estimated 46,000 to 69,000 vehicles will evacuate the County. Twenty-four hours before the onset of gale force winds the Governor will advise a voluntary evacuation of Sussex County.

The evacuation routes in Sussex County will be outlined in this section. They are broken up into three categories: primary, secondary, and local routes. Primary routes are those that have unlimited access. They have many entrances and exits and would be hard to limit who gets on the roadway. It is also assumed that traffic flow will continue normally along these routes. It is expected that evacuees will use the outbound lanes and emergency vehicles using the inbound lanes. All of these routes should be signed. DelDOT developed several routes to get beach traffic away from the at-risk area and to primary evacuation routes without all taking the same roads.

Fenwick Island: All evacuating vehicles from this area and Northern Ocean City, MD will be routed west on SR 54 towards Selbyville.

South Bethany/ Bethany Beach: All evacuating vehicles from this area will be routed west on SR 26 towards Dagsboro.

Dewey Beach/ Rehoboth Beach: All evacuating vehicles from this area will be routed north on SR 1 towards Five Points.

Lewes: All evacuating vehicles from this area will be routed west on US 9 towards Georgetown and/or north on SR 1 to continue north on SR 1 towards Milford or to travel west on SR 16 towards Milton and Ellendale.

Table 10. Primary Evacuation Route (North/South)

ROUTE	FROM	TO
SR 1	Maryland border	Kent County border
DEL 5/ DEL 23	Masseys Landing	US 9/ DEL 404
DEL 20	DEL 54	DEL 26
US 113	Maryland border	Kent County border
US 13	Maryland border	Kent County border
DEL 30	US 9/ DEL 404	Kent County border

Table 11. Primary Evacuation Routes (East/West)

ROUTE	FROM	TO
DEL 24	DEL 5	DEL 20
DEL 54	SR 1	US 113
DEL 26	SR 1	US 113
DEL 9/ DEL 404	SR 1	US 113
DEL 404	US 113	Maryland border
DEL 16	SR 1	Maryland border

Secondary evacuation routes direct local traffic to the primary evacuation routes and can reroute traffic if the primary routes reach their capacity. All secondary evacuation routes should be signed.

Table 12. Secondary Evacuation Routes (East/West)

ROUTE	FROM	TO
DEL 24	DEL 24/ DEL 26	US 13
DEL 20	US 113	US 13
DEL 26	US 113	DEL 24
Redden Road (Rd 40)	US 113	US 13
DEL 5	Williams Farm Road	SR 1
US 9	US 13	US 113
DEL 30	DEL 26	DEL 24

Local routes are roads that are not primary or secondary routes. They are generally smaller and will get evacuees to the other routes. Local municipalities will perform traffic control along these roads.

DelDOT developed a travel model to determine the evacuation times along evacuation routes in the resort areas. This area is defined by US 9 to the north, Maryland state line to the south, US 113 to the west, and Atlantic Ocean to the east. Inputs to the model include existing traffic volumes, posted speeds, roadway types, origin/ destination data (o/d data), and route choice data. This model assumes all roads are open and a constant demand throughout the evacuation period. This means a constant number of people would want to leave the area throughout the evacuation period, no peak times. Using these assumptions it is estimated to take 24 hours to process the travel demand and evacuate the vulnerable populations. The estimated evacuation times found by DelDOT for various routes are listed in the table below.

Figure 2. Map of Sussex County

Table 13. Evacuation Times on Designated Evacuation Routes

CORRIDOR	SUMMER VOLUME	VPH	ESTIMATED EVAC TIME (HRS)
SR 1	20,000-26,000	1,600	12.5 – 16.25
US 9	16,000-22,000	800	20.0 – 27.5
SR 24	15,000-20,000	800	18.7 – 25.0
SR 26	9,000-11,000	800	11.2 – 13.7
SR 54	22,000-45,000	800	20.0 – 25.0

4.4. Behavioral Assumptions for Delmarva Hurricane Planning

Information from this section is found in the Behavioral Assumptions for Hurricane Evacuation Planning in the Delmarva Peninsula (2003).

Part of a Hurricane Evacuation Study (HES) is a behavioral analysis. This is to try to predict how the public in a vulnerable area will act if a hurricane were to threaten their coast. The Army Corps of Engineers compiled a behavioral analysis for the Delmarva Peninsula's HES. They wanted to see the

number of households that would plan to evacuate and how many cars they would use, to input these numbers into the various models to come up with expected clearance times. In most cases, prior experience as well as expected behavior is used to get an estimate. In Delmarva's case, the only prior experience people had, was with Hurricane Gloria in 1985. In November and December 2002, around 700 residents were interviewed by phone. People were interviewed in various risk locations (i.e. at-risk to Category 1 storms up to Category 4 storms, and also residents that would not be at-risk to storm surge) across the Peninsula. The locations were broken up into eight categories: (1) those living along the Delaware Bay north of Rehoboth, (2) The Delaware Atlantic Beaches, (3) the Delaware Atlantic Mainland (this includes areas that are on the Delaware or Indian River Bays that are subject to storm surge), (4) Ocean City Beach, (5) Ocean City Mainland (the inland areas around Ocean City that are subject to storm surge), (6) the Southern Peninsula (Virginia), (7) the Chesapeake Bay, and (8) non-surge areas. The study found an under response of high-risk locations, and over response from low-risk locations. There was little difference in the perceived vulnerability and evacuation intentions among Category 2,3, and 4 surge area residents.

The study found approximate evacuation participation rates. It was assumed that a mandatory evacuation order was issued for areas that have possible tidal inundation by a storm and all mobile homes. It was also assumed that the evacuation orders were communicated aggressively. The following tables show the results.

Table 13. Participation Rate of Non-mobile Homes (%)

RISK ZONE	CATEGORY 1 STORM	CATEGORY 2 STORM	CATEGORY 3 STORM
Non-surge	30	40	45
Category 2-4	40	50	70
Category 1	50	60	80

Table 14. Participation Rates of Mobile Homes (%)

RISK ZONE	CATEGORY 1 STORM	CATEGORY 2 STORM	CATEGORY 3 STORM
Non-surge	50	60	65
Category 2-4	60	70	80
Category 1	65	75	95

Residential households are expected to use on average 65% - 70% of available vehicles to evacuate. This averages to 1.3 vehicles per household. Also to be kept in consideration is that 7% of evacuating residents will pull trailers or take motor homes or campers. These vehicles take up more room on the road and need to be factored in too.

Timing is another important issue in evacuation that is dictated by human behavior. Fewer than 20% of evacuees leave before an official evacuation order is issued. Those that analyzed the study results found three different timing response curves that are illustrated in the below figure.

Figure 3. Cumulative evacuation response curves. From Behavioral Assumptions for Hurricane Evacuation Planning in the Delmarva Peninsula (pg. 33)

Some evacuees will leave shortly after the evacuation order is given during daylight hours, then departures will basically stop when night falls, and pick up again the next morning.

Thirty-six percent of Delmarva residents say they will take advantage of shelters. The authors of the study, however, believe that this number is grossly overestimated. Most of the time half as many people go to shelters as originally planned. 20% of residents say they will take refuge in a hotel or motel, shelter, or friend or family's house in their own neighborhood, 25% say they will take refuge in their own

County, 25% would shelter elsewhere on the Delmarva Peninsula, and 30% would shelter off of Delmarva.

A main part of an evacuation on the Delmarva Peninsula would be tourists. There is little data on this subject. A survey of vacationers was not completed in the 2005 Hurricane Evacuation Study. There were assumptions made on this population based on intended-response survey findings with tourists to other locations and existing data on how tourists respond in general. Surveys were conducted previously in beach areas of Delaware and Maryland on the Peninsula, and Virginia Beach. It was believed that 90% to 95% of vacationers will evacuate if the orders are issued. At most 5% will go to shelters and 5% will go to a hotel or motel, but the rest will drive home. More than 95% of tourists to the Delmarva Peninsula drive from their home to their destination using their own personal vehicles. The time they will evacuate follows the same curve as the residential evacuation response curve.

5. Analysis of Delaware's Plans

5.1 Rehoboth as a case study

Rehoboth Beach is one of the beach towns in Delaware. It has a residential population of 1,260 but in the summer, peak hurricane season, this number swells to around 75,000 residents and tourists (http://www.sussexcountyonline.com/towns/ rehobothbeach.html).

In this section, I compiled some basic calculations for evacuating this one beach to assess the validity of the numbers Delaware's plans developed. The Delaware plans assume the best case scenario with free flowing traffic and constant demand throughout the day; here I will assume a more realistic scenario.

ASSUMPTIONS	
My Assumptions	**Delaware's Assumptions**
75,000 residents and tourists evacuate Rehoboth (population on a typical summer day)	90,000 to 115,000 cars evacuate statewide
2.5 people per car – 30,000 cars evacuate	Constant traffic demand all day
All cars take SR 1 northbound- the most convenient way to leave Rehoboth	Open roads – free flow
Sustained speeds varying from 20mph to 5mph	24 hours to evacuate vulnerable area
18 foot cars with 2 sec spacing between	90% to 95% of tourists will evacuate

I will go through three different scenarios with varied sustained speeds in this section.

General Equations Used

v =sustained speed of vehicles in miles per hour

d=distance in between 2 cars in feet

h=the headway in feet

a=number of vehicles per lane per mile

b=number of vehicles per hour per lane

t=time to evacuate vulnerable population out of risk area

$$\frac{88\ (\frac{ft}{sec})}{60\ mph} \times v \times 2\ sec = d \quad (1)$$

$$d + 18\ ft\ car = h \quad (2)$$

$$\frac{5280}{h} = a \quad (3)$$

$$a \times v = b \quad (4)$$

$$\frac{30{,}000}{b \times 2\ lanes} = t \quad (5)$$

When v=20 mph	**When v=10 mph**	**When v=5 mph**
d = 58 *feet*	*d* = 29 *feet*	*d* = 15 *feet*
h = 76 *feet*	*h* = 47 *feet*	*h* = 33 *feet*
a = 68.8 *vehicles/lane/mi*	*a* = 112 *vehicles/lane/mi*	*a* = 160 *vehicles/lane/mi*
b = 1376 *vph/lane*	*b* = 1120 *vph/lane*	*b* = 800 *vph/lane*
t = 10.9 *hours to evacuate*	*t* = 13.4 *hours to evacuate*	*t* = 18.75 *hours to evacuate*

The time estimates developed in these calculations fit into the time estimates DelDOT developed, but these only consider one town: Rehoboth Beach. When you add in all the other

evacuees from various locations across the state and peninsula, this number is sure to increase greatly. I think this suggests the use of possibly inadequate numbers on the planner's part.

5.2. Examining the gaps

By reviewing the sociological literature and other state's plans, some clear strengths and weaknesses have developed in Delaware's evacuation plans. The table below shows some major categories in evacuation and which states include them in their plans in some way.

	Texas	North Carolina	Florida*	Virginia	Massachusetts	Delaware
Responsibility lies in local jurisdictions	X	X		X	X	
Contraflow plans	X	X	X	X		
Special Needs population evacuation plans	X	X			X	
State border control plans	X	X		X		
Detailed shelter plans	X	X			X	
Evacuation plan for pets	X					
Evacuation "comfort stations"	X	X		X		
Monitor availability of fuel and distribute	X				X	
Other means of keeping traffic flowing	X	X				
Control direction of traffic flow	X	X	X		X	X
Means for dissemination	X	X		X	X	
Highway advisory radio station	X					X
*** Not an accurate representation of Florida's plans. The transportation analysis was only found**						

The fact that Delaware is a small state in this instance can actually be a strength. In the event of a hurricane, all of Delaware's Counties will be affected. That means it is a state problem and not just individual counties like in most other hurricane prone states. Plans are then developed for each county, but compiled by the same people. This leads to a standard through each county's plans. There is no need to worry if a county left out a certain part of the plan, because they are all set up exactly the same. Delaware is actually very up to date dealing with Intelligent Transportation Systems. DelDOT owns and operates their own radio station to keep evacuees up to date on traffic conditions. This also feeds into the

idea of being a small state helps. This one radio station can broadcast over the whole state rather than just one city or county. DelDOT also has cameras set up at intersections and main stretches of roadway feeding constant and near-real time information back to DelDOT. There is also a great deal of coordination among the various agencies and organizations that are likely to respond to an evacuation. They all know their tasks, and for the most part, in a prioritized fashion. Lastly, Delaware has all of its plans, studies, and maps posted on the DelDOT website for all of the public to access. This is a useful tool that all Delawareans should know about and be able to access.

This leads me to the weaknesses. The fact that Delaware is a small state can also be a weakness. A hurricane would affect the whole state, and leave no area where resources could be pulled to help the devastated area recover. Since Delaware is so small, the only person who can order an evacuation is the governor. In all the other states I found this information for, local governments could order the evacuation. They have a better idea of when something is not right than the governor and could start an evacuation faster.

Delaware's biggest potential weakness that I can tell is its lack of communicating with the public. They have plans on the website, but who knows they are there and can easily understand them. Most other states I have read about have hurricane awareness weeks, hand out hurricane guides every year, or have public safety announcements on TV. Delaware has pamphlets on coastal storm preparedness and a brochure on the Delaware Emergency Notification System posted on the DEMA website. The state emergency management web pages for Massachusetts, Connecticut, New Jersey, North Carolina, and Florida, all have links on Hurricane preparedness on the homepage. DEMA only had a link for natural hazards, and even there the only hurricane related information was the coastal storms brochure and tips for pets and livestock in a hurricane. The internet is a great tool, but not every Delaware resident or especially tourists, have a computer hooked up to the internet in their home. Delaware should not rely solely on the internet as their way to disseminate information.

The assumptions used for the models that created the evacuation time estimates are also questionable. I wonder if those evacuating from elsewhere on the peninsula- Maryland and Virginia or shadow evacuees where considered. These two factors will greatly increase the total number of evacuating motorists. Also, DelDOT used a behavioral study conducted for the Army Corps of Engineers to determine an estimate of the number of evacuating vehicles on the roadways. This is good, but some bias was possibly developed. They conducted phone interviews with a little less than 700 residents throughout the Delmarva Peninsula in November and December. This might not be an adequate sampling of those who would inhabit the beach in the summer, which is hurricane season. The idea that there will be constant traffic demand all day is basically ruled out by research done by social scientists. A large number of people will leave in the morning and then the evacuation rate will diminish as the day progresses. It is also not written in the plans if evacuation delay is incorporated into the 24 hours it is said would take to evacuate the vulnerable area. People do not drop everything and get right into their car. They pick up family, protect their house, drive home from work, among various other tasks. This also adds to the evacuation time estimates.

I also question how much interaction Delaware has with other states if an evacuation was ordered. It seems like they made a plan to get the evacuees to state borders and then developed no other plans with bordering states. Nothing was written in the Hazards Annex stating cooperation with Pennsylvania or New Jersey. The only part of Maryland mentioned was Ocean City.

One of the recent innovations dealing with evacuation, contraflow, was not written into Delaware's plans at all. Contraflow was mentioned as being able to see the benefits of this practice with the model DelDOT developed, but no written plans have been found. Contraflow has its downfalls, but as a last case scenario to get people out quickly, it can be a great tool. There should at least be a plan, even if it is never put into practice.

Another area in which Delaware's plans are somewhat lacking is in the evacuation of special needs populations. It is said that it needs to be done, but there are no concrete plans as to how the

evacuation will be executed, using which resources. Texas plans to use contracted school buses, public transit, and even railways to evacuate those without personal vehicles and those who can not evacuate themselves. They set up evacuation hubs where these people can meet. Delaware can also improve plans to make the evacuation as smooth as possible for motorists. Comfort stations could be available like in Texas and Virginia where predetermined exits provide a place for evacuees to get off the highway and rest. A plan to monitor fuel could also be useful so motorists are not stranded on the roadway, blocking traffic flow. Lastly, some sort of sheltering plan should be included in the hazards annex. Shelters are tied to evacuation. They are possible destinations and should be incorporated into both the plans and the evacuation routes. Plans for pet owners who wish to go to shelters should also be considered. Red Cross shelters do not accept those who come with pets, and therefore, cause some in danger to stay home to be with their pet.

Delaware has a strong background in planning for an evacuation, but somewhat lacks in keeping up with current practices. It should take the lessons leaned by other states who have more experience with the natural hazard, and put them into practice in Delaware's plans. A hurricane may not hit Delaware tomorrow, but eventually it will happen and the state better be ready for it.

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