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Abstract

The Hampton Roads region of Virginia has developed a hurricane evacuation plan to facilitate the movement of large numbers of vehicles as they attempt to leave the region in advance of a storm. Although the plan considers many aspects of hurricane evacuation, this evaluation focuses on its impacts on traffic operations.

A traffic control plan (TCP) was developed that describes the procedures to be followed in the event an evacuation is ordered. Ramps providing access to I-64 are designated as open or closed, and many are metered in an attempt to influence the route choice of evacuees and thereby balance the demand across available evacuation routes. Although considerable work has gone into the development of the TCP, it has not been evaluated from a microscopic perspective to determine the performance characteristics with respect to traffic flow. This study provides that microscopic analysis for the freeway portions of the evacuation routes.

The evaluation found that under less severe hurricane conditions (Category 1 or 2), the TCP performs reasonably well under the assumptions made in this study. The most significant assumption made was that all background traffic, including individuals evacuating their homes but remaining within the region, will not use the interstates during the evacuation period. Although background traffic will likely exist, there was insufficient information available in this phase of the study to assign background traffic to the network in any reasonably accurate manner. As the intensity of the hurricane intensifies to a Category 3 or 4, the TCP begins to be less effective. Ramp metering rates, designed in the TCP to ensure free-flowing conditions on the interstate mainlines, result in significant queues at the ramps and back onto the arterial network. Under Category 4 conditions, these queues would likely result in gridlock throughout the arterial network and lead evacuees to search out alternative routes, possibly negatively impacting the performance of those routes as well. The evaluation concludes that lane reversal is warranted under any storm predicted to make landfall as a Category 4 or higher and should be strongly considered for any Category 3. The study further finds that when lane reversal is implemented, the ramp metering rates should be significantly increased to reduce ramp queuing and allow more efficient use of available mainline capacity.

The recommendations offered in this report will help to ensure an efficient evacuation of vehicles from the Hampton Roads region, should one be required. The revised ramp metering strategies and guidance on the use of lane reversal will help to maximize the available capacity provided by the interstate routes. Assumptions made throughout the study could render the results uncertain. Background traffic using the interstate routes could add to the congestion reported here. In addition, conditions outside the bounds of the network modeled in this project could negatively impact evacuating vehicles leaving Hampton Roads.

FINAL REPORT

AN OPERATIONAL ANALYSIS OF THE HAMPTON ROADS HURRICANE EVACUATION TRAFFIC CONTROL PLAN

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ABSTRACT

The Hampton Roads region of Virginia has developed a hurricane evacuation plan to facilitate the movement of large numbers of vehicles as they attempt to leave the region in advance of a storm. Although the plan considers many aspects of hurricane evacuation, this evaluation focuses on its impacts on traffic operations.

A traffic control plan (TCP) was developed that describes the procedures to be followed in the event an evacuation is ordered. Ramps providing access to I-64 are designated as open or closed, and many are metered in an attempt to influence the route choice of evacuees and thereby balance the demand across available evacuation routes. Although considerable work has gone into the development of the TCP, it has not been evaluated from a microscopic perspective to determine the performance characteristics with respect to traffic flow. This study provides that microscopic analysis for the freeway portions of the evacuation routes.

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INTRODUCTION

Hurricanes pose a significant threat to the gulf and Atlantic coastal areas of the United States. Although the gulf coast and eastern coast of Florida have been hit the hardest in recent years, damage resulting from hurricanes remains a threat in many other areas. In August of 2005, Hurricane Katrina provided a painful illustration of the damage that can result from a strong storm striking vulnerable areas. It also illustrated the importance of a comprehensive emergency management plan that includes sound evacuation strategies.

Hurricane evacuations have proven to be a difficult task from an operations point of view. Stop-and-go traffic lined up for miles is the image most people have when they think of evacuations. In more recent years, transportation professionals have joined forces with the emergency management community and police agencies to set in place plans that will help to facilitate the efficient evacuation of large numbers of vehicles from a region. The transportation community now recognizes a need for greater involvement in evacuation planning after several recent storms caused significant back-ups of evacuation traffic.

History has shown that the number of hurricanes to threaten the coastal United States tends to follow a cyclical pattern. The number of storms increased in the 1940s, 50s, and 60s, including Hurricane Camille in 1969, a Category 5 storm with a similar landfall to Hurricane Katrina. Table 1 lists the wind speeds associated with the various storm Categories according to the Saffir-Simpson Hurricane Scale.[1] Beginning in the 1970s, the storm activity lessened for several decades. Weather experts believe that 1995 marked the beginning of another active period that will likely last several decades.[2] Because the human memory is short, one of the consequences of this cyclical pattern is that during less active periods, the population and development of coastal areas increase dramatically. Although the ability to track storms has improved greatly, the exact path of any storm is difficult to predict with the accuracy necessary to spread the evacuation of coastal areas over several days in advance of landfall. With increasing populations and limited evacuation routes, this results in a very challenging situation from a transportation operations perspective.

Table 1. The Saffir-Simpson Hurricane Scale

Storm Category	Maximum and Minimum Wind Speeds
Category 1	74–95 mph
Category 2	96–110 mph
Category 3	111–130 mph
Category 4	131–155 mph
Category 5	>155 mph

All states within the hurricane threat area have hurricane evacuation plans in place to evacuate people from vulnerable areas, but the plans have been developed with varying levels of detail in terms of operational analysis of the routes designated as evacuation routes. In the 1980s, the Federal Emergency Management Agency (FEMA) encouraged the development of hurricane evacuation studies (HES) that combined a number of important components of evacuation planning into a more integrated approach. An HES consists of a storm hazard and vulnerability analysis, an evacuee behavioral analysis, a sheltering analysis, and a transportation analysis.[2] Combined, these analyses identify the areas requiring evacuation based on storm category, the number of people located within those areas, how the public will react to an evacuation order, available shelters for evacuees, and the roadway capacity of evacuation routes. Obviously, these analyses require a number of assumptions, but much knowledge has been gained in recent storms that can be used in formulating these assumptions. For example, regardless of the potential storm threat or evacuation recommendations given, there will always be people who cannot or will not evacuate. The HES attempts to take this into account in determining the number of evacuees that will be traveling out of the region or seeking refuge at local shelters.

The manner in which an evacuation order is given is important to consider. Although getting as many people out of harm's way as possible is desirable, coordinating the physical exodus of hundreds of thousands of vehicles is a carefully orchestrated process. Many states, including Virginia, use a phased evacuation in which neighborhoods considered most at risk are encouraged to evacuate first, followed by the remaining evacuation zones. Public information and education are critical in ensuring that local residents and visitors know the best route to take and when to leave. Often, not all areas in a region are at risk. A Category 1 or 2 storm, for example, may pose a significant threat to zones nearest the coast and low-lying, flood prone zones while allowing the rest of the region to avoid evacuation and in fact provide shelter to evacuees. If the wrong populations make the choice to evacuate, roadways may become unnecessarily congested and delay the evacuation of those who truly need to leave their homes. This phenomenon, known as "shadow evacuation," is a serious concern for evacuation planners.

Hurricane Evacuation in Virginia

Virginia's HES takes the form of an abbreviated transportation model (ATM.) The ATM is a series of linked spreadsheets that uses population and behavioral characteristics combined with threat assessments by geographic zone to determine the number of people (and vehicles) who will evacuate from each zone within each jurisdiction in the Hampton Roads region. Those evacuating are then further broken down into those who will evacuate the region and those who will seek shelter within the region at a public shelter, hotel/motel, or friend's or relative's home.

The total number of vehicles leaving the region is then estimated for each category of storm. The ATM assigns vehicles to one of the region's designated evacuation routes based on the origin zone. Clearance times (the time for all evacuating vehicles to leave the region) are then computed based on the total number of vehicles using each route divided by an assumed capacity of the route. This is intended to be a very high-level assessment used primarily to determine the lead time required to evacuate all vehicles before the onset of tropical storm force winds.

Hampton Roads Hurricane Traffic Control Plan

The Hampton Roads region of Virginia has developed a hurricane evacuation plan intended to facilitate the movement of large numbers of people in vehicles as they attempt to leave the region in advance of a storm. In addition to the ATM discussed previously, a traffic control plan (TCP) has been developed that provides detailed information on how evacuating traffic will be managed.[3] The intent of the plan is to provide the most efficient movement of vehicles out of the region. Ramps on I-64/I-664, the only interstate route out of the region, are designated as open or closed in an attempt to influence route choice and therefore balance demand across all available routes. In addition, the TCP uses a phased approach to ensure that those most at risk are given the opportunity to leave the region first. There are no provisions in the plan to force any individual driver to take a particular route or to leave or not leave at any given time. Public information and education campaigns are designed to encourage the public to follow official advice with respect to route and time of departure, and the TCP assumes that the majority of people will do so. In addition to I-64, Routes 17, 460, 58, 60, and 10 are all designated evacuation routes and the ATM assigns vehicles to each based on their originating zone. Figure 1 illustrates the current evacuation routes as provided by VDOT.[3]

Phase 1 of the TCP includes evacuating people from Virginia Beach, Norfolk, York, Poquoson, and parts of Hampton along with the Middle Peninsula, Northern Neck, and Eastern Shore. The Phase 1 evacuation is assumed to take place 24 to 14 hours prior to the onset of sustained tropical storm force winds (winds between 39 and 73 mph). Phase 2 evacuates those at risk in Portsmouth, Chesapeake, Suffolk, Newport News, and the remainder of Hampton and is assumed to take place beginning 14 hours prior to and ending with the onset of sustained tropical storm force winds. When large numbers of vehicles need to be evacuated, especially under the stronger storm categories, 24 hours is a very short period of time. Some regions of the United States have assumed a longer lead time for evacuation, and although this extra time makes the movement of vehicles out of the region better in terms of congestion in hurricane preparation analysis, it is often unrealistic in practical terms. Hurricanes are notoriously unpredictable and will often change course in the final days or even hours before landfall. Calling for an evacuation of a region too early can lead to the "crying wolf" syndrome when the public evacuates for what they later see as a false alarm. Those people are then much less likely to evacuate when asked to do so in the future, possibly putting themselves at risk.

In addition to the phased evacuation, a lane reversal plan has been developed to help facilitate the large number of evacuating vehicles that are anticipated under more severe storm

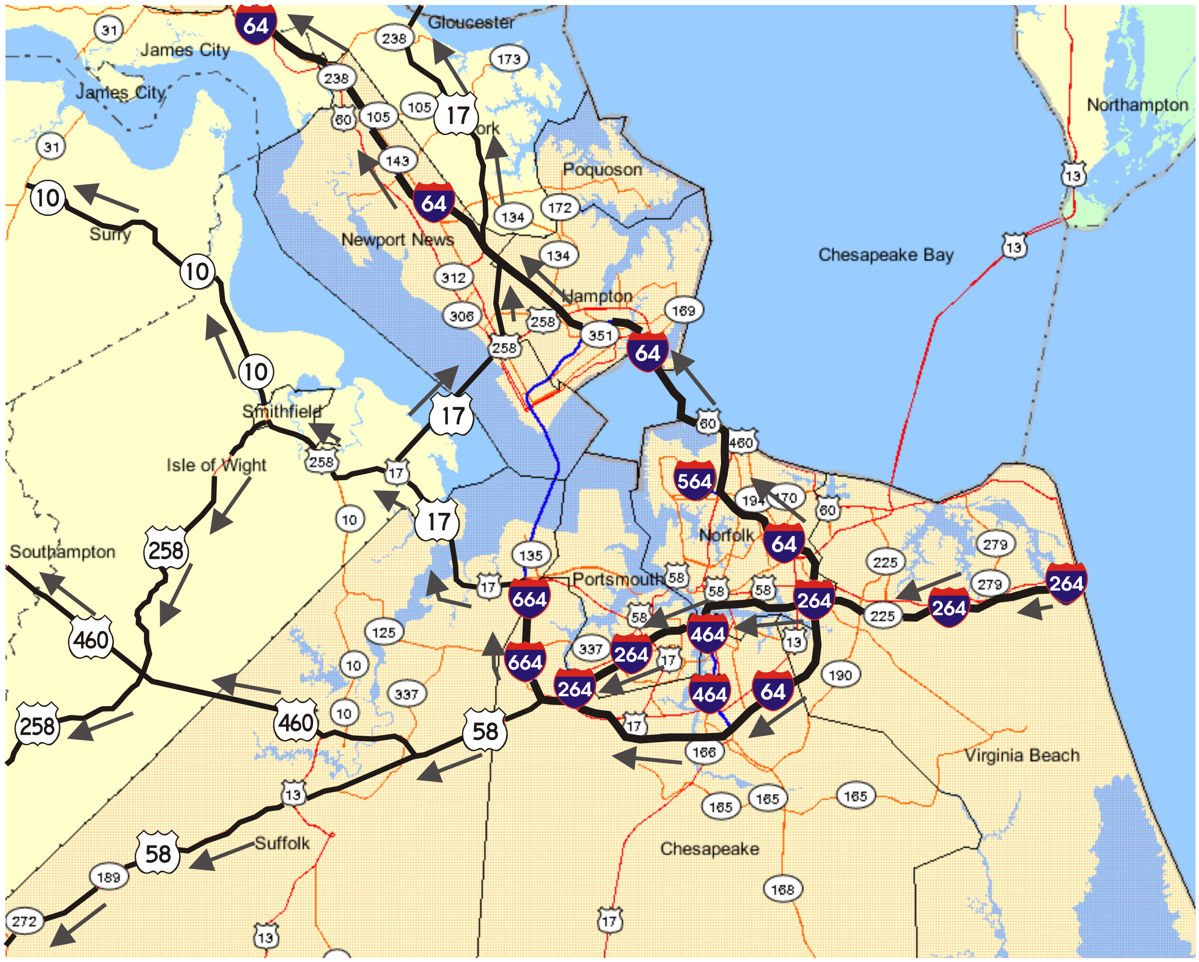

Figure 1. Hampton Roads Hurricane Evacuation Routes

conditions. Under this plan, I-64 would be dedicated to westbound (WB) traffic from just east of the Hampton Roads Bridge-Tunnel (HRBT) to just east of the I-64/I-295 interchange east of Richmond. WB traffic on I-64 on the Southside (the area of Hampton Roads south of the HRBT and Monitor-Merrimac Memorial Bridge-Tunnel [MMMBT] would be diverted to the eastbound (EB) lanes just west of the 4th View Exit by way of a two-lane crossover. This traffic would then travel through the tunnel in the EB lanes and continue WB out of the region. Exit ramps are provided in the Williamsburg area for vehicles requiring services. Traffic entering I-64 west of the HRBT will access the WB lanes and will have access to open ramps to exit the roadway or may continue out of the region. One criticism of this plan has been that only one tube of the available four (two at the HRBT and two at the MMMBT) is used for evacuating traffic. The plan was recently modified to shift the crossover several miles east such that traffic entering I-64 at 4th View enters the WB lanes and uses the WB tunnel to leave the region. The MMMBT is still not used for evacuating traffic under the current plan because of concerns that congestion would result at the merge point of I-664 and I-64 on the peninsula.

PURPOSE AND SCOPE

Much thought, effort, and resources have gone into developing Virginia's hurricane evacuation plan. As with most states, however, the operational characteristics of the plan at a microscopic level (e.g., how fast traffic will move, where the queuing will occur, how long the queues will be) are not known. The ATM adequately describes the numbers of evacuating vehicles, where they will originate, and what route the drivers will likely take as they leave the region. It does so at a macroscopic level and does not attempt to determine how vehicles will get from their origin to their desired evacuation route. The purpose of this study was to determine where trouble spots might occur based on ramp loading, mainline congestion, or other operational difficulties and to provide an opportunity to address them prior to the need to implement an evacuation of the Hampton Roads region.

Specifically, this study evaluated the TCP for Hampton Roads from a microscopic perspective to identify areas of improvement and provide an estimation of what should be expected should an evacuation be needed. The study focused on the interstate routes in the region (I-64, I-264, and I-664), but a model was developed such that the other evacuation routes could be added in future phases.

METHODOLOGY

Four tasks were undertaken to achieve the study objectives. Throughout the duration of the study, an iterative approach was taken as the need for additional scenarios was identified. For example, although the bulk of the model development work occurred up front, some modifications were required in later stages when additional scenarios were tested.

1. *Develop a model.* A microscopic simulation model approach was chosen as the best method of evaluating the performance of the TCP under the varying conditions resulting from the different storm categories. The microscopic nature of the model allows very detailed output to be obtained and the impacts of individual vehicular behavior to be considered. The microscopic nature of the model also results in a need for a great deal of data on the network geometry and operating characteristics. This task focused on obtaining the required data and creating the input files necessary for model execution.

2. *Identify and develop scenarios.* The ATM includes three storm categories (1-2, 3, and 4) and both a low- and high-occupancy volume condition for each, reflecting the impact of hotel occupancy on the number of evacuees expected. In addition to these six scenarios, two scenarios were initially developed to evaluate the performance of the lane reversal plan in the TCP and a revised lane reversal plan under development at the time. The primary difference in these last two scenarios was the location of the crossover from the WB lanes to the EB lanes. Subsequent to the evaluation of these eight initial scenarios, another set of scenarios was created to test lane reversal under more storm categories and the elimination of the phased evacuation strategy. All scenarios were developed in cooperation with the Hurricane Committee, a group that

includes representatives of the Virginia Department of Transportation (VDOT), the Virginia Department of Emergency Management (VDEM), the Virginia National Guard, the Virginia State Police (VSP), and the Hampton Roads Planning District Commission (HRPDC.)

3. *Execute the model and obtain the results.* In this task, input files created for each scenario were executed within the model to obtain results. Output files provided by the model were collected and formatted for ease of evaluation.

4. *Analyze the results and make recommendations for change.* Output from each scenario included volume and speed at designated locations, number of vehicles denied entry to the network due to excessive queuing at on-ramps, and number of vehicles eliminated from the network because of excessive delays from queuing on particular links. This output was evaluated to determine where bottlenecks were occurring in each scenario and the overall performance of the TCP. Criteria including length of queue, speed, throughput, and arterial queuing as a result of ramp delays were all considered with respect to judging overall performance. Based on the results of the scenarios evaluations, specific recommendations for modifications to the TCP were developed.

RESULTS

Model Development

The microscopic simulation model *VISSIM*, Version 4.016, was chosen as the analysis tool for this effort. It was selected because of its ability to model large networks, the flexibility in terms of handling the lane reversal scenario, the ability to code network centerlines from a GIS import, and the familiarity of the researchers with it. *VISUM*, which is a metropolitan scale travel demand modeling framework (sometimes referred to as a four-step model), was used as middleware between the geographic information system (GIS) applications and *VISSIM*. *VISUM* and *VISSIM* are both part of the *PTV Vision Suite* and, therefore, were designed to share data. The use of GIS data to code centerlines was necessary to reduce model development time and to cope with the computational difficulty in handling a mosaic of high resolution aerial photographic images for such a large area of the state.

Eight high-level steps were performed to develop the *VISSIM* model:

1. Prepare the GIS data.
2. Import shapefile into *VISUM.*
3. Correct the Inp file.
4. Code the ramp meters.
5. Develop the demand volumes.
6. Code the scenarios.
7. Code the reversal scenarios.
8. Place the detector stations for output.

Prepare GIS Data

The model was created by importing centerline data from the same spatial databases that are used to provide data to the GIS integrator. The model includes the entire freeway network from Virginia Beach to Short Pump and, in the Richmond area, from Hopewell to Ashland. For these analyses, the metropolitan Richmond section of the model was not active, and vehicles exited the network in the vicinity of the interchange of I-295 and I-64 near Seven Pines. Route 168 and the Chesapeake Expressway in Chesapeake City were not included in the model except as points of vehicle entry.

The interstate centerlines, ramps, and arterial sections were then merged into a single shapefile and imported into *VISUM*. A numeric field coded with the link type (interstate, surface, ramp, collector-distributor (CD) road) was added.

Import Shapefile into *VISUM*

When a polyline shapefile is imported into *VISUM*, an additional link, in the reversed direction, is added to each link from the shapefile. This is problematic because the interstate links in the shapefile were already unidirectional, and the ramps have only one-way traffic. These erroneous links were eliminated by exporting the link data from *VISUM* to *Excel,* manipulating and deleting the inappropriate reversed link data, and re-importing them (not as a shapefile, but as a table of links) into *VISUM.*

Data from various user-defined fields in the shapefile (e.g., number of lanes, link name) were copied to the appropriate *VISUM* fields designated to hold these data, and the network was exported as a *VISSIM* network, hereafter designated as an inp file. The advantage of these spatial data manipulation steps is that the *VISSIM* file had the number of lanes, link type (freeway, right-side-rule), and link names that proceeded along a route in an orderly fashion from one end of the network to the other.

Correct the Inp File

Despite the work of the previous steps, the inp file created was not sufficient to run the model. This is because a number of requisite inputs, such as traffic volumes and traffic control parameters, are not coded by *VISUM* unless the export to *VISSIM* is performed from a working four-step model. In this adjustment step of model design, the researchers corrected errors in the inp file and connected the model links together to form a continuous network. (When *VISUM* creates an inp file from a shapefile, the file is actually a network of unconnected links.)

After the researchers corrected the discontinuities in the simulation network, they compared it to the actual road network, as recorded by aerial photography in the GIS Integrator. Essentially, they slowly panned through the simulation network and the corresponding locations in the GIS Integrator and modified the simulation network to match the aerials. The most common modification was the creation of auxiliary lanes at interchanges and the coding of traffic flow parameters to make them function as merging and weaving sections.

Code Ramp Meters

The researchers coded the ramp meters indicated in the TCP as fixed time signals. In some cases, an exact match for the meter rate could not be obtained; however, in these cases, the deviation was on the order of four vehicles per hour (vph).

Develop Demand Volumes

The ATM is based on tracts and population data from the 2000 U.S. Census. The researchers also obtained maps (non-digital) prepared by the U.S. Army Corps of Engineers showing these tracts and referencing them to the ATM tables of evacuating population and destination (Richmond by way of I-64, Fredericksburg by way of U.S. 17, or Southside by way of U.S. 58 or U.S. 460).[4] Using these maps and the ATM data, the researchers manually assigned the evacuating traffic from each census tract to a logical interstate on-ramp. Although the simulation model does not have a surface street network, some evacuating traffic that eventually would use one of the arterial routes mentioned was assumed to travel on an interstate to reach the arterial, e.g., using I-64 WB to U.S. 17 North at Exit 258, and was therefore included in the model. The product of this step was essentially a set of origin-destination tables. The researchers combined these into a single table, normalized it, and imported it into a relational database using Microsoft Access as the relational database management system.

Code Scenarios

The ATM has six evacuee scenarios reflecting combinations of storm intensity (Saffir-Simpson scale) and hotel occupancy (*L* for low occupancy, *H* for high.) Storm categories 1 and 2 and 4 and 5 are combined into one category by the ATM. The researchers expanded the six ATM categories to eight; the additional two scenarios were for testing two different EB I-64 lane reversal scenarios.

Scenarios 1-2L through 4H use the same geometric and traffic control parameters in the simulation model; the reversal scenarios 4r and 4r-old (Category 4 storm with lane reversal under the new and old plans, respectively) differ, but only in that the EB lanes of I-64 are reversed at the crossovers. The old reversal scenario places the crossover at the 15th View interchange, and the new reversal scenario places the crossover at the 4th View interchange. There are more than 200 separate volume inputs in each scenario that vary with each scenario except the two reversal scenarios, which use the same traffic volumes as does 4H but use different lane reversal crossover locations.

Typically, when a simulation model is developed, it is validated by calibrating it against observed conditions such as volume counts or travel times. However, since the researchers were modeling hypothetical traffic scenarios, it was impossible conduct this step of the model development process in this phase of the study. However, an inspection of the results suggests that the speed profiles, which inherently reflect varying traffic density, are consistent with traffic flow theory.

Code Reversal Scenarios

Once the non-reversal scenarios were finalized, the researches used the 4H scenario as a base for the reversal scenarios. *VISSIM* has a feature that allows a user to reverse the direction of a link; however, the connectors (special short segments that connect links) must be deleted and recreated. *VISSIM* also has the capability to create a network from separate inp files. To increase the efficiency of the coding process, the researchers created an inp file representing only the EB lanes of I-64 from approximately mile 274 to approximately mile 200. They reversed the links, recreated the connectors, and stored the network as a separate inp file. This separate file was then merged with the inp file containing the remainder of the network sans EB lanes and saved as a working reversal scenario. The advantage of saving the reversed lanes as a separate file is that the time-consuming work of deleting and recreating connectors was necessary only once. Two separate networks were created from this reversal base inp file, one with a crossover at the 4th View interchange and the other at the 15th View interchange. Last, the researchers placed data collection stations upstream and downstream of the crossovers and reduced the speed on the crossovers to 45 mph.

Place Detector Stations for Output

After the geometry, traffic controls and flow parameters, and demand volumes were coded, virtual "count stations" were placed in the model between major interchanges on I-64; upstream of both the downtown tunnel and the Berkley Bridge on I-264 WB; both tubes of the HRBT; near the reversal crossovers; and at the flyover from I 664 WB to I 64 WB. These virtual count stations consisted of virtual double-loop detectors in each lane of the road cross section and were programmed to collect instantaneous spot speed and volume in hourly increments. *VISSIM* count stations are similar to their real-world counterparts.

Scenario Identification and Development

Analysis Assumptions

Although the majority of data required for this analysis was drawn directly from the ATM and the TCP, a number of assumptions and simplifications was required where data were incomplete or unavailable. These are discussed briefly here.

Background traffic. In addition to the evacuating traffic from each zone in the region, there will be some level of background traffic. In this report, *background traffic* refers to vehicular traffic within the network that is not included in the traffic evacuating from the region. As such, background traffic will include pre-evacuation trips made in preparation for evacuation, trips made to gather supplies by those who do not intend to evacuate, and trips made by those evacuating from their homes but not leaving the region. With the exception of the last category (in-region evacuees), the ATM uses a percentage factor to account for the background traffic on major links in the network. Because the researchers started at each origin and assigned traffic to routes according to their destination (evacuation route), it was not possible to use a simple factor to account for background traffic. Without knowledge of where the vehicles were coming from or going to, it was impossible to assign them to the network. It is improbable that all background traffic will use the surface streets and avoid the interstates that are the focus of this phase of the evaluation, but lacking better information, the researchers had to make this assumption. In the scenarios added after the initial set, all volumes were increased by 10 percent and a minimum level of traffic was assumed to enter the region from North Carolina in an attempt to provide some level of background traffic.

Ramp loading. Although the percentage of vehicles using each route was taken from the ATM, the ramp they would use to access I-64 (if I-64 was their chosen route or if they chose to take I-64 to their route) had to be determined manually. In many cases, multiple routes could be used to travel from the origin zone to I-64, resulting in different ramps used for entry to the freeway for a single origin zone. In these cases, an effort was made to balance the demand across all available entry ramps such that no one ramp would be inundated. The volumes by ramp for each storm category are given in Table 2. In addition to background traffic there is an issue of vehicles that are evacuating within the region. This analysis is based on vehicles that are leaving the region on one of the designated evacuation routes. The ATM includes data on vehicles whose drivers will evacuate their place of residence but stay within the region at a shelter, hotel/motel, or the home of a friend or relative. The number of these vehicles is often as high as those leaving the region, meaning that the current analysis considers only half of the evacuating traffic. The reason those not leaving the region are not included is that no information is currently available that describes where these vehicles are going. Without some idea of their destination, it is impossible to place them on the network. If vehicles from Virginia Beach zones are assumed to be headed for inland areas in Hampton, they would likely travel on I-64 WB through the HRBT, which would have a huge impact on those links. If instead they are assumed to be headed west to Chesapeake, they would use entirely different routes with different impacts to the network.

Table 2. Phase 1 Evacuation (Out of Region) Volumes by Ramp

Metering Rate (vph)	WB I-64 Ramp	Demand by Storm Category (Vehicles)					
		1-2L	1-2H	3L	3H	4L	4H
None	234	25	25	102	102	166	166
None	243	16	17	38	39	107	113
120	256	501	501	2232	2328	5850	5946
420	263	3155	3155	4367	4447	10088	10167
420	265	753	753	1025	1025	1563	1563
420	273	3036	4595	3836	5459	5578	7318
360	Granby	175	189	2756	2806	5006	5057
300	277	1069	1415	3757	4096	6173	6584
480	279	525	938	2482	3144	8424	9115
480	282	2781	3432	4035	4550	10196	10780
240	284 (I-264)	139	271	840	1075	1659	1893
None	289	462	690	1020	1175	3534	3715
None	291	50	125	101	105	379	407

Metering rates. The TCP includes metering rates for a majority of the open ramps providing access to WB I-64 and a number of ramps providing access to EB I-64 (used as a means of accessing Routes 58 and 460.) The metering rates were designed to ensure free flowing traffic on the mainline, and in some cases may be excessively restrictive. The TCP assumes that the metering will be deployed by means of a state police trooper at each ramp as opposed to an actual ramp meter. Within VISSIM, fixed time signals were used to model this manual metering.

Table 3 shows the metering rate for each entry point. In the latter scenarios, these rates were modified in an attempt to balance ramp demand and mainline performance.

Table 3. Interstate Ramp Metering Rates

Entry Point	Phase 1		Phase 2	
	WB	**EB**	**WB**	**EB**
4th View (Ex. 273)	420 vph	180 vph	360 vph	180 vph
Bay Ave (Ex. 274)	No ramp	180 vph	No ramp	180 vph
Granby St.	240 vph		360 vph	
I-564 (Ex. 276)	Closed	480 vph (2 lanes)	Closed	360 vph (2 lanes)
Tidewater Dr. (Ex. 277)	300 vph (No EB Rt. 168)	360 vph	360 vph	180 vph
Chesapeake Blvd. (Ex. 278)	Closed	Closed	Closed	Closed
Norview Ave. (Ex. 279)	480 vph	360 vph (No WB Norview)	200 vph	360 vph
Military Hwy. (Ex. 281)	Closed	No ramp	Closed	No ramp
Northampton Blvd. (Ex. 282)	480 vph	300 vph	480 vph	300 vph
I-264 (Ex. 284)	240 vph (from EB I-264 only)	900 vph (2 lanes)	240 vph (from EB I-264 only)	900 vph (2 lanes)
Indian River Rd. (Ex. 286)	Closed	240 vph (2 lanes, NB/SB)	Closed	180 vph (2 lanes, NB/SB)
Greenbrier Pkwy. (Ex. 289)	No meter	Closed	No meter	360 vph (2 lanes, SB/NB)
Battlefield Blvd. (290)	No meter	Closed	No meter	480 vph (2 lanes, SB/NB)
I-464 (Ex. 291)	No meter	480 vph	No meter	420 vph

Temporal distribution of traffic. Clearly not all evacuating vehicles will depart from their origins the moment an evacuation is called for. Neither will the demand be uniformly distributed across the time period available. Experience has shown that a significant percentage of the evacuating traffic will depart several hours after the evacuation order is given in a surge of demand. Compounding this issue is the fact that hurricanes may make landfall at any time of the night or day, making the timing of the evacuation order even more difficult. Fewer people will be aware of an order given in the middle of the night. This analysis has assumed unlimited daylight hours as a simplification of the problem. More analysis will be needed to determine the impact of nocturnal hurricane approaches. The distribution of demand over time used in the model is shown in Table 4. Note that the Phase 1 and Phase 2 evacuation flows are assumed to have different characteristics. There is an assumed delay between the evacuation order and significant movement of vehicles out of the region. This is due to the need to prepare, travel from work or other locations away from home to gather with other family members, etc., prior to evacuation. Since the Phase 2 evacuees have the benefit of the previous phase, they will likely

Table 4. Temporal Distribution of Traffic Demand

Start Hour	End Hour	% of Total Demand	Evacuation Phase
0	5	10	1
5	10	60	1
10	14	20	1
14	24	10	1
14	18	60	2
18	24	40	2

be more prepared when the order is given for Phase 2, which will result in a more immediate response.

The temporal distribution was altered in the latter scenarios to correspond more closely to response curves produced by the U.S. Army Corps of Engineers. These curves are shown in the more detailed discussion of those scenarios.

Route 13 loading. In an effort to balance the demand across all available WB I-64 ramps, a percentage of traffic was routed west on I-264 from the Virginia Beach area, through the interchange with I-64 (which does not provide access to WB I-64 under the TCP) to Route 13. Traffic could then follow Route 13 NB to Chesapeake Boulevard where it will turn left to enter I-64 WB at Exit 279. This seems to make sense from a pencil and paper standpoint, but a number of practical issues make it infeasible. Route 13 is an arterial route with a number of signalized intersections through which evacuating traffic would have to travel. In addition, the left turn onto Chesapeake Boulevard will add considerable delay. As a result, many of the vehicles assigned to this route are being dissolved from the network by the model because of their inability to make the necessary left turn movement onto Chesapeake Boulevard. Although this will be rectified in future analyses, the impact remains a limitation of these results.

Geometry. The only practical means of correcting a model of this spatial scope in a time-efficient manner was to use data already collected by VDOT and disseminated on the GIS Integrator. These data included high-resolution aerial photography and roadside images. However, if major construction projects have resulted in semi-permanent geometric changes (such as a lane reduction implemented with a Jersey barrier) since the aerial survey, the model will be inconsistent with reality in those areas. The most notable of such changes is a result of the Coliseum project on I-64 in Hampton. When the aerial photos were taken, construction was underway and lane closures were in effect. Because the traffic from both the Southside of Hampton Roads and the Peninsula flows though this lane reduction, the model may be somewhat conservative in its congestion predictions if the lane closures have been removed.

Initial Scenario Analysis Results

Each storm category was modeled under the same set of assumptions, discussed previously. Speeds on I-64 were measured at various locations and reported in 1-hour increments. In addition, information on the number of vehicles unable to enter the network because of queuing at entrance ramps was collected. The results are discussed here.

Table 5 summarizes the volume-related results from each modeled scenario from the original set of scenarios. Expected volumes as provided by the ATM at the HRBT and leaving the region on I-64 are provided along with the volumes at those locations produced by the VISSIM model. In cases where ramp demand was not completely served because the demand exceeded the metering rate, the number of denied vehicles prior to the count location is also provided. The final column lists the maximum hourly volume observed in the model on I-64.

Table 5. Total Volume Observed at Critical Locations

Scenario	ATM Volume Leaving Region	VISSIM Count Leaving Region	No. of Vehicles Denied Entry at WB Ramps	ATM Volume at HRBT	VISSIM Volume at HRBT	No. of Vehicles Denied Entry at Ramps South of HRBT	VISSIM Max. Hourly Volume
1-2 L	14,815	13,647	0	9,201	9,206	0	1,550
1-2 H	18,022	17,742	775	12,690	12,272	775	1,880
3 L	29,250	28,492	2,074	19,832	18,419	1,022	2,800
3 H	33,437	29,185	3,482	23,758	20,706	2,522	2,900
4 L	61,377	49,381	16,664	35,444	29,918	7,488	3,580
4 H	66,129	51,663	17,947	39,730	32,280	10,008	3,600

The TCP uses only a limited number of ramps to provide access to the WB lanes of I-64 within the Hampton Roads region during a hurricane evacuation. Those ramps that are open are metered, in most cases, to ensure that speeds remain high on the mainline. The meter rates were determined based on an assumed downstream mainline capacity. In other words, the sum of the meter rates at each ramp upstream of a mainline location should equal the assumed capacity of the location. In some cases, the demand at a particular ramp exceeds the metering rate for one or more hours of the evacuation period. Table 6 compares ramp demands to metering rates assuming a uniform temporal distribution and the surge distribution used in this analysis. It is clear that metering rates at all four of these ramps will result in extremely long queues under almost every storm category. Under a Category 4 storm, the demand is more than double and in some cases triple what the metering rate will allow. The impacts of this strategy on the arterial roadways leading to these ramps will lead to gridlock. The extent of the gridlock is not discernable from this analysis since arterials are not part of the modeled network, but it is assumed to be significant.

Table 6. Selected Meter Rates Compared with Corresponding Demand

Ramp (WB I-64 @ Exit No.)	Meter Rate (vph)	Category 3H				Category 4H			
		Total Demand (veh)	Uniform Distribution Demand (vph)	Max Surge Demand (vph)	Excess Demand (vph)	Total Demand (Veh)	Uniform Distribution Demand (vph)	Max Surge Demand (vph)	Excess Demand (vph)
263	420	4447	444	534	114	10167	1017	1220	800
273	420	5459	546	655	235	7318	732	878	458
277	300	4096	410	492	192	6584	658	790	490
282	480	4550	455	546	66	10780	1078	1294	814

The impact of this issue is not insignificant with respect to the model results. VISSIM, like many other microscopic simulation models, will allow vehicles to queue on a link when congestion exists. The queue is not allowed to extend indefinitely, however. Once the available storage on the link upstream of the meter is full, vehicles will be forced to wait outside the network until space on the link becomes available. If the wait becomes too long, vehicles will simply be eliminated and their quantity noted in the error messages. Obviously this will have significant impacts on the results since the demand will be reduced accordingly.

Specific Results for Each Scenario

Category 1-2 L/H

- *A Category 1-2 hurricane will result in evacuating volumes that are within the capacity of the network for both the low and high hotel occupancy scenarios, under the assumption that no background traffic is present and vehicles that do evacuate from their origin but stay within the region do not use the interstate to get to their destination.* Ramp metering rates are such that all vehicles are able to access the mainline. The only exceptions are the ramps at 4th View and Northampton Boulevard where demand exceeds the metering rate during the surge from a high-occupancy storm. The excess demand can easily be served in the post-surge interval.

- *Due to the relatively low ramp demand under a Category 1-2 hurricane, several of the WB metering locations are likely unnecessary unless background traffic significantly increases the demand.* At a minimum, metering is likely not necessary at Granby Street, Chesapeake Boulevard, and LaSalle Avenue.

- *The maximum mainline hourly volume remains well below capacity for a Category 1-2 hurricane.* It is cautioned, however, that the likelihood of background traffic on the network is highest under this scenario since much of the region will not be subject to evacuation and will be traveling in the network preparing to weather the storm. Data provided in ADMS Virginia indicate that normal hourly volumes on I-64 WB in this region range from 2,200 vph in the mid-morning off-peak period to 3,600 in the afternoon peak. If an evacuation should occur under these types of background conditions, significant congestion would likely result, especially through the HRBT and west of the tunnel on the Peninsula.

Category 3 L/H

- *A Category 3 storm results in a greater number of evacuating vehicles and therefore more queuing at the entry ramps where vehicles are attempting to access I-64W.* In all, VISSIM reported 2,074 vehicles unable to enter the network because of ramp queuing under the low-occupancy scenario and metering rates as described in the TCP. It is likely that many of those denied would, in reality, be served in post-surge intervals when the ramp demand decreases. The vehicles at the ramp at Tidewater Drive are the most likely to experience unacceptable delays, with 725 vehicles denied entry.

- *The maximum hourly volume observed in the network for the Category 3 L scenario was 2,798 vehicles.* This maximum occurred during the Phase 1 surge. If no background traffic is assumed to use the network, the evacuating traffic proceeds without significant delay although some decrease in speeds is observed. Given the relatively high volume of evacuating traffic alone, any background traffic will result in significant congestion.

- *The Category 3H scenario is similar to the Category 3L scenario except that the queuing at entry ramps becomes more pronounced:* 3,482 vehicles are denied entry because of ramp demands that exceed the metering rates at the ramps. The worst locations appear to be the ramps at 4th View (1,124 denied), Tidewater Drive (935 denied), and Victory Boulevard (960 denied) on the Peninsula.

- *The maximum mainline volume for the Category 3H scenario is 2,887 vph.* Given the relatively high volume and the number of denied vehicles, the metering locations will be critical in keeping the mainline flow moving efficiently. In addition, any background traffic will result in significant congestion as some decline in speeds is seen even with the aggressive metering rates.

Category 4 L/H

- *Both the low and high occupancy scenarios for a Category 4 hurricane result in evacuating volumes that exceed metering rates during the surge and in many cases in the post-surge intervals.* This results in 15,569 vehicles denied entry at WB ramps in scenario 4L and 16,664 vehicles in scenario 4H. In addition to those at the WB ramps, 6,777 vehicles were denied entry at EB ramps in the low-occupancy scenario and 7,731 in the high-occupancy scenario.

- *The maximum mainline volumes for the low and high scenarios are approximately 3,600 vph, occurring between 7 and 9 hours after the start of evacuation.* Volumes over 3,000 vph are observed between miles 231 and 264, until 11 hours after the start of evacuation. Volumes over 2,000 vph are observed throughout the network, in some locations as late as 18 hours after the start of evacuation. Speeds begin to decline as a result of these high volumes.

- *The peak hourly volume in the WB tube of HRBT for both scenarios is about 2,800 vehicles, about 89 percent of the published daily peak hour volume.* Volumes over 2,100 vph are observed for a 6-hour period, 5 through 11 hours after the start of the evacuation in scenario 4L. Under scenario 4H, these conditions extend until 14 hours after the start of the evacuation.

Category 4 Lane Reversal

- *Three reversal scenarios were modeled for the Category 4 storm conditions within the original set of scenarios: (1) crossover located at the 15th View Interchange, all southside traffic uses EB reversed lanes; (2) crossover located at the 4th View Interchange with meters are described in the TCP; and (3) crossover located at 4th View,* *without a ramp meter.* Both 4th View scenarios allow vehicles entering at 4th View to use the WB lanes of I-64; all other southside traffic uses the crossover and the reversed EB lanes. All three reversal scenarios used the same demand volumes as the Category 4 high-occupancy scenario.

- *The crossovers were coded with an 85th percentile speed of 45 mph, and there are no operational differences shown in the model with respect to crossover location.* However, a distinct advantage of using the 4th View location is that the ramp meter at 4th View is no longer necessary. Removing the meter from this interchange under a reversal scenario allowed approximately 2,000 more vehicles to access the interstate during the 5-hour surge period. An inspection of model speeds in the WB lanes at miles 231, 254, and 240 suggests that this additional traffic from the unmetered 4th View ramp does not reduce speeds in the WB lanes, compared to the 4th View metered scenario. This result is entirely based on the reduced interstate volume attributable to the other ramp meters and the assumptions about background traffic. If a significant amount of background traffic is allowed to access the interstate during a Category 4 reversal situation, the additional 4th View traffic could be a problem.

- *Lane reversal greatly increases the capacity of the mainline however metering rates are currently controlling the number of vehicles reaching the mainline.* Given that reversal takes place just prior to the HRBT, further analysis is needed to determine how much additional traffic could be added to the southern (eastern) portion of I-64 without seriously degrading performance.

Additional Scenarios Analysis Results

While the analyses were underway, the catastrophic impacts of Hurricanes Katrina and Rita were playing out in the Gulf Coast region. The images of miles of stopped traffic resulting from the evacuation of the Houston area were unpleasant reminders of what often results from an evacuation of a large urban area. As a result of ensuing discussions with the Hurricane Evacuation Planning Committee, the following additional scenarios were evaluated:

- 10 percent increase in all entry volumes to account partially for background traffic
- addition of minimum traffic entering Hampton Roads as a result of the evacuation of the Outer Banks of North Carolina
- elimination of phased evacuation
- all storm categories with lane reversal.

In addition, a new set of temporal distributions was assumed based on response curves from a U.S. Army Corps of Engineers publication. Three curves are shown for slow, medium, and quick response from the public to the evacuation order (Figure 2). For the sake of simplicity and to account for the worst case condition, all analyses were conducted assuming high tourist populations.

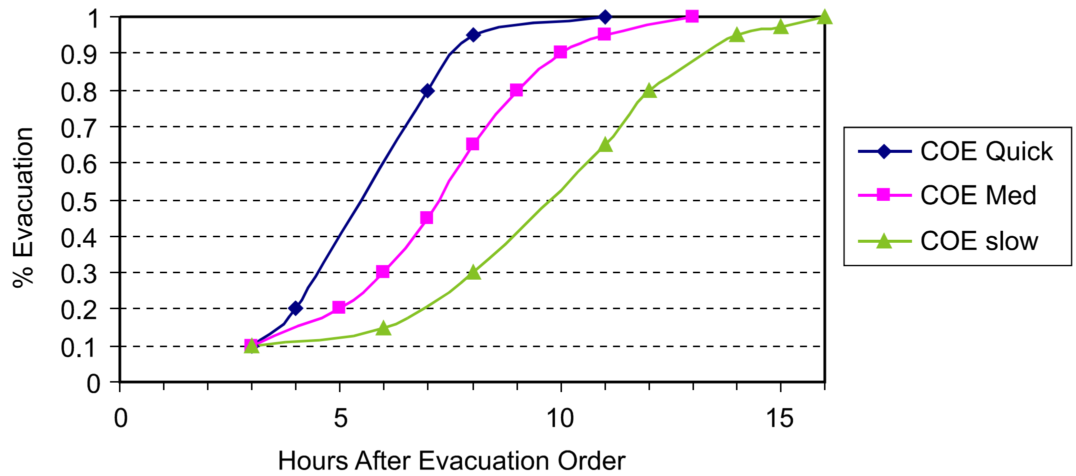

Figure 2. U.S. Army Corps of Engineers Evacuation Response Curves

Category 1-2 L/H

- *Three conditions were evaluated:* Ramps metered as described in the TCP, all meters removed but ramp closures as in TCP, and lane reversal without meters.

- *Results of the evaluations indicate that although speeds do drop in the immediate vicinity of the HRBT under the "no meter" condition, all at-risk traffic is able to leave the region without significant delay under the assumptions previously discussed (Figure 3).* It is important to note that although speeds are higher under the metered scenario, significant queuing will result at several ramps, with approximately 1,000 vehicles denied entry.

- *The assumption of no background traffic is restated here as it is likely to have the biggest impact under this lower storm severity.* A larger percentage of the population will not need to evacuate but will likely be making additional trips within the region as they prepare to weather the storm at home. If a large number of these people use I-64 as a means of moving within the region, particularly during the peak evacuation hours, substantial congestion could result.

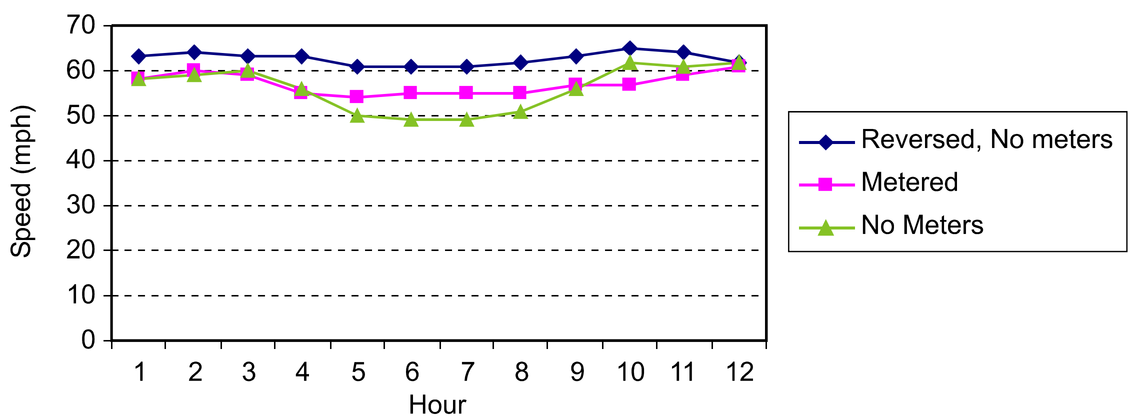

Figure 3. Speeds at Westbound HRBT, Category 1-2 Scenarios

Category 3 L/H

- *Similar to the Category 1-2 analysis, evacuation conditions under a Category 3 hurricane were also evaluated.* Three scenarios were considered: ramps metered as described in the TCP, lane reversal with TCP ramp metering, and lane reversal without metering.

- *Figures 4 and 5 illustrate the conditions at the HRBT for the various scenarios.* At first glance it would appear that the metered condition provides the best results with respect to speed at both the EB and WB tubes of the HRBT. Upon further inspection, however, it can be seen that the metered condition results in significant queuing at ramps, with more than 6,700 vehicles denied entry to the network. In reality, such queuing would result in extensive congestion on the arterial network.

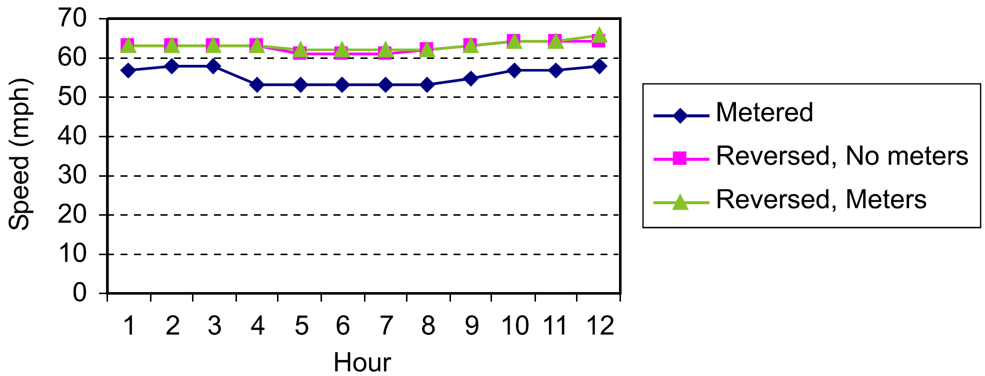

Figure 4. Speeds at Westbound Tube of HRBT, Category 3 Scenarios

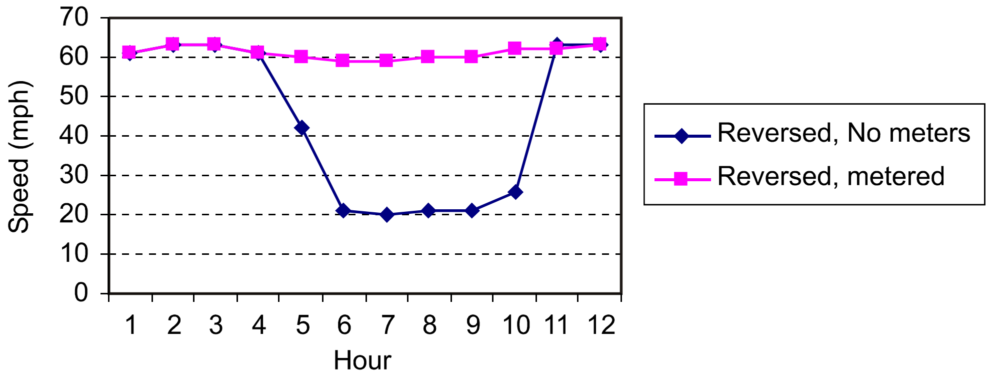

Figure 5. Speeds at Eastbound/Reversed Traffic Tube of HRBT, Category 3 Scenarios

- *Metering of ramps will improve mainline conditions and provide some cushion against breakdown in the event of an incident.* The metering rates provided in the TCP can be increased to reduce queuing at ramps. Under the medium response curve conditions, although speeds do drop to approximately 20 mph for 2 hours during the surge at the HRBT, the delays do not extend geographically beyond this immediate area.

Category 4 L/H

- *Significant time was spent evaluating the Category 4 storm conditions under the new set of assumptions (new temporal distribution, elimination of Phase 1/Phase 2 separation, etc.).* Scenarios considered included reversal with no ramp meters; reversal with ramp meters at three high-volume ramps and metering rates of 900, 720, and 600 vph; and meters at all WB ramps south of the HRBT at varying metering rates.

- *There is no question that lane reversal provides much needed capacity for the demand expected from a Category 4 hurricane (see Table 7).* The question that remained was how best to balance the desire to reduce the number of vehicles waiting behind meters at interstate on-ramps with the desire to keep speeds on the mainline at acceptable levels. As a starting point, all meters were removed and conditions evaluated under the medium response curve temporal distribution. Even without meters in place, some demand remained un-served at ramps on the southside because of extensive queuing from the HRBT and crossover location south to approximately mile marker 284. Speeds in this region dropped to or below 20 mph from the onset of the volume surge throughout the remainder of the evaluation period. Once traffic is through the HRBT, speeds pick up significantly and vehicles are able to leave the region. Figure 6 illustrates the speeds estimated by the model at various locations throughout the network under the scenarios evaluated. Note that although speeds drop south of the HRBT for several of the scenarios, the extent of the congestion varies.

Table 7. Total Volume, Category 4 Scenarios

Scenario	Total Volume
No Meter	74,120
3 Meters, 900 vph	78,293
3 Meters, 720 vph	78,120
3 Meters, 600 vph	77,071
All WB ramps metered, stringent rates	74,953
All WB ramps metered, relaxed rates	76,169

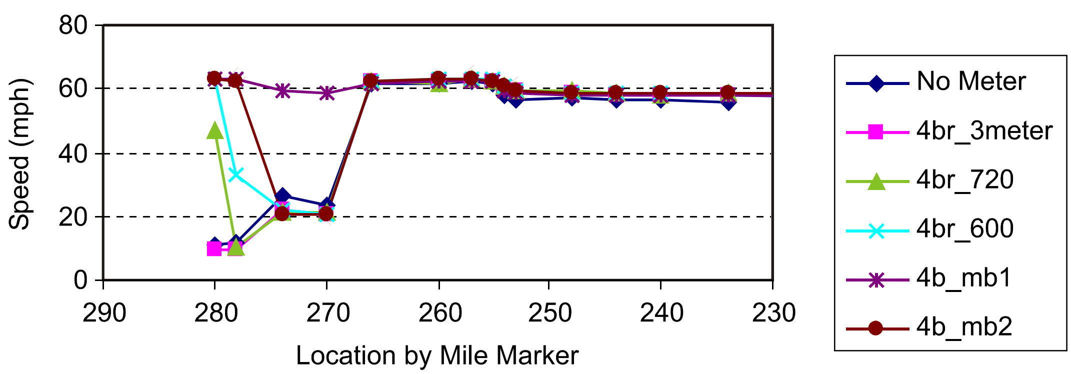

Figure 6. Speeds for Westbound/Reversed Traffic, Various Scenarios: Nine Hours Post Order

- *Meters were replaced at ramps at exits for Granby Street and Exits 277, 279, 282, and 289.* Metering rates were varied until an acceptable balance was achieved between mainline speeds and denied entries at ramps. The best case was achieved with metering rates of 420 vph at Granby and Exits 279 and 289 and 720 vph at Exits 277 and 282. Under these metering rates, speeds drop to approximately 20 mph at the crossover during the surge periods but it appears that the congestion is confined to the immediate area. Speeds at other locations remain at or above 50 mph. It should be noted that 3,215 vehicles are denied entry at Exit 282 and another 1,453 vehicles are denied entry at Exit 277. These are significant numbers, and the impact of the resulting queues should be carefully considered.

- *Total volume leaving the region under each scenario is shown in Figure 7 (also see Table 7). Note that the highest volume actually occurs in the scenarios with meters at three ramps.* There is some question regarding the practicality of metering only three ramps as the public will quickly learn which ramps are not metered and move toward them. This could flood the network and create a situation more like the "no meter" scenario where speeds drop to the point that throughput is impacted.

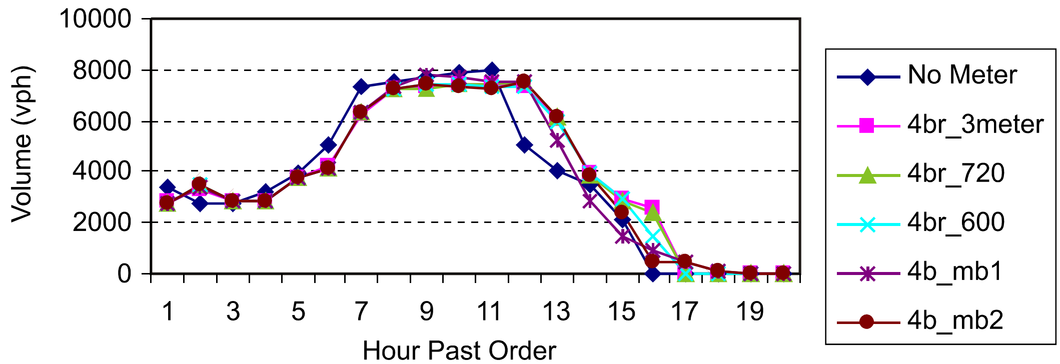

Figure 7. Total Evacuating Volume (Mile Marker 230) Leaving Region, Category 4 Scenarios

FINDINGS AND CONCLUSIONS

- *Without background traffic, the evacuation plan for a Category 1-2 storm should work with limited congestion.* The presence of background traffic could result in conditions more similar to those shown for a Category 3 storm. There are benefits to metering under a Category 1-2 storm, however; unless there is significant background traffic, those benefits may not be worth the significant investment in human resources required to implement the metering strategies.

- *Without background traffic or vehicles evacuating within the region, vehicles evacuating from a Category 3 storm will encounter congestion at ramps leading to WB I-64 but will be able to leave the region within the prescribed evacuation period.* Under the additional scenarios evaluated, it appears that lane reversal will improve conditions significantly and potentially eliminate the need to invest the resources required for ramp metering. Speeds will drop during the peak of the surge conditions, under a medium response curve scenario, but these conditions do not extend either temporally or geographically to a significant extent.

- *Even without background traffic or vehicles evacuating within the region, vehicles evacuating from a Category 4 storm will encounter significant congestion as they attempt to access entry ramps to I-64.* Gridlock will result on arterial roadways leading to these ramps and could impact the ability of vehicles to access other evacuation routes. Peak volumes on the mainline are also nearing the theoretical capacity, making the potential for significant congestion, queuing, and delays much higher.

- *The benefits of lane reversal under the existing TCP are limited because of the aggressive metering of ramps south of the HRBT.* Increasing these metering rates would allow for more efficient use of the available capacity.

- *When metering rates are modified, lane reversal appears to have significant benefits for a Category 3 storm or higher.* Under lane reversal, Phase 1 and Phase 2 regions are effectively separated by the reversal such that they may evacuate simultaneously without detrimental effects within the Hampton Roads region. The impacts of these volumes reaching the Richmond area have not been evaluated to date. If severe enough, queuing from the joining of flows in Richmond could have significant impacts on Hampton Roads.

- *Under a Category 4 storm, metering of select ramps is still required to keep mainline volumes at levels that result in acceptable speeds.*

- *Significant congestion occurs at the crossover location during the lane reversal scenarios for Category 3 and Category 4 storms.* There is a potential to improve the flow of traffic from the Southside through the HRBT by providing additional crossovers or by moving only one lane of the WB traffic to the EB lanes south of the HRBT. This would help to use the existing capacity more efficiently through the HRBT in the EB and WB tubes. Both alternatives would have drawbacks as additional crossovers would require additional financial resources to construct, and allowing more traffic to use the WB tube could negatively impact conditions for evacuating vehicles from the peninsula. Neither of these alternatives was evaluated in this study.

RECOMMENDATIONS

1. *VDOT's Hampton Roads and Richmond districts and Traffic Emergency Operations Center should always implement lane reversal when a Category 4 or higher storm is forecast.* The number of vehicles attempting to leave the region under these conditions far exceeds the capacity of the non-reversal scenario routes included in the TCP. Without reversal, heavy congestion will exist for many hours. Locating the crossover at the 4th View interchange appears preferable to the 15th View location.

2. *VDOT's Traffic Emergency Operations Center should consider lane reversal for all Category 3 storms.* Although not as critical as under Category 4 conditions, delays are significantly reduced with lane reversal.

3. *VDOT's Hampton Roads District (Smart Traffic Center and Traffic Engineering) in conjunction with the Hampton Roads Hurricane Committee should modify the ramp metering rates from those in the TCP when lane reversal is implemented for a Category 3 or 4 storm to allow more vehicles to enter the mainline.* Rates approximating 420 vph at Granby, Exit 279, and Exit 289 and 720 vph at Exits 277 and 282 will maintain acceptable conditions on the mainline while reducing the queuing that occurs on the arterials under more stringent metering rates.

4. *HRSTC and others involved in implementing the TCP must be flexible and adjust the plan in response to real-time conditions.* The plan is based on a number of assumptions that vary from actual behavior. If more evacuees choose to use a particular ramp or route than the plan assumes to be the case, ramp metering strategies and public information messages will likely need revisions to manage the change.

5. *VDOT's Hampton Roads and Richmond districts in coordination with VDOT's Operations Management Division should investigate methods for collecting real-time data on evacuation routes.* Having these data would allow for real-time management of evacuation flows among available evacuation routes. The arterial congestion that is anticipated as a result of these analyses is further evidence of this need.

6. *The Hampton Roads Hurricane Committee in coordination with VDOT's Operations Management Division should sponsor the further study of a number of issues:*

   - Given the large number of evacuating vehicles from Hampton Roads, the impacts of this traffic on downstream destinations should be evaluated. This is particularly true in Richmond where evacuating traffic could be arriving via I-95 and I-64. The elimination of the phased evacuation approach in the latter scenarios tested in this project could be a problem as the I-64 lanes (both regular and reversed) come together with traffic from I-95 NB southeast of Richmond.

   - Background traffic and traffic evacuating from primary residences but remaining in the region could have a significant impact on evacuation routes. A method of estimating the routes used by this traffic and its volume needs to be developed.

   - Arterial evacuation routes were not explicitly evaluated in this effort. Given the significant proportion of traffic these routes carry, the operational characteristics of these routes must be defined.

   - Interstate volume conditions approach or exceed theoretical capacity under both Category 3 and Category 4 storm conditions. Under neither storm condition were the impacts of incidents on flow considered. It is very likely that, given the nature of evacuating traffic, a number of incidents will occur. The inclusion of random incidents in the model will provide a more complete picture of the evacuation.

BENEFITS AND COSTS ASSESSMENT

The benefits of implementing the recommendations of this report include the following:

- More efficient use will be made of available capacity on evacuation routes through improved ramp metering strategies under both standard and lane reversal scenarios.

- Delays on the mainline lanes of I-64 will be balanced against the demand at ramps such that throughput is maintained and arterial queuing reduced.
- Evacuating traffic will be able to reach their out-of-region destinations in acceptable time frames. Delays will occur, but the TCP will be designed to minimize those delays to the extent possible.

The expected risks of implementing the recommendations are as follows:

- Since arterial routes were not included in this analysis, conditions on those roadways could limit the ability of vehicles wishing to evacuate via I-64 to reach the interstate.

- The assumption of no background traffic on the interstate could significantly alter the results if proven wrong. Especially in the case of a Category 1 or 2 storm, the potential for a large volume of background traffic exists.

- Congestion in Richmond where multiple evacuation routes converge, could result in queues that impact the western boundary of Hampton Roads and potentially further east towards the HRBT.

ACKNOWLEDGMENTS

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