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Modeling Decision Making Related to Incident Delays During Hurricane Evacuations

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ABSTRACT

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Successful evacuations from metropolitan areas require optimizing the transportation network, monitoring conditions, and adapting to changes. Evacuation plans seek to maximize the city's ability to evacuate traffic to flee the endangered region, but once an evacuation begins, real time events degrade even the best plans.

To better understand behavioral responses made during a hurricane evacuation, a survey of potential evacuees obtained data on demographics, driving characteristics, and the traffic information considered prior to and during an evacuation. Analysis showed significant levels of correlation between demographic factors (e.g., gender, age, social class, etc.) and self-assessed driver characteristics, but limited correlation with the decision to take an alternate route. Survey results suggest evacuees' decisions to divert are functions of the length of time a driver has been in congestion, the amount of travel information provided, and its method of delivery. This association differs significantly from those identified by other studies that focused on routine, non-evacuation, conditions. A decision-making model that forecasts decision tendencies using these factors was created.

The model was integrated in and tested using a dynamic evacuation simulation. The combined model and simulation allow assessment of the impacts traveler information content, timing, and method of delivery have on traffic flow and evacuation times, imitating the impact of traffic information systems. The effectiveness of alternate route use was assessed by measurements of total vehicle volumes processed and queue persistence. Effectiveness was highly dependent on the road network in the immediate vicinity, especially the number of accesses to the alternate route and vehicle capacity on the alternate route and accesses. Integration of the decision-making model in a dynamic hurricane evacuation simulation is unique to this study.

This study yields a greater understanding of evacuee decisions and factors associated with related travel decisions. It provides the novel integration of a behavioral model and a dynamic evacuation simulation, increasing the realism of evacuation planning and providing a valuable tool supporting the decision process. Understanding gained may contribute to reduced evacuation times and enhanced public safety.

This dissertation is dedicated to my wife, Nancy Sue Robinson, whose love, patience, and encouragement have been abundant and rock-solid. Her determination to prevail over the toughest of challenges is a continuing inspiration.

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1. INTRODUCTION

1.1. THESIS STATEMENT

Some natural events require evacuations, which can be severely hampered by roadway incidents that occur on evacuation routes and cause congestion. The route choice decisions made by evacuating drivers are associated with demographic factors and individual responses to stated and revealed preference questions and can be accurately represented with a decision-making model. The model can be integrated with a traffic simulation and used to assess the impacts of route choices on evacuating traffic flow. Knowledge gained through this use of modeling and simulation (M&S) can be used by emergency response and management professionals to fine-tune and better assess evacuation plans, train for the evacuation of metropolitan regions, maximize traffic flow rates, and improve public safety.

1.2. PROBLEM STATEMENT

The number of tropical storms and hurricanes impacting the United States' Atlantic and Gulf coasts increased by 40% in the ten year period from 1997 – 2006 as compared to the previous 140 year average. With continued warming of the ocean surface temperature, this increase is expected to continue (1). With fully 55% of the population of the United States living within 50 miles of the coast – a population density that is also expected to grow – it is imperative that evacuation plans to remove residents from hazardous areas be effective (2, 3). Increasingly, these plans are being created and tested using computer modeling and simulations. These allow large scale, dynamic tests and exercises to assess processes, procedures, and planning prior to a catastrophe, promoting greater understanding of a plan's strengths and weaknesses and providing opportunities to train emergency managers and decision makers. However, most tools focus on individual or group decisions (whether or not to evacuate, when to evacuate, what mode of transportation to use, etc.) or the traffic flow resulting from the mass evacuation of a community or region. They do not address the accidents and incidents affecting road conditions after an evacuation begins and do not address the decisions made by evacuees when problems are encountered.

Evacuation studies indicate that, if a hurricane hit Florida's southwestern region with little warning time, it could cause massive gridlock on the available highways, trapping motorists in its path (4). The limited egress routes from most coastal cities suggest similar problems could also occur if road capacities are reduced during an evacuation. Such reductions may occur if congestion is caused by the high number of evacuating vehicles exceeding a road's design limits and causing bottlenecks (volume induced congestion) or by accidents or incidents blocking or reducing the capacity of exit routes (incident induced congestion). Evacuation planners may prevent the occurrence of volume-induced congestion by careful consideration of different hurricane scenarios and continuing evaluation of plans. Accidents and incidents still may occur, but their impact can be mitigated by better understanding of traffic flow and adjustments to plans using forecasts of driver behavior. Emergency management officials and transportation controllers must anticipate evacuees' actions and plan accordingly. Should the use of alternate routes be encouraged? Or will that lead to back-ups on routes currently flowing smoothly? How can evacuees be motivated to make the decisions that will be most advantageous to the overall evacuation?

Dynamic evacuation simulations are needed that include predictions of the locations, severities, and frequencies of likely accidents and incidents, how evacuees respond to such events, and how this response can be used to create contingency plans that may be quickly implemented during real world events. Key questions that must be answered before such simulations can be developed include:

- How are drivers likely to respond to delays and information?
- Can drivers' responses be externally influenced through dynamic provision of information?
- Can dynamic driver route choice decisions be modeled in an evacuation simulation, and if so, how will route choice decisions affect traffic flows and the time required to complete an evacuation?
- Will the evacuation plan accommodate expected traffic flows?
- To what extent will network performance (delays, evacuation time) degrade when traffic incidents occur?

- Where are problems (volume induced bottlenecks, accidents, and incidents) likely to occur?

The objectives of the research are to:

- Examine the decision-making processes of evacuees making a route choice decision when an alternative route to avoid congestion is suggested by traffic management professionals during a mass evacuation;
- Determine which factors have the greatest impact;
- Develop a decision-making (D-M) model representative of evacuee route choices in different traffic information scenarios that forecasts the rate at which evacuees would divert to an alternate route when confronted with congestion; and
- Integrate the model with a dynamic hurricane evacuation simulation, allowing assessment of anticipated evacuee decisions.

1.3. CONTRIBUTIONS

Results of the behavioral survey completed in this study contribute to a deeper understanding of evacuees' response to congestion encountered during an evacuation. Influencing factors were quantified and relationships between evacuee characteristics, external influences, and route choice assessed. The affect of route-choice decisions on evacuation traffic flow was objectively measured.

This dissertation provides a decision-making (D-M) model for evacuee route-choice decisions and a new method of application to forecast and analyze the process leading to, and the results of, evacuees diverting to an alternate route from a planned evacuation path in order to bypass known, temporary impedances to traffic flow. It introduces a computational decision-making model representative of the decisions made during an evacuation and uses transportation software to assess the impacts of evacuee decisions on overall traffic flow. Additionally, it provides data useful for modeling the influence of stimuli considered by evacuation managers prior to encouraging (or discouraging) diversions and by evacuees choosing between preplanned and alternate routes and suggests methods of information transfer from government officials to the evacuating public to better motivate decisions in compliance with the desires of the emergency managers. The following are the specific contributions of this research:

- A behavioral survey collected and quantified evacuee characteristics, and factors influencing route choice decisions made during an evacuation. Results differed significantly from those anticipated using reports of previous research in non-evacuation scenarios in that demographics, past history, and self-assessed driver personality were not significant factors in the route choice decision. Instead, the decision was a function of the length of time an individual was in congestion, the content of traffic information provided, and its method of delivery. This finding implies significant influence on driver behavior may be gained through wise use of Advanced Traveler Information Systems (ATIS).
- A decision-making model predicting the route choice decisions made by evacuees as a function of time and traffic information is provided. The model was tested using stated preference survey responses from potential evacuees and validated using a reserved set of responses from the same survey.
- A dynamic hurricane simulation, integrating both predicted accidents and incidents and the route choice decision-making model and forecasting the impact of decisions on traffic flows is presented.

Decisions made during the course of an evacuation have significant, even life-and-death importance. Simulations capable of rapidly integrating a variety of conditions and forecasting the consequences of multiple alternative actions can improve the performance of emergency managers and the success of evacuations. This research improves evacuation simulations by including the effects of traffic impediments and the decisions involved in overcoming these impediments. As the use of transportation simulations increases, especially in the planning and testing of evacuation plans, and as greater investments are made in ATIS, this research provides a timely means of integrating the influence of the two systems and assessing the impact of ATIS use in emergency evacuations.

1.4. MOTIVATION

Encouraging endangered residents to evacuate in advance of a hurricane's arrival may be critical to the saving of hundreds, or even thousands, of lives. But simply getting residents to leave their homes and communities is only the beginning of an evacuation. The massive traffic jams which occurred during the evacuations for Hurricanes Floyd in

1999 and Rita in 2005 showed what can happen when an evacuation goes awry. Florida evacuees for Hurricane Floyd reported travel times of greater than 24 hours (5), while many Texas evacuees for Hurricane Rita were stuck in traffic jams for over ten hours (6).

During the evacuation from Charleston, South Carolina, for Hurricane Floyd, most motorists chose to remain on the heavily used Interstate system despite the presence of readily accessible and only lightly tasked smaller highways and roads. The resulting extended travel times exposed evacuees to dangers potentially even greater than those faced had they remained at home. Though the motivation for evacuees' decisions was not formally pursued, Dow and Cutter speculate, based on anecdotal information from radio call-in programs after Hurricane Floyd, that evacuees were concerned about the availability of services on alternate routes and this led them to remain on the Interstate system (7).

When evacuees leave congested roadways and use alternate routes to bypass congestion, evacuating traffic flow rates may increase. However, route changes may also overload other evacuation routes. Diverting traffic may also disrupt the flow of recovery supplies or inhibit emergency vehicle traffic by clogging supporting arterial roads. Understanding, from a transportation controller's perspective, how to best motivate evacuees to choose to take the desired route may improve dynamic traffic management in an evacuation and improve public safety.

1.4.1 Intended Practitioners

Transportation planners and engineers are responsible for providing transportation planning services for transit, highway, and government agencies. They typically conduct quantitative and qualitative analyses for interchange area and access management, corridor planning, travel demand forecasting, traffic and safety analysis, impact fee development, environmental documentation and regional transportation planning. Their efforts concentrate on creating a transportation network capable of meeting the current and anticipated normal demands of a region's residents and guests. While transportation planners must account for the effects of weather, they have often not been included in the creation of plans for disaster evacuations. Emergency Managers are responsible for coordinating disaster response and crisis management activities, providing disaster preparedness training, and preparing emergency plans and procedures for disasters. This work includes large-scale evacuations, but decisions may sometimes be made without an adequate understanding of transportation flow concerns. Both groups benefit from the use of traffic simulations and will benefit from the results of this study. Transportation planners and engineers with a better understanding of what motivates travelers and how best to accomplish it will be better able to prompt desired behavior. Emergency planners will be able to quickly anticipate potential traffic flow changes if alternative routes are provided and will be better prepared to encourage (or discourage) route diversions. A more complete understanding of alternative evacuation routes, including costs of diverting from preplanned procedures, will improve performance both during an evacuation and during recovery from an evacuation.

1.5. APPROACH

The approach used produces a simulation with integrated D-M model capable of accurately representing the decision processes associated with diversion around an incident impeding traffic along the evacuation route. The algorithms developed can be easily adapted to future data obtained expressly for the purpose of answering questions on decision-making. The methodology is comprehensive, examining the importance of both the behavioral considerations (decision-making) and the transportation network limitations and their combined influence on an evacuation.

Research began with a review of past evacuations and evacuation simulations, searching for factors most influential in the decision-making process. Previous studies of evacuations have addressed decisions made prior to leaving, but neglected those made during the evacuation. Therefore, the factors influencing decisions on whether or not to evacuate were extended as an estimate to assist in designing survey questions and developing a decision-making model.

A survey of potential evacuees in the Hampton Roads region of Virginia gathered information on demographics, driver characteristics, past and anticipated driving tendencies, and route choice expectations when confronted with congestion during an evacuation. The survey was cross-sectional. The sample population did not represent all regions in proportion to the number of actual residents and demographics. The decision evaluated was the choice of whether to divert from a planned evacuation route when a downstream incident was reported and an alternate route suggested. Scenarios provided varying amounts of information on alternative routes and services and used three methods of information distribution. Decisions were expected to be influenced by individual prior knowledge and familiarity with the area, demographics, and individual evacuee traits. Survey participants were not provided information on the availability or accessibility of alternate routes when asked to make a route choice.

Virginia's Hampton Roads region was used as the evacuation location. Evacuating traffic was simulated using the Avenue module of Citilabs, Inc.® Cube transportation software. A variable in the software can be adjusted to influence route choices at the beginning of each simulation run. This feature was used to approximate the influence of ATIS (radio broadcasts, freeway message signs, etc.) that might be used by an evacuee deciding whether or not to divert from a planned route and is further discussed in sections 3.3 and 6.2.

Figure 1 illustrates the research and analysis path. The study began with a review of relevant past research on the topics of evacuation behavior, evacuation planning, ATIS influence, and evacuation modeling. This information was used to design a prototype survey and also in the modification of a previously developed hurricane evacuation simulation. The survey was directed towards adult drivers and gathered information on demographics, the extent of individual preparations made for an evacuation, self reported driving tendencies, and a self-assessment of characteristics that might be related to route choice decisions. Survey goals included identification of variables considered by evacuating drivers when deciding whether to divert from a planned route, obtaining information allowing the assignment of levels of influence (weighting factors) to these variables, and determining if these variables correlate with decisions made by evacuees.

A pilot survey was administered and completed by 32 respondents. The pilot survey used variables identified during the literature review. Survey participants were invited to suggest additional responses to some questions to identify additional key factors. A revised survey was prepared and made available for completion on the Internet using the commercial survey tool SurveyMonkey (available at http://www.surveymonkey.com/). In addition to the 32 pilot surveys, 852 online surveys were completed. After excluding

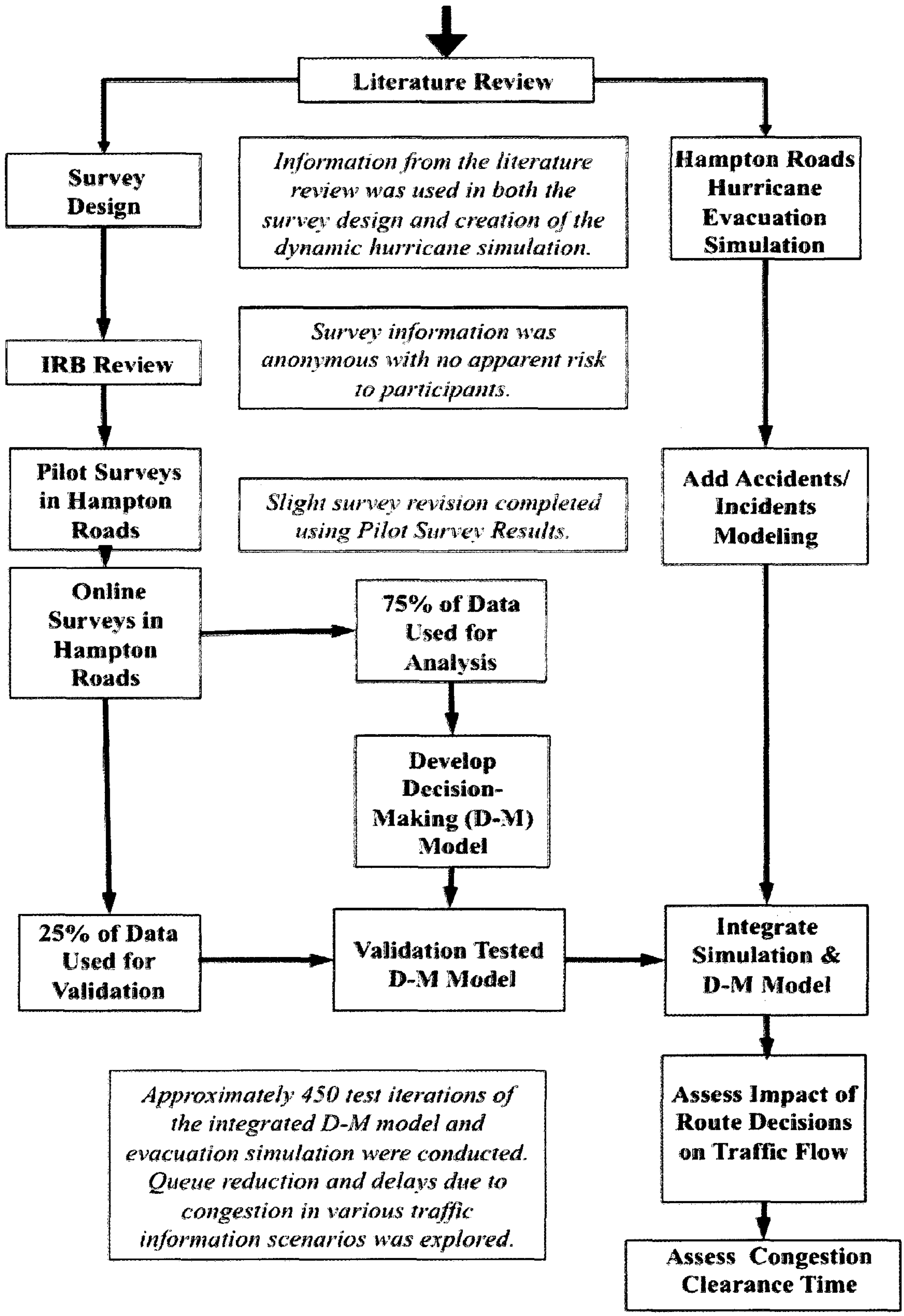


FIGURE 1 Research and analysis paths.

responses that failed to answer a substantial number of questions, 841 valid surveys were considered. Of these, 75% (631) were used for analysis and 25% (210) were reserved for validation testing.

Survey data was analyzed and a decision-making model created to forecast the route choice decisions made by evacuees when faced with congestion during a hurricane evacuation. After these analyses, the decision-making model was validated using the 25% of survey results held in reserve to determine which method provided results most accurately reflecting participant response.

The hurricane evacuation simulation employed utilized the most current regional flood zone maps developed by the Army Corps of Engineers and the Traffic Demand Model (TDM) provided by the Commonwealth of Virginia. Within each traffic analysis zone (TAZ) in the TDM, appropriate trip origin-destination pairs were assigned to represent the number of residents living in all flood zones included in the TAZ. Participation rates from each zone were suggested based on typical values seen in more hurricane prone areas. Evacuees were dynamically loaded using a logit rate curve. Evacuation destinations were assigned using the results of a survey conducted independently of the evacuation simulation. The simulation is discussed in detail in Section 3.

The decision-making model was integrated into the evacuation simulation and multiple simulations of a hurricane evacuation from the Hampton Roads region of Virginia were run. Each run included injection of a simulated incident restricting traffic flow on a primary evacuation route. These events, called Congestion Test Events (CTE), modeled the occurrence of accidents or incidents leading to congestion. Simulation scenarios were tested with paired runs assessing traffic flow with and without modeled traffic responses to information concerning the CTE using the D-M model. At each CTE, queue size was recorded in six-minute increments. Queue duration was determined as the time required for the queue to dissipate after initially growing after the CTE. The impact of decisions to use an alternate route was assessed by the reduction in queue duration between runs with and without the D-M model.

1.6. DISSERTATION ORGANIZATION

The remainder of this dissertation is organized as follows:

- **Section 2. Background.** A literature review provides an introduction to evacuation and transportation modeling and simulation (M&S), reviews past research in the areas of hurricane evacuee behavior, evacuation planning, the use of advanced traveler information systems (ATIS) to inform and motivate traveler behavior, and evacuation modeling relevant to this study. Modeling and simulation topics and potential applications are integrated into each of these sections. Final sections introduce two mathematical models and discuss the significance testing of statistical results.
- **Section 3. A Dynamic Hurricane Evacuation Simulation.** Section 3 provides an overview of the development of dynamic evacuation simulation using the commercial traffic software by Citilabs, Inc.®, Cube Avenue. Adjustments to the basic regional traffic network, estimates of citizens' participation rate and the evacuation response rate, and the injection of accident and incident considerations are described.
- **Section 4. Survey Content, Distribution, and Analysis.** Section 4 reports on the survey used to obtain data on the demographics, past decisions and actions, and anticipated future decisions of potential hurricane evacuees. Survey development, distribution, and response are discussed. A detailed analysis of results is provided.
- **Section 5. A Quantitative Model of the Route Choice Decision.** An explanation of the development of the decision-making model that was subsequently integrated with a dynamic transportation simulation to represent anticipated evacuee route choices when faced with congestion during an evacuation is provided. An alternative model, which could potentially be used to provide expanded results analysis and more detailed decision forecasting in future studies, is introduced.
- **Section 6. A Dynamic Traffic Simulation with Integrated Decision-Making Model.** The final major section discusses the integration of the decision-making

model into the evacuation simulation. Testing is described and results of the integrated simulation are provided.

- **Section 7. Conclusions.** A summary of the research effort, suggestions for real-world applications, and an introduction of future study ideas are provided.

2. BACKGROUND

The following sections provide an introduction to evacuation and transportation modeling and simulation (M&S) and review past research in the areas of hurricane evacuee behavior, evacuation planning, the use of advanced traveler information systems (ATIS) and their effectiveness, and evacuation simulations. As appropriate, summaries of gaps in past research are noted. Section 2 concludes with an introduction to the analysis methods used in this study.

2.1. INTRODUCTION TO TRANSPORTATION AND EVACUATION MODELING AND SIMULATION

A model may be described as a simplified, logical, mathematical representation of a system or process, a purposeful abstraction of a more complex reality. A simulation is the operation of a model over time to show the outcomes that might occur in the real world.

Modeling and simulation tools have been used in transportation studies since the early 1950s. Early computer simulations of transportation represented vehicle interactions at intersections and freeway flows (8). The use, breadth, and detail of transportation simulations have grown rapidly with new capabilities accompanying advances in hardware technology and computer availability. Modern simulations are capable of representing large road networks accurately.

Computer simulations in support of hurricane analysis and decision-making have been in use since the middle of the last century while simulations of mass evacuation transportation issues have been in use for at least three decades. In the 1970s, simulations emphasized hurricane evacuations, but following the nuclear accident at Three Mile Island in 1979, attention shifted to evacuations from nuclear sites. Interest in hurricane evacuation simulations renewed in the 1990s after powerful Hurricane Andrew struck Florida in 1992 and then Hurricane Floyd ravaged the U.S. east coast in 1999. The deadly hurricane season of 2005, with the most named storms in history, damages over $100 billion, and over 2000 confirmed deaths, ensured continuing interest. Most evacuation simulations emphasize transportation assignment. A brief listing of the progressive development and use of evacuation simulations can be found in (9). The

2006 U.S. Department of Transportation Report to Congress "Catastrophic Hurricane Evacuation Plan Evaluation" (10) provides brief descriptions of eight current tools.

Many simulations, including those used for transportation systems and evacuations, can be categorized into three groups by level of detail. Microscopic simulations (micro-simulations) typically focus on small or isolated areas or populations. Micro-simulations are able to represent details of individual entity movements and incorporate individual behaviors and decision-making. Microscopic transportation simulations can represent individual vehicles and individual driver behaviors. They are also capable of accurately simulating the impacts of traffic incidents and accidents and roadway restrictions in the immediate vicinity. The large number of calculations required limits the scope of micro-simulations, though advances in computing technologies have significantly reduced this limitation of technology.

Macroscopic transportation simulations model large areas and/or populations. Typically used for large network planning, such as regional traffic demand models, macroscopic models provide engineering level estimates and represent traffic flows in much the same way one would model fluids. Macroscopic simulations estimate traffic flows on known networks during specified intervals. Because computational complexity is reduced, macro-simulations require less computer capability and can quickly provide "big picture" estimates. However, their lack of detail makes them ill suited to assessing the effects of road geometry (e.g., sharp road curves, changes in grade, and intersections/merge areas) and the temporary, but potentially significant effects of traffic accidents and incidents.

Mesoscopic simulations bridge the gap between microscopic and macroscopic levels of detail. Vehicles are aggregated into packets, reducing the total number of calculations required, reducing hardware requirements, and speeding computational time. Packet sizes are adjustable and typically represent ten to forty vehicles each. Mesoscopic transportation simulations maintain the ability to model with some of the detail available in microscopic simulations, including assessing the impacts of traffic incidents and bottlenecks, though not to the same level of detail. The primary simulation used in this research is Cube Avenue, a mesoscopic simulation distributed by Citilabs, Inc.®.

When simulations are used for routine transportation planning, analysis periods of several hours may be sufficient and static traffic assignments may be employed. However, during an evacuation, travel times may exceed 10 hours or more. If static traffic assignment alone is used over such long periods, results may be compromised by the lack of knowledge of how speed, volume, density, delay, and travel time vary. Dynamic simulations can integrate these influences and bridge gaps in the understanding of evacuations.

The simulation used in this research follows the traditional four-step model – Trip Generation, Trip Distribution, Mode Choice, and Trip Assignment -- common to transportation studies. **Trip Generation** employs two primary origin-destination (O-D) matrices. The matrix used for background traffic makes use of the regional daily O-D matrix provided by the Virginia Department of Transportation (VDOT). Background traffic is modeled for only a portion of an evacuation day. This is accomplished by stochastically selecting the correct number of trips and dynamically loading vehicles at the proper rate over the course of the simulation test. Evacuating traffic uses a separate O-D matrix created using origins and intended destinations developed using information from a survey conducted independent of this study (11). Evacuee participation rates are traditionally modeled by a logit curve. The modeling of both background and evacuation traffic are further explained in Section 3. All vehicles are loaded from Traffic Analysis Zone (TAZ) centroids. The region is divided into such TAZs with one or more TAZs used to represent the portion of each neighborhood or community within a particular flood zone. Smaller secondary roads are not considered in the simulation; most vehicles are loaded directly from the TAZ centroids to primary arterials that then load onto the primary evacuation routes. A few TAZs may connect directly to primary evacuation routes, bypassing arterials.

Trip distribution is controlled by the O-D matrix and by prejudicing vehicles to follow one of the six regional evacuation routes. The method used to induce vehicles to use these routes is explained in Section 3.3. Mode choice is not addressed by the study. All trips are made using personal vehicles. **Trip assignments** are controlled by the simulation. Prior to vehicles being loaded onto the network, the summation of trip times over all links traveled from origin to destination for each vehicle is calculated. The first iteration of each run considers only the length of the segment and travel speed; loading on segments and resulting congestion are not considered. Subsequent iterations adjust trip assignments to better balance volumes on the evacuation routes. Because evacuation routes are assigned by region, and residents are expected to take assigned routes, only two to four iterations are conducted for each simulation run. The repeated iterations improve traffic flow (over the initial iteration), but do not provide optimal trip assignments.

2.2. EVACUATION BEHAVIOR

Many studies have looked at hurricane related decision-making. Most have sought to determine the influences that lead an individual or household to decide whether to evacuate or when to begin an evacuation. Earl J. Baker summarized the results of several studies completed following hurricane evacuations made between 1961 and 1989 (12). These studies included responses from almost every hurricane susceptible state along the Atlantic and Gulf coasts of the United States and involved storms of varying strengths. Baker's summary provides a good starting point for looking at hurricane behaviors. He concluded that variation in response behavior was largely accounted for by five variables:

- Risk level of the area;
- Actions by public authorities (including the timing, type and distribution method of any evacuation orders issued);
- Housing (permanent dwelling, mobile home, structural soundness, etc.);
- Prior perception of personal risk; and
- Storm specific threat factors (such as strength and proximity).

Perhaps just as importantly, Baker discounted the importance of several factors often assumed to be significant influences in the pre-evacuation decision process, including age, sex, family status (including the presence of children), pets, previous experience, and education. The survey used in this study examines the role of these factors in decisions made after an evacuation has begun.

There are significant difficulties when one seeks to forecast individual and group behavior and decision-making, especially when anticipating future events that may not ever occur. Models of individual and group incident decision-making often use one of two data sets: post-incident surveys and interviews of actual decisions made in a similar event and advance surveys of planned intentions. Neither method enables creation of a completely accurate model. As noted by Baker, "respondents are usually asked to explain the reasons for some of their behaviors, but one must view self-account data cautiously, as many respondents oversimplify and cannot accurately articulate the intricacies of their decisions" (12, p. 291).

Fishbein and Ajzen asserted that agreement between stated intentions and actual future behavior is directly related to the length of time between expressing the intention and the real world event that involves it, the level to which the behavior is actually performed in the interim period, and other influences. The relationship between intentions and subsequent behavior is addressed by the theory of reasoned action (13). This theory asserts that individuals deliberately determine in advance how to act in different circumstances and that the intentions formed are accurate predictors of future behavior. The authors note that increased accuracy of predictions of future behavior may be obtained – though not explained -- by aggregating behaviors from more than one occasion, situation, or action as this tends to nullify the influence of factors unique to a particular situation. They caution, however, that the accuracy of using current intentions as predictors for future acts is increased when the related action is performed repeatedly and reduced if significant time lapses between stating the intention and the event observed. In Ajzen's subsequent theory of planned behavior, the earlier work is extended by the addition of perceived behavioral control (14). Perceived behavioral control refers to an individual's own belief about the ease or difficulty of performing a particular behavior of interest. Ajzen provides three critical conditions that must be met for accurate predictions to be made. First, the measures of intention and of perceived behavioral control must correspond to or be compatible with the behavior that is to be predicted. The second condition is that intentions and perceived behavioral control must remain stable in the interval between their assessment and observation of the behavior. Intervening events may produce changes in intentions or in perceptions of behavioral control, with the effect that the original measures of these variables no longer permit accurate prediction of behavior. The third requirement for predictive validity has to do with the accuracy of perceived behavioral control. Prediction of behavior from perceived behavioral control should improve to the extent that perceptions of behavioral control realistically reflect accurate control (14). These three conditions were integrated into the survey of evacuees used in this research by obtaining information on both stated and revealed preferences in the context of routine driving and emergency evacuations and comparing these results to a respondent's past evacuation participation, and minimizing the time between the historical action and the decision (when the survey was completed). Whether or not an evacuee could take an alternate route as anticipated was not explicitly measured, but was modeled in the dynamic evacuation simulation by prejudicing the appropriate portion of evacuees to choose an alternate route, but limiting the number who actually took an alternate route to those permitted by location in the transportation network. (An evacuating vehicle's characteristics could be adjusted to predispose taking an alternate route, but if no exits to a route were made available or access to the alternate route was blocked, the route selection could not be made.)

Kang et al. (15) compared the actions taken by hurricane evacuees for Hurricane Lili with the actions the same evacuees said they expected to take when surveyed two years earlier. The three primary goals of the study were:

1) To determine if people's expectations concerning information sources and evacuation decisions correspond to their later behavior in response to a hurricane threat.
2) To determine if people's expectations about evacuation time components correspond to the time it actually takes them during an actual hurricane evacuation.
3) To determine if people's expectations about the logistics of evacuation (choice of transportation modes, number of vehicles and trailers, destination, and type of shelter) correspond to later behavior in response to a hurricane threat.

The initial questionnaire referenced in the study was conducted in 2001 and included 559 usable responses. Hurricane Lili made landfall in the surveyed region in October 2002 and the subsequent survey was completed in 2003. This second survey included items that were similar, if not identical, to the previous questionnaire, allowing comparison of the 51 usable responses generated. The study found that evacuees had accurate expectations about information sources they would use, evacuation transportation modes, the number of vehicles taken, and evacuation shelter types. It showed that in these areas, responses were likely to be based on pre-existing beliefs, whereas predictions about other behaviors (what evacuees would bring, how much preparation time would be required, preparation steps) were likely "pseudo-attitudes" constructed at the time of the questionnaire's administration. Because respondents might not have formed a specific intention to engage in the queried behavior, it would be more accurate to identify the answers to hypothetical questions as evacuation *expectations*, rather than evacuation *intentions*.

Heath et al. (16) studied reasons households did or did not evacuate for flooding after an evacuation notice had been issued in California in July 1997. He and colleagues found that the most consistent factor associated with household evacuations in previous events was the presence of children while the factor most often associated with evacuation delay or failure to evacuate was the increasing age of household members. The influence of children as a motivating factor to evacuate was again present in the California evacuation. However, the study found that the risk of evacuation failure was not associated with the age of the head of household or the presence of other seniors, though the report noted that considerable resources might often be required to evacuate seniors. The study also reported that owning pets was the most significant reason that households without children failed to evacuate. The findings on the influence of children and pets were contrary to those reported by the earlier study by Baker (12). The importance of these three factors – having children, seniors, or pets in a household – were examined by the behavioral survey conducted for this study.

Dow and Cutter (17) examined the changing relationships between household evacuation decisions and emergency management practices as the availability and diversity of information on hurricanes increased. They found that residents actively sought information from an array of sources and considered it in light of their own past experiences and understanding of risks to make decisions on whether to evacuate. The study noted that staying abreast of advances in communication technology and understanding their use in risk communication and management will be one of the important measures of success in future hurricane seasons. Just as noted by Heath et al. (16), Dow and Cutter report that protecting and maintaining access to property before and after an evacuation, job obligations, and providing for the care and security of pets may often outweigh the guidance of officials and lead households to not evacuate when safety alone would dictate otherwise. In a follow-on study, Dow and Cutter (7) reported that transportation issues would become more important in coastal evacuations as traffic problems grow and influence decisions to evacuate. Their study, which included a survey of coastal South Carolina residents following Hurricane Floyd in 1999, found that approximately one-fourth of all evacuees took two or more cars and nearly one-half of all evacuees left in a single 6-hour period. They also learned that while the majority of evacuees had road maps, only one-half of those with maps used them. Most germane to this current study, Dow and Cutter found that evacuees remained on heavily congested Interstate routes even though more lightly traveled alternate routes (which were also designated as hurricane evacuation routes) were readily available. Anecdotal information seemed to indicate that though most travelers had access to information on the alternate routes, they wanted assurance that services would be available on the new path and wanted to be sure they would not be isolated in a rural area in an emergency. Dow and Cutter suggested that more work is needed on this aspect of decision-making and issues of services, communications, and security on alternate routes.

Prater et al. (18) examined the distribution of information during 1999's Hurricane Bret, a strong category 4 hurricane, including how information was promulgated before and during the storm. They noted differences in the way that residents used various information sources in the evacuation decision. The importance of a well planned and coordinated communications policy was emphasized. The report included recommendations to use all available media to educate the public in advance of a storm, particularly on plans for reversing Interstate lanes (contraflow traffic) and to increase awareness of alternate routes and destinations. It also recommended the greater use of signs to increase public awareness of evacuation routes and suggested that during an evacuation, officials work closely with local radio stations to improve reporting on evacuation traffic conditions. A survey conducted as part of the study showed that television networks were the single most important source of information prior to the storm; local radio broadcasts were the second most important source. Less than one half of respondents reported any use of local newspapers and less than one-third reported any use of the Internet to get information when they made the evacuation decision.

Lindell, Lu, and Prater (19) collected data on the evacuations from coastal Louisiana and Texas for Hurricane Lili in 2002. They sought to answer questions about the factors influencing a household's decision to evacuate, the information sources relied upon in making the evacuation decision, and the timing of any evacuation. It provides insight on what people might actually do in an evacuation as compared to what they themselves predicted they would do. The study surveyed the importance of the five variables listed by Baker (12) augmented by variables suggested as important by the work of Gladwin et al. (20). The results of the study showed that local news media, especially television, were the most extensively used source of hurricane information for risk area residents. However, it found that evacuation decisions were actually more strongly correlated with reliance on peers and local authorities than with the local news media, implying that the extent to which an information source is used is not the same as the impact it has on evacuation decisions.

Gladwin, Gladwin, and Peacock (20) modeled individual and household hurricane evaluation behavior using data obtained from South Florida residents who had experienced both Hurricanes Andrew in 1992 and Erin in 1995. Results were tested using interview results gained from other South Florida residents in nearby areas who had also experienced Hurricane Andrew. Again expanding on Baker's five variables, they found that key inputs to evacuation decision-making included beliefs about the safety of their own homes, agreement between members on the necessity for evacuating, the physical ability to leave, the time and effort required to evacuate, individual preparedness to leave, and the time available. Additional considerations included the destination's ability to provide medical care for family members who would require it, lodging for pets, economic considerations for food and housing, and whether or not they might be caught in traffic jams along evacuation routes.

Past studies in the field of evacuation behavior have concentrated on the period immediately prior to and at the end of an evacuation. Factors considered by potential evacuees making the decision to stay or leave have been well researched and quantified. The research, which has extended over several decades, allows one to see evolutions in attitudes and factors, such as the influence of age, children and pets, which were discounted as influences by Baker in 1991, but which appeared to be significant in later studies. Due to the emphasis of previous studies on activities and decisions prior to and after an evacuation, the decisions made during an evacuation, specifically the decision made when evacuees are faced with congestion, have been largely unexamined. This study concentrates on the evacuation period, when residents are actually on the road, and identifies and assesses route choice factors. Then, using revealed and stated preference questions, it relates past behavior to future intentions. Changing attitudes towards traffic information and information sources are identified.

2.3. EVACUATION PLANNING

Alsnih and Stopher (21) emphasized the importance of combining the skills and knowledge of law enforcement, transportation planners, and emergency planning professionals when developing evacuation plans. They provide a list of several items that should be included in a transportation analysis, including among these the incorporation of population characteristics for affected areas, use of accurate population response rates and origin-destination pairs, the provision of updated traffic conditions as they become known, and the simulation of changes in link capacities as a result of weather conditions or traffic volumes. The report also includes brief assessments of several emergency existing evacuation models.

Two comprehensive papers by Wolshon et al. discuss areas that should be considered in the creation of a successful hurricane evacuation plan. The papers are a digest of procedures used in several states and localities and offer an excellent source of introductory information. The first of these (22) reviews aspects of planning, preparedness, and response, including decision making in different states, specific planning considerations (including timing, evacuation types, public awareness campaigns, and planning for evacuating those with special needs), and a brief introduction to evacuation modeling. In the second paper (23), the focus shifts to evacuation traffic. The paper includes a very informative, succinct discussion of contraflow concerns and then addresses particular issues involving Intelligent Transportation Systems (ITS). The study notes that as a result of inadequacies in ITS during evacuations for hurricanes Georges and Floyd, emergency managers were unable to direct traffic from overloaded routes to nearby roads that carried little or no traffic.

2.4. ADVANCED TRAVELER INFORMATION SYSTEM INFLUENCE

Subramaniam et al. (24) proposed a system to closely replicate traffic incident management processes in use at the time, ideally representing the expertise of an entire incident management team. The description of system architecture provides a good template for other studies examining the impact of accidents and incidents on a traffic network, including a list of factors considered by traffic controllers desiring to divert traffic to alternate routes to bypass the affected route.

Mehndiratta et al. (25) used data collected in 1997 as part of the ongoing Puget Sound Regional Council's transportation panel travel diary study to identify likely ATIS user groups and showed the potential of segmenting users by travel purpose, demographics, and technological savvy as well as other factors. In contrast to other studies, user group composition was based on respondents' particular needs and intended uses for the information, not demographic characteristics. Goulias et al. (26), using a later year's version of the same Puget Sound regional study, examined the relationships among technology ownership and availability, ATIS awareness, and frequency of ATIS use. Their focus on awareness and use of available information probed an area still not well documented: While many types and sources of information have become available, who are the users and how is the information used?

Khattak et al. (27) sought a better understanding of drivers' en route decision-making in response to traffic delays as a contribution to efforts seeking to reduce traffic congestion. Their work identified several key factors influencing the likelihood of drivers diverting. These factors included:

- The source of traffic information;
- The expected length of delay;
- The regular travel time on the usual route;
- The number of alternate routes used recently;
- The anticipated congestion on the alternate route;
- The gender of the driver;
- The residential location;
- A self-evaluation about risk behavior (personality); and
- Driver stated preferences about diverting.

The study also showed that real-time traffic information broadcasts provided a basis for en route diversion decisions and suggested that the effectiveness of radio broadcasts would increase with information about delay lengths and traffic conditions on alternate routes. A significant finding of the study was the sensitivity of drivers to proportional changes in time delays, as opposed to strict increases in time units. A given percentage increase in the length of delay had the same effect on diversion regardless of the current value of delay. Interestingly, even though the traffic situations queried involved daily commuters – the kind of repetitive actions identified as important by the theory of planned behavior – the study revealed a significant disparity between stated intentions and actual behavior.

In a subsequent study extending this work, Khattak et al. (28) investigated how people deal with unexpected congestion during the pre-trip stage and their responses to Advanced Traveler Information Systems (ATIS). In this study, surveys were taken of automobile commuters in the San Francisco Bay area. In addition to gathering personal information on traveler age, gender, and occupation, the surveys questioned respondents on normal travel patterns, pre-trip responses to unexpected congestion information, en-route response to unexpected congestion information, and their willingness to change driving patterns. A total of 62 survey questions were used, but in the interest of shortening the time required for the survey, individual respondents were not asked every question. Survey questions gathered information on both driver intentions (stated preference) and behavior (revealed preference). The study found that a lack of experience with alternate routes was a critical factor in travelers' willingness to divert and suggested that real-time information on alternatives would encourage diversions.

Al-Deek et al. (29) developed a framework for evaluating the effect of ATIS using a composite traffic assignment model that combined a probabilistic traveler behavior model for route diversion with a queuing model under incident conditions. The study used a simplified corridor with one alternate route and no access considerations in a simulation as a test platform.

Khattak et al. (30) conducted a study to assess whether increasing travelers' access to public traffic information systems is associated with increased use of the information in decisions and also which (if any) information medium is associated with a higher likelihood of influence. The results of a 2006 behavioral survey of over 5,000 individuals in the Research Triangle of North Carolina was assessed. Two logit models were developed; one model represented changes in whether to travel, and the second modeled the decision to divert from the planned route. The study found that travelers are generally reluctant to make changes to routine plans, a tendency attributed to behavioral inertia, even when information was provided that would improve a specific commute. However, it identified a significant increase in the likelihood of plan changes when more than one source of traffic information was used. Of all technologies assessed in the study, the Internet was associated with the highest propensity to change travel decisions (time, mode, route, or trip cancellation), followed by radio and television. However, radio was the dominant influence on changes to routes only. The authors note that at the time of the survey, few Variable Message Signs (VMS) were deployed in the area surveyed.

Scheisel and Demetsky (31) assessed the influence of Dynamic Message Signs (DMS, equivalent to the Variable Message Signs discussed elsewhere in this report) on a traveler's choice to change his or her route. The study was conducted over a one year period in Hampton Roads, Virginia, and the change assessed was the choice to divert from the Hampton Roads Bridge Tunnel (HRBT) to the Monitor-Merrimac Bridge Tunnel (MMBT) based on messages displayed on the DMS system. Data was collected from loop detectors and comparisons were made between traffic volumes when the DMS system was in use with similar periods when the DMS system was not in use. The interchange studied was the Route 44 (now I-264)/I-64 interchange south of the HRBT. This is the last interchange with reasonably close travel times to the north side of Hampton Roads via the HRBT and MMBT. Analyses sought to determine the value of any diversion prompted by the DMS system. Though the results of the study were inconclusive, the report provides a good discussion of the study process and sensitivity analysis.

Paselk and Mannering (32) used duration models to predict the delays encountered by travelers at the US/Canadian border in northern Washington. Delays are encountered when surging numbers of motorists exceed the capacity of customs inspectors. Staffing increases have reduced some delays, but the delays have been difficult to predict and result in periods of both excess and inadequate personnel numbers. Four primary routes are available to motorists in the region. By using queue lengths, Paselk and Mannering sought to accurately and automatically model delay times, provide this delay information to motorists using fully automated traffic information systems, and suggest alternate routes. This rerouting would lower the peak volume faced by any single crossing, potentially resulting in reduced delays, smoother (and more predictable) traffic flow, and fewer accidents. The study process is clearly described, with a detailed discussion of the considerations in and selection of a mathematical model. It also includes a listing of concerns the authors had with the validity of data and the model.

Yim et al. (33) used information gained from behavioral surveys in the San Francisco Bay Area between 1995-1999 to develop a conceptual model assessing the value and impact of travel information sources. Though assessing survey data now 10 or more years old, the report already noted a reduction in the availability of radio traffic information, though radio remained the most frequently used source. The study also reported an increase of the Internet and cellular telephones as sources of pre-trip information, though at the time of the survey neither was as frequently used as now seen. Analysis also showed that survey respondents who used the Internet and cellular telephone as sources were more likely to make travel changes as a result of information received. Survey information showed that the most desirable types of information in order of desirability were:

1) Current traffic conditions, frequently updated.
2) Detailed information about alternate routes with compared travel time.
3) In-car navigational computer with a display showing roads and location of congestion.
4) Estimate of delay due to unexpected traffic congestion.
5) Estimate of time to get from origin to destination on various routes.
6) Interactively accessible information about traffic conditions at specific locations.
7) Detailed information about alternative modes including schedules and stops.
8) Automatic notification of unexpected traffic congestion.

The study recommended the conduct of additional simulation studies to assess the benefits of the information reported.

Pan and Khattak (34) assessed the benefits of dynamic traveler information and its effect on traffic network delays when 1) travelers observe the incident, 2) the percentage of commercial trucks in traffic increases, 3) truck drivers divert to alternate routes at the same rate as other motorists (as opposed to a lower rate of diversion), and 4) when commercial trucks are assigned a higher value of time compared with passenger vehicles. A basic five-link model was used with approximated values of time for automobile and truck drivers to assess total driver costs. Substantial network performance benefits, including reduced average travel time and reduced total travel cost, were predicted by effectively disseminating traveler information even though the study considered only the difference in value of time in the benefits analysis. The authors predicted that considerations of other factors, such as the impact on network congestion and total travel times, costs associated with late arrivals, fuel, hazardous emissions, and inventory uncertainties would likely increase the benefit of dynamic information.

Another study on the impact of ATIS showed that travel characteristics, the time of information provision (pre-trip vs. en route), the source, and the content of information significantly affect commuter's switching decision. Using data obtained from travelers' diaries collected for the Puget Sound Region Council studies, Tsirimpa and Polydoropoulou (35) examined the influence of information obtained on changes in travel behavior. The report contains a summary of several pertinent travel surveys and studies since the early 1990s, useful to gaining insight into driver behaviors and survey development. Development of models is well described. The authors found that significant inertia must be overcome to prompt route changes; travelers tend to maintain habitual route patterns. The greatest impact on route changes was obtained when travelers were provided information that led to a reduction in total travel time. The study reported that different sources of travel information were found to be more attractive to different market segments, a result that could be used to better target information to specific demographic groups.

Many studies, including (but certainly not limited to) those by Baker (12), Dow and Cutter (17), Lindell et al. (19), Fu et al. (36), and Fu et al. (37) note the significant impact of advice or orders from public officials with respect to hurricane evacuations. In fact, Fu and Wilmot (38) note that in an analysis of evacuations for Hurricane Andrew, "All else being equal, the presence of an evacuation order makes a household 1.7 times more likely to evacuate" (p. 216).

2.5. EVACUATION MODELING

Many transportation simulation packages exist and simulations are now applied to almost all aspects of transportation planning and design. Few, however, are specifically intended for use in evacuations, and thus those employing packages for this purpose must use particular care. Fu and Wilmot state this most clearly: "Travel during a hurricane evacuation is very different from the day-to-day travel modeled in conventional urban transportation planning. It involves long travel times, high levels of extended congestion, the uncertainty of road conditions on the route ahead, and the possibility that destinations may need to be changed because of closed roads or excessive congestion. In urban transportation planning, many trips are discretionary, in that they can be postponed from one time to another or, in certain cases, forgone entirely. However, in an evacuation, relatively little flexibility on timing is available and evacuation is sometimes mandatory, thereby virtually eliminating the discretion of the individual traveler. Evacuees are also generally more willing to follow directions from officials as to which route to use and are less likely to choose the shortest path than urban travelers making regular trips" (39, p. 19).

Southworth (40) reviewed the state of regional evacuation modeling nearly 20 years ago. Though the software tools discussed and the simulations described are now dated, the work remains an excellent source for understanding model development, considerations, and difficulties. It includes an exceptionally good discussion on how to create traffic generation models and the difficulties encountered when assessing local populations depending on time of day. A section on testing, analyzing, and revising models after development is very informative.

Murray-Tuite and Mahmassani (41, 42) used microscopic level trip chain simulations and linear programming to predict delays and traffic densities occurring before an evacuation begins, primarily as households travel within home regions to gather all members before leaving. Their work predicted evacuation time increases of up to 50% greater than predicted by those who failed to consider such trips and provides a framework for incorporating household trip-chaining behavior into network evacuation models. The simulations consider a relatively small number of vehicles, but a high number of road segments assessed (as compared to regional evacuation models). Factors identified in the reports were valuable to the development of questions that assessed behaviors when confronted with congestion.

Wilmot and Mei (9) compared the relative accuracy of various forms of trip generation for evacuating traffic, testing different models using data from evacuations for Hurricane Andrew in southwest Louisiana. Neural network and logistic regression models predicted evacuation more accurately than traditional participation rate models.

Theodoulou and Wolshon (43) reported on a model created to evaluate the planned use of contraflow in a hurricane evacuation from New Orleans. Like Hampton Roads, New Orleans has a large population, few evacuation routes, a very high number of water crossings, and low surface elevation above sea level. Considerations in the development of a plan for New Orleans were thus very similar to those needed in Hampton Roads. The study in New Orleans compared traffic flow directions and volumes and predicted high evacuating populations with real world observations from recent hurricanes, results not available in Hampton Roads. The model was developed using CORSIM, a microscopic transportation simulation. This program limits the total number of vehicles that can be simultaneously modeled in a simulation and also the maximum time period the model can represent. This restricted the simulation to relatively small sections of roadway and short time intervals (one hour). Even so, the model was able to clearly show the significant benefits of using contraflow while also identifying improvements that should be made to the existing plan.

Williams et al. (44) developed a simulation of contraflow operations planned for evacuations from coastal North Carolina in the event of high Category 2 or stronger storms. The report includes the researchers' suitability assessment of several simulation software packages, but like Theodoulou and Wolshon in the aforementioned New Orleans study (43), CORSIM was eventually selected. Research included a post-Isabel evacuee survey and provided estimates for participation rates, valuable in that Hampton Roads and North Carolina residents may react similarly to hurricane threats, though North Carolina has a higher frequency and severity of hurricane landfalls. As in the New Orleans study, researchers found that the success of contraflow operations depends largely on traffic management at the entrance and exit points and the length of queues developed at these nodes.

Barrett et al. (4) pointed out that traditional transportation models were designed for long range planning with fixed and easily determined origins and destinations, but that evacuations are by nature neither fixed nor orderly. Their report emphasized the importance to behavioral modeling of accurate information about a population's makeup, including age, household size, education, and income level. They also highlighted the necessity of hurricane models being able to incorporate changes in destinations and route choices as they occur during an evacuation and also being able to simulate the use of intelligent transportation system technologies. They provided guidance on the development of dynamic traffic models for hurricane evacuations, including considerations of timing, the area involved and its population, anticipated destinations, the status of the transportation network, and other factors and provide sample flow diagrams for developing a planning model.

Fu and Wilmot (39) presented work using a sequential logit model to represent hurricane evacuee response. The model developed assumed that the decision of whether to evacuate and the decision when to evacuate are made together. It also assumed that households repeatedly review and assess all factors involved in the evacuation decision, choosing to evacuate if the assessed risk of staying exceeds a threshold set by the decision-maker. Fu, Wilmot, and Baker (36) reported on continued work with sequential logit models. Fu and Wilmot (38) expanded work in this area with the development of two dynamic travel demand models for hurricane evacuation which used survival analysis and were subsequently tested using data from evacuations in Louisiana for Hurricane Andrew. The first model used a Cox proportional hazards model and the second a piecewise exponential model. The two models were used to estimate households' probability of evacuation within discrete time intervals before hurricane landfall. Model inputs include socioeconomic characteristics, hurricane characteristics, and the timing, method, and applicability of evacuation orders from authorities. Both models were found to produce acceptable results, but the piecewise exponential model had the advantage of being capable of accommodating time-dependent variables. The report describes model development and testing.

Fu et al. (37) sought to develop a hurricane evacuation response curve that considered the influences of hurricane characteristics, time of day, and the type and timing of the hurricane evacuation order. Building on the findings of previous studies, their work began with a sequential logit model and sought to calculate the utilities of a household evacuating or not evacuating in a particular time interval. Data from the evacuation in South Carolina for Hurricane Floyd in 1999 was used to create the model; data from the evacuation for Hurricane Andrew in Florida in 1992 was used for validation testing. The report is especially useful to those wishing to model the impact of different variables and conditions on evacuee response rates and provides an example of assessing the importance of different variables. The report provides a description of how the model was developed and the different factors considered including figures for several hurricane evacuation scenarios.

Liu et al. (45) noted that different parts of an evacuation network may suffer different levels of severity over different time windows and pointed out the importance of minimizing surges of traffic demand. Their work focused on the use of staged evacuations, in which populations from different geographic areas would be directed to begin evacuating in pre-determined time increments, to minimize adverse impacts to traffic flow. A cell based network model used demand generation to smooth traffic flow and reduce congestion on an evacuation network by providing a more uniform distribution of vehicle loading onto the network. In the model, only the starting time for the evacuation of each staged zone could be controlled. Their report provided a method of optimizing start times for the evacuation of each zone, but did not address adjustments to traffic flows caused by events after an evacuation had begun.

Dixit and Radwan (46) looked at the congestion that occurs during evacuations as a result of a large number of evacuating vehicles overloading the limited capacity of exit ramps offloading traffic onto the heavily loaded network of a destination city. Their report asserts that the extended travel times reported by evacuees at the South East U.S. Regional Transportation Analysis Meeting in 2000 were primarily the result of evacuees overloading the limited capacity of exit ramps at the end of the evacuation routes. In their pursuit of a remedy to this issue, Dixit and Radwan used microscopic modeling and a process they term "network breathing." This process is a method of using external controls to throttle on and off the entry of evacuating vehicles exiting the evacuation network, allowing congestion developed at exit points to clear, thus managing congestion and improving outflow. This process is a shorter term example of the congestion clearance noted in Robinson et al. (47) when during nighttime periods with all new evacuation starts curtailed, severe congestion cleared, reducing the travel times of those evacuees beginning their trips at daybreak the following morning.

Han et al. (48) recognized the abundance of studies and processes being developed to optimize evacuation and planning and saw in this abundance the need for a set of well-defined metrics for evaluation. They noted that the major challenge faced in any large-scale evacuation is that the surge of evacuees usually far exceeds the capacity of the transportation network available. Since the high cost of increasing traffic network capacity likely disallows it as a solution, identifying new ways of maximizing the utility of available capacity must be the focus. Their report proposes a four-tier evaluation system, with tiers including total evacuation time, individual travel times and exposure, and temporal/spatial risk factors. Within each measure of effectiveness tier, an optimization formulation was presented. The discussion and development of these formulae are valuable to better understanding factors impacting evacuations.

The cited works and many others are useful for planning mass evacuations, but leave important questions unanswered. None model the accidents and incidents that may be anticipated during an evacuation and how these impact traffic flow and evacuation times. None explicitly look at how evacuees make decisions during an evacuation (as opposed to prior to) and how these decisions, especially decisions to take an alternate route, affect overall traffic flow. None assess the traffic information sources referenced during an evacuation and the influence these sources have on route-choice decisions. None used a mesoscopic simulation system to view animation of a very large (hundreds of thousands of vehicles) regional evacuation. Robinson (49) describes a hurricane evacuation simulation project that used a mesoscopic simulation to model a large regional evacuation. The project integrated anticipated accidents and incidents and assessed their impact on traffic flow and evacuation times, an aspect addressed in detail in the earlier study (47). The simulation developed provides the laboratory used in this current study. Because of the extent of its innovations and its direct application to this study, the simulation is described in detail in Section 3. The current study extends the simulation by exploring the variables associated with decisions to take an alternate route, integrating the D-M model in the traffic simulation, and simulating the resultant impact on traffic flow using a dynamic evacuation simulation.

2.6. ROUTE CHOICE EXPECTATIONS

Using information from the literature review, several factors were hypothesized to increase an individual evacuee's likelihood of taking an alternate route when confronted with congestion. These factors include:

- The likelihood of taking an alternate route will monotonically increase with the length of time spent in congestion.
- Evacuees using more real-time or on-demand traffic information sources (GPS, mobile phones) would be more likely to take an alternate route than those using passive receipt information sources (VMS, radio).
- Provision of information increasing an evacuee's sense of security or safety, such as reporting on the availability of services or indicating the guidance of on-site police, would increase the likelihood of taking an alternate route.
- Individuals traveling alone (and thus immediately responsible for only themselves) were expected to be more likely to take an alternate route than evacuees traveling as a group, especially in groups that included children or those with special medical or lodging requirements.
- Demographic factors, such as age, gender, education level, and household income, were expected to influence route choice decisions, but the impact of the factors on whether to take an alternate route was undefined.

2.7. MATHEMATICAL MODELS AND METHODS

2.7.1 Michaelis-Menten Equations

Michaelis-Menten equations are typically used to model simple chemical reactions between enzymes and substrates. They relate the initial reaction rate v_0 to the initial substrate concentration S and the Michaelis constant (K_M) for the reaction. The equation is normally written:

$$v_0 = \frac{v_{\max} S}{K_M + S}$$

Values for each of the factors are easily obtained by observation and graphical analysis. Analyses of survey responses revealed evacuees' intentions to divert when faced with congestion may be graphed as a Michaelis-Menten function. This use is described in Section 5.3.

2.7.2 Negative Exponential Equations

Cumulative distribution functions may be modeled as negative exponential equations with the form $f(x,\gamma) = \alpha(1 - e^{-\gamma x})$ where both x and γ are greater than zero and α is a constant. These functions are used to describe events in Poisson processes, where successive events occur continuously and independently of one another at a constant average rate. Modeling as a Poisson process requires three conditions be met:

1) Events occur individually;
2) The number of events occurring in one time interval is independent of the number of events occurring in a prior interval; and
3) The distribution of arriving events is independent of time for all times assessed.

The first two conditions are met by decisions made by evacuees when faced with congestion may be modeled as Poisson processes since (1) each evacuee reaches the decision point independently and continuously (decisions are not made by groups of evacuees at once) and (2) the number of arrivals during one time interval is independent of the number arriving at prior intervals. However, if the time interval measured were large (such as for an entire day), the decisions made by evacuees could be influenced by other factors related by time, such as the change from day to night or drivers facing extreme fatigue with extended travel times. This third condition can be met by limiting the length of the analysis time. Modeling of decisions using a negative exponential function is described in Section 5.5.

2.8. ANALYSIS OF RESULTS FOR STATISTICAL SIGNIFICANCE

2.8.1 Applications with Binomial Distributions

Significant simplification of analyses can occur when dealing with binomial distributions and Bernoulli variables (a variable with two outcomes, where one has the probability p and the other probability q). Survey responses are typically provided in terms of yes (x_i=1) and no (x_i=0).

Consider a situation where n total responses are received with n_1 yes responses and n_0 no responses. Note that the response mean, $\bar{x}$, is equal to the number of yes responses divided by the total number of responses.

$$\bar{x} = \frac{n_1 * 1}{n} = \frac{n_1}{n}.$$

It is easy to see that the mean is actually equal to the probability (p) of a yes response, such that $p = n_1 / n$. Likewise, the probability of a "no" response, q, is seen to be

$$q = \frac{n_0}{n} = \frac{n - n_1}{n} = 1 - p.$$

Therefore, the variance of a binomial distribution is seen to be

$$\sigma^2 = \frac{\sum (x_i - \bar{x})^2}{n} = \frac{n_0 p^2 + n_1 q^2}{n} = \frac{n_0}{n} p^2 + \frac{n_1}{n} q^2 = qp^2 + pq^2 = qp(p+q) = qp.$$

Since $q = 1 - p$, $\sigma^2 = p(1-p)$ and the standard deviation is simply $\sigma = \sqrt{p(1-p)}.$

2.8.2 Welch's t-test

In a Student's t-test, the t variable is defined as $t = (\hat{\theta} - \theta)/s_{\hat{\theta}}$, where θ is the population parameter of interest, $\hat{\theta}$ is the parameter estimate determined by a random sample, and $s_{\hat{\theta}}$ is the standard error of the sample estimate. The t-test requires that the distribution be normally distributed. The Welch's t-test is an adaptation of the Student's t-test and is used for two samples that may have unequal variances.

When used to test whether population means are different, $t = (\bar{x}_1 - \bar{x}_2)/s_{\bar{x}_1 - \bar{x}_2}$ where $\bar{x}_i$ is the sampled population mean and $s_{\bar{x}_1 - \bar{x}_2}$ is the standard deviation of the sampling distribution. When used to analyze binary results, the means are equal to the probabilities, and for a Bernoulli random variable (a variable with two outcomes, where one outcome has probability p and the other has probability (1-p), the variance is p(1-p). Therefore, the magnitude of t is calculated as:

$$|t| = \frac{\bar{x}_1 - \bar{x}_2}{s_{\bar{x}_1 - \bar{x}_2}} = \frac{|p_1 - p_2|}{\left[\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}\right]^{1/2}}$$

Analysis of the *t* value significance requires determining the degrees of freedom. This was calculated using the Welch-Satterwaite Equation.

$$df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\left[\frac{s_1^4}{n_1^2(n_1-1)} + \frac{s_2^4}{n_2^2(n_2-1)}\right]} = \frac{\left[\frac{n_1 p_1(1-p_1)}{n_1} + \frac{n_2 p_2(1-p_2)}{n_2}\right]^2}{\left[\frac{(n_1 p_1(1-p_1))^2}{n_1^2(n_1-1)} + \frac{(n_2 p_2(1-p_2))^2}{n_2^2(n_2-1)}\right]} = \frac{[p_1(1-p_1) + p_2(1-p_2)]^2}{\frac{[p_1(1-p_1)]^2}{(n_1-1)} + \frac{[p_2(1-p_2)]^2}{(n_2-1)}}$$

Results were used with the TDIST function in Microsoft® Excel® to obtain a p-value. A p-value 0.05 or less implies there is a 95% probability that the two compared data sets were collected from different samples and the difference in responses is statistically significant.

Survey responses were assessed considering Strongly Agree and Somewhat Agree answers as positive (value equal to 1) and neutral, Somewhat Disagree, and Strongly Disagree answers as negative (value equal to 0). An average value was calculated for the positive responses and converted to a probability scale between 0 and 1.

3. A DYNAMIC HURRICANE EVACUATION SIMULATION

Robinson (49) reports the development of a mesoscopic simulation of Virginia's plan for evacuating the Hampton Roads region in southeastern Virginia in the event of a hurricane. This work was critical to the development of ideas and methods used elsewhere in the research. The simulation provided the test platform for research. Because of its importance, it is described in detail in this section.

Virginia's evacuation procedures for Hampton Roads in 2008 employed six designated egress routes. Three of these routes (US 58, US 460, PR 10) are south of the James River, which bisects the northern and southern halves of the region, and proceed west towards Emporia or northwest towards the Richmond-Petersburg metropolitan area. Two of those on the north side of the James River also head towards Richmond (US 60, I-64); the final exit route (US 17) leaves to the north. Each route requires passing over multiple bridges and may also necessitate traveling through one of the region's four tunnels. Figure 2 shows the exit routes from the region and connections to I-95.

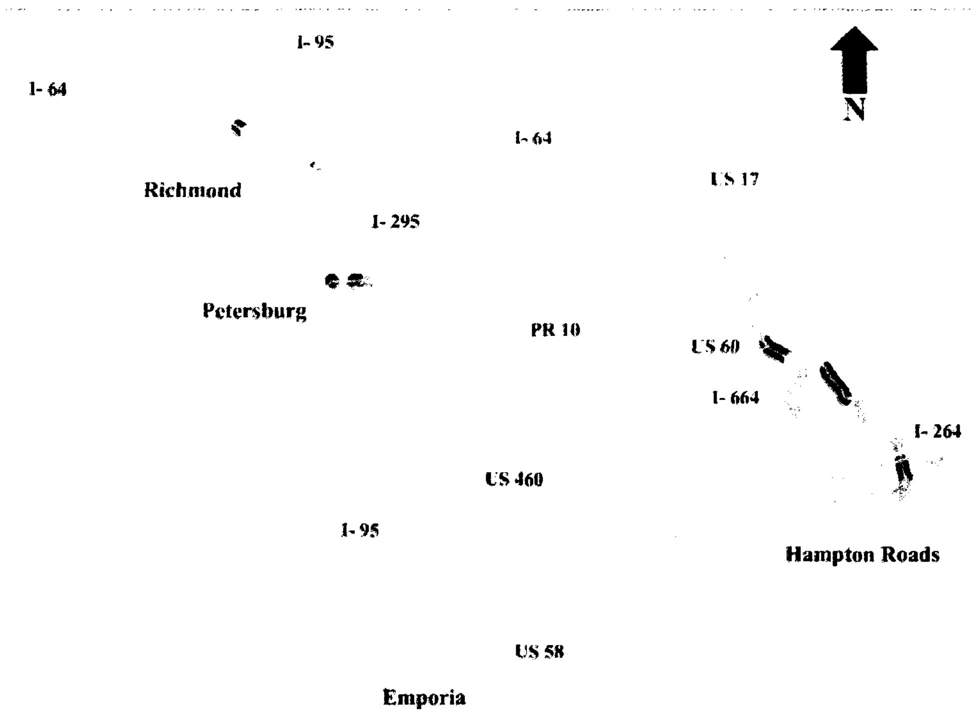


FIGURE 2 Hurricane evacuation routes from Hampton Roads.

The evacuation simulation focused on the six designated exit routes and connecting Interstate segments. The simulation uses the Virginia state traffic demand model. The portion representing the Hampton Roads region was updated with regionally specific information provided by the Hampton Roads Planning District Commission and then further updated with the addition of Interstate and highway on/off ramps (modeled as intersections in the macroscopic model) and increased detail and accuracy in the assignment of road segment characteristics.

The simulation uses Citilabs® Cube Avenue®, a mesoscopic traffic simulation. With Avenue, one can control the rate at which vehicles begin trips (dynamic vehicle loading), a feature very important when modeling the rate at which endangered citizens begin their evacuation. The simulation also allows using multiple load rates in the same simulation run, a feature that allowed tailoring the rate of vehicle loading for origin location (primarily the residence's flood zone), dwelling type (permanent home, mobile home, hotel or motel), and the length of time since the regional evacuation began. These modifications are further discussed in subsequent sections.

The simulation models anticipated traffic flow from the region prior to the arrival of Category 1 through Category 4 strength hurricanes (Saffir-Simpson scale). Evacuating vehicles are loaded into the simulation at rates representative of those expected in a hurricane evacuation and merge with background traffic. In a significant advance over previous mass evacuation simulations, the impacts of vehicle accidents and incidents on traffic flow and travel times are modeled. Figure 3 summarizes the steps used in simulation development.

3.1. VEHICLE LOADING

Vehicles were loaded into the network in two main groups: background traffic (vehicles not evacuating the region) and evacuating traffic. Each group used a different dynamic load rate and matrix. Vehicles enter the network at Traffic Analysis Zone (TAZ) nodes in the Hampton Roads Traffic Demand Model (HRTDM) provided by the Virginia Department of Transportation (VDOT). From the TAZ nodes, traffic traveled to evacuation routes via arterial connections. The simulation focuses on the six main evacuation routes and no evacuation specific changes (signal light adjustments, on site traffic control, etc.) were considered on feeder arterials. A regional daily O-D matrix was provided by VDOT and was used to model background traffic. Concurrent with development of the hurricane evacuation simulation, the Virginia Department of Emergency Management (VDEM) contracted a survey and analysis to assess the region's readiness for and anticipated response to a hurricane evacuation (11). At the request of VDEM, evacuation simulation participation rates, response rates, and evacuation destinations were guided by this analysis. An origin-destination matrix for evacuating vehicles was created with origins in appropriate TAZ and destinations guided by the Baker report. Only evacuations using privately owned vehicles were considered (no public transportation). Vehicle occupancy was assumed to be 2.3 persons/vehicle.

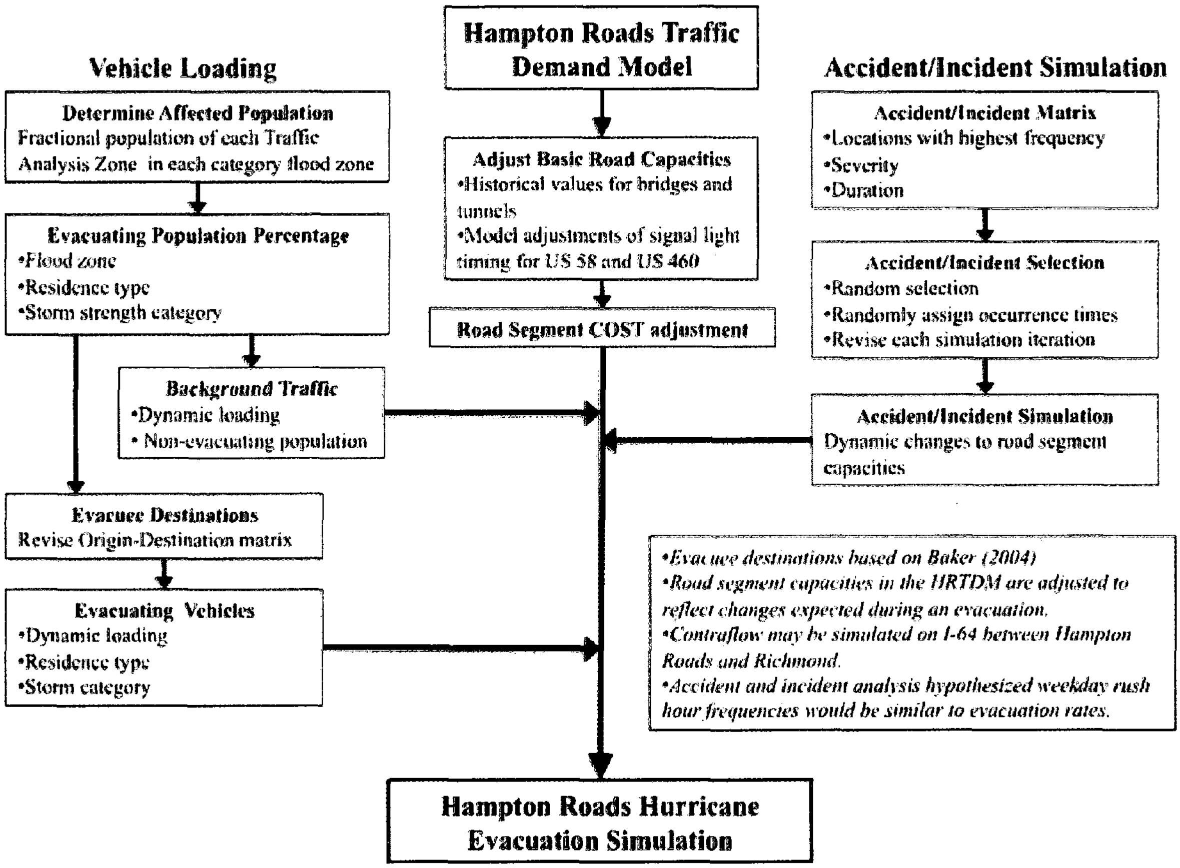


FIGURE 3 Evacuation simulation development process.

3.1.1 Evacuee Participation and Response Rates

Individual decisions of whether to evacuate are obviously largely influenced by whether a person lives in an area potentially affected by the storm, especially by potential flooding. The simulation models evacuation groups that correspond to the storm flood zone assigned by the U.S. Army Corps of Engineers. The decision to leave is also influenced by the perceived ability of the dwelling to withstand a storm, with mobile home residents much more likely to evacuate than residents of less substantial structures. The simulation models these influences by providing escalating evacuation participation rates as storm strength increases and dwelling permanence decreases. Since no hurricane evacuations have been ordered for the Hampton Roads region, after consultation with the project sponsor, evacuation rates were set to agree with those suggested by Baker (11). For example, in a category 1 hurricane 55% of all permanent home residents living in level 1surge zones will evacuate. If a category 2 hurricane is simulated, 60% of permanent home residents in level 1 and 2 zones evacuate; for category 3 and higher storms, 70% of residents evacuate. All storm strengths assume 90% of mobile home residents living in the affected zone or lower evacuate. Residents of zones not expected to be affected by the storm may also evacuate even though not required. This is called shadow evacuation and is also considered in the simulation. By default, 20% of residents in the next higher flood zone are assumed to evacuate. The simulation assumes all evacuees use personal vehicles; no buses or other modes are modeled.

Evacuating vehicles are dynamically loaded onto the network. A logistic curve estimates the evacuee response rate. A logit function can be written as $f(z) = 1/[1+e^{-z}]$. As the value of the exponent in the "e" term increases, the term shrinks to a value ever closer to zero and the value of $f(z)$ increases to near the maximum value of 1. An explanation of logit modeling for evacuation analysis may be found in Hobeika and Kim (50). A detailed discussion on tailoring regression coefficients to accurately reflect conditions for a specific scenario is found in Fu et al. (37). When used to model an evacuation response rate, the logit function can be rewritten as:

$$p(t) = \frac{1}{1+e^{-\alpha(t-H)}}$$, where

- $p(t)$ = fraction of evacuees who have begun evacuation by time = t
- t = time since evacuation order was issued (minutes)
- H = time by which ½ of all evacuees have begun evacuation
- α = factor influencing the rapidity of response

This equation is modified (40, 51) by creating a value "δ" equal to αH, such that $p(t) = 1/\left[1 + \delta e^{-\alpha t}\right]$. Using this equation and assigning a value for the percentage of evacuees leaving in advance of the evacuation order enables determining the value of δ. For example, when 10% of evacuees leave in advance of an evacuation order, $p(0) = 0.1 = 1/[1+\delta]$, leading to $\delta=9$. This result was used with the three suggested response rate curves by Baker (11) to determine values for H and for α. For the three suggested rates used, H is 5.6 hours (for rapid responses), 8.4 hours (for medium responses), and 12.5 hours (for slow responses). Respective values for α are:

- Rapid response rate $\alpha=6.539*10^{-3}$
- Medium response rate $\alpha=4.360*10^{-3}$
- Slow response rate $\alpha=2.930*10^{-3}$

The simulation normally uses the slow response rate for those living in permanent residences, who are assumed to require more time to prepare and be generally less inclined to evacuate; the fast rate is used for residents of mobile homes and temporary residents (primarily tourists). On the first full day following a mandatory evacuation order, when preparations for leaving would likely have been completed, all evacuees are simulated to leave at the rapid rate. Figure 4 displays the three response curves with these rates. No evacuations are initiated during hours of darkness, modeled as 8 PM to 6 AM. Prior to each evacuation run, the user determines the hurricane strength and the time of the evacuation order. The hurricane strength determines the number of evacuees and the time of the order is used as the time the evacuation begins. Early evacuees make up 10% of all evacuees and leave in the three-hour period prior to the evacuation order time. The main evacuation begins at the time of the evacuation order (time zero in Figure 4). Appropriate evacuees are randomly selected from the matrix of all evacuees. Total evacuees range from approximately 155,000 for a Category 1 hurricane to over 915,000 in a category 4 storm. Category 3 hurricanes, the strongest reasonably expected, simulate the evacuation of almost 690,000 residents. Using the simulation and assigned participation, the estimated time required for category 2 storm evacuees to clear the region ranged from two to five hours and the time to reach planned destinations typically ranged from two to seven hours. Under non-evacuation conditions, the same trips would

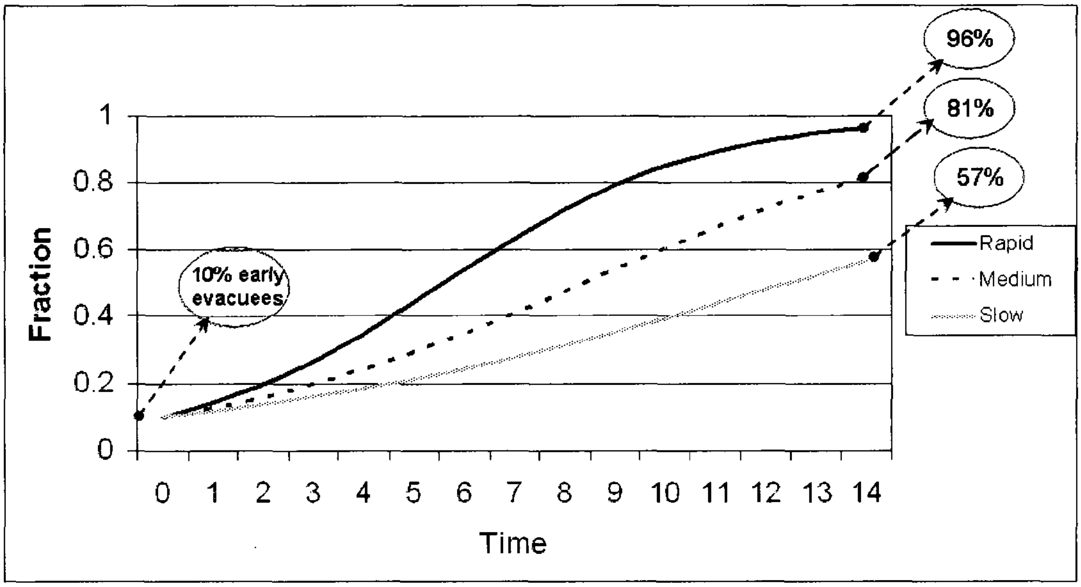


FIGURE 4 Modeled fractional evacuee departure rates.

require two to four hours. Table 1 summarizes the number of evacuees from each flood zone for each category storm. The second column in Table 1 provides the total number of people living in the indicated flood zone. Columns 3 through 6 show the number of people in that flood zone expected to leave at the expected storm strength.

TABLE 1 Evacuating Population and Number of Vehicles from Each Flood Zone for the Indicated Storm Strength

Flood Zone	Total Modeled Population	Evacuating Population and Vehicles for Indicated Hurricane Strength			
		1	2	3	4
1	182,187	100,202 43,566	109,312 47,527	127,531 55,448	127,531 55,448
2	276,818	55,364 24,071	166,091 72.213	193,772 84,249	193,772 84,249
3	438,987	0 0	87,797 38,173	307,290 133,606	307,290 133,606
4	301,235	0 0	0 0	60,247 26,194	210,865 91,679
Other	392,039	0 0	0 0	0 0	78,408 34,090
Total	1,591,266	155,566 67,638	363,200 157,913	688,841 299,496	917,867 399,072

The simulation allows selecting either high or low background traffic levels. When high background traffic is selected, 80,000 vehicles/hour are loaded on to the network until the start time for the evacuation. The rate of background traffic then decreases linearly until equaling 12.5% of first hour volume, at which time the addition of background traffic ends. Low background traffic rates follow the same pattern, but begin at ½ the initial rate (40,000 vehicles/hour). No background traffic is simulated outside of the region. Background traffic begins prior to the start of an evacuation to ensure evacuating traffic does not unrealistically access roads devoid of other vehicles.

3.2. ROAD CAPACITIES

The HRTDM provided by VDOT required adjustments to some road capacities to better replicate conditions expected during a hurricane evacuation to account for temporary changes at intersections to maximize flow. Changes made in the simulation were assigned with assistance from the Virginia Transportation Research Council (VTRC) and using the guidance of the Transportation Research Board (TRB) Highway Capacity Manual 2000 (HCM) (52).

Freeway capacities within the metro area were assigned using a base free flow speed (base FFS) of 70 mph that was adjusted per the HCM for lane width, lateral clearance, number of lanes, and interchange density. The average adjusted FFS calculated across the region was 65.45 mph. The HCM provided maximum service flow rate capacity for a freeway with this FFS is 2350 passenger-cars/hour/lane (pcphpl). The presence of tractor-trailers, buses, and large recreational vehicles also influence the rate of traffic flow, and Hampton Roads hosts the third largest port on the East Coast and has large volumes of tractor-trailer traffic. It is also a tourism center with significant amounts of tour bus and recreational vehicle traffic, especially during the summer months, coincident with hurricane season. After adjusting for these types of vehicles, the maximum hourly Interstate capacity was reduced to 2075 vehicles per hour per lane (vphpl).

Historical peak period traffic counts measured during the August – October hurricane season were provided by VTRC and used to assign values for the Hampton Roads Bridge Tunnel (HRBT), the Downtown Tunnel (DT), and the High Rise Bridge. These are the most restrictive road sections along the six regional evacuation routes. The hourly values used are:

- HRBT: 1870 vphpl
- DT: 1800 vphpl
- High Rise Bridge: 1930 vphpl

The posted speed limits along divided multilane highways outside of the Hampton Roads I-64/I-664 beltway ranges from 35 mph (through populated areas) to 60 mph (in rural areas). An average of 50 mph and base capacity of 2000 vphpl was assigned. This value is modified to determine actual flow capacities in much the same manner as is done for freeway traffic. After adjustment, a capacity of 1785 vphpl was determined and used in the simulation for all non-freeway multi-lane highways.

Two special case roadways were assessed separately. Areas along the US-58 Bypass through southern Suffolk and all of Route 10 have higher population densities than most rural areas and a large number of traffic signals. The Commonwealth Hurricane Emergency Response Plan directs the Virginia State Police to implement traffic enhancements, as necessary, particularly at intersections, to maximize westbound traffic flow. With the assistance of VTRC, HRTDM assigned capacities were revised with the assumption made that signal cycle lengths will be adjusted to provide 70% of the cycle to outbound movements. Revised capacities for the two road segments are 1146 vphpl on this US 58 segment and 1244 vphpl for the length of Route 10.

3.3. ROUTE ASSIGNMENT

The traffic simulation used (Citilabs, Inc.® Cube Avenue®) provides for vehicles' route selection using the variable COST. The equation used to calculate COST can be defined by the user; the default equation uses the sum of all link travel times on available routes from a vehicle packet's current position to the end destination. The value of COST is first calculated just prior to vehicles entering the network, when the software assesses and compares the length of each segment, the anticipated vehicle speed, and any delays caused by existing volume on a segment for each possible route. When high volume on the segments of an O-D route results in longer trip times, the COST calculated for that route rises. During each time segment, the simulation calculates remaining COST for all vehicle packets on all available routes; each packet then moves forward to the destination along the route with lowest COST (reversing direction to a route already passed is not possible).

The number of COST calculation iterations completed each time segment is also user assigned. The default number of iterations for Avenue is one calculation per time segment. With nearly one hundred time segments in a typical evacuation simulation run, the large number of O-D pairs (and thus potential routes), and the modeling of 25,000 or more packets, attempting more than one iteration per time segment frequently resulted in the simulation software freezing.

Vehicle packets were predisposed to remain on designated evacuation routes by adding a multiplying factor to the link travel times in the COST calculation for other routes. In order to assess the importance of route compliance, varying magnitudes of this multiplying factor were tested. With all routes equally assessed (multiplying factor set equal to one), each individual packet sought uniquely beneficial routes. The lack of controlled traffic flows resulted in extensive congestion throughout the network and the time required to complete a regional evacuation exceeded the design length of a simulation run. When the multiplying factor was set high, all vehicles remained assigned to the designated routes regardless of the state of congestion. This, too, extended the time required to complete an evacuation beyond the limiting number of time intervals. (The CUBE system includes more refined route assignment using a modified Frank-Wolfe algorithm, but this has no effect when only a single iteration is run.) Increasing the COST of travel on alternate route links by a multiplying factor of 20 provided realistic results. Most vehicle packets remained on the designated evacuation routes, but when congestion was most severe, some packets switched to alternate routes.

3.4. MODELING TRAFFIC INCIDENTS

No hurricane has made landfall in Hampton Roads in more than 25 years. No mass evacuation from the region has ever occurred. In the absence of empirical data, the frequency, severity, and duration of accidents and incidents that might occur during a hurricane evacuation were hypothesized to be approximately the same as those observed during rush hour periods during the hurricane season. This section summarizes the estimation and assignment of accidents and incidents used with the evacuation simulation. A more detailed explanation is provided in Robinson et al. (47).

Analysis was made of events occurring during the peak rush hours (4:00 PM-6:00 PM) on weekdays (Tuesday, Wednesday, and Thursday). Regional data for year 2006 was obtained from the Hampton Roads Smart Traffic Center (HRSTC); statewide crash data was obtained from the Hampton Roads Planning District Commission (HRPDC). This data, augmented by information from Hampton Roads Safety Service Patrol (SSP) reports, provides information on most of the incidents that occurred in Hampton Roads including event locations, times of day, durations, and the number of lanes blocked.

Incident durations represent the period during which a SSP vehicle was assigned to respond to the incident. The reported time is often less than the actual incident duration due to delays in SSP arrival at the scene or the arrival of another responder (police or fire department, tow truck operator) superseding the SSP report. Dougald and Demetsky (53) reported that SSP durations are also lower than Virginia State Police (VSP) estimates of incident clearance times.

Using the accident and incident event database developed, a matrix of approximately 100 likely accident and incident road segment locations was created to assign events throughout the course of each scenario run. The simulation assigns all accident and incident events to one of these segments.

The maximum time anticipated to evacuate the region is 70 hours. Three accident and incident scenarios are available with each simulating a different number of events. In the typical case, approximately1650 accidents or incidents are stochastically assigned to the pre-determined locations across the full 70-hour simulation period. Selecting the best case scenario injects approximately 1300 events; the worst case selection simulates over 2000 events. The rate at which events occur remains constant throughout the evacuation period, regardless of time of day or the traffic volume simulated. A lognormal distribution of durations around the median value provided the best fit with reported data and was selected to vary the durations of simulated accidents and incidents.

The impact of accidents was assigned using the following event classifications and severities:

- Abandoned vehicles (5% of all events)
  - 100% of abandoned vehicle incidents affect the shoulder only
- Disabled vehicles (83% of all events)
  - 90% of disabled vehicle incidents affect the shoulder only
  - 10% of disabled vehicle incidents affect one lane

- Accidents (12% of all events)
    - 75% of accidents affect the shoulder only
    - 18% of accidents affect a single lane
    - 7% of accidents affect two lanes

The simulation approximates the impact of an accident or incident by modeling the impact on the road (closure of the shoulder or one or more lanes) and the duration of the event. Road segment capacity reductions used HCM recommendations with the assumption that reductions for freeway impacts could be extended to other highways. Table 2 provides a summary of available capacity remaining as a function of accident severity and number of lanes available (52).

TABLE 2 Simulated Available Remaining Road Capacity (%) Following Accidents or Incidents

Lanes Available (by direction)	Shoulder Blocked	One Lane Blocked	Two Lanes Blocked
2	81	35	0
3	83	49	17
4	85	58	25

The very high number of vehicles simulated and the extended period modeled prevented using the number of time slices that would be required to simulate the actual lengths of simulated events. Instead, the short term impact of accidents and incidents were simulated as hour-long events and capacity reductions. For example, using the HCM, an accident that closes one of three lanes on a freeway for 30 minutes would be expected to reduce capacity by approximately 50% during the time the lane is closed. In the simulation, capacity would be reduced to 75% of normal for one hour.

3.5. HURRICANE EVACUATION SIMULATION RESULTS

Several evacuation scenarios for storm strengths 1, 2, and 3 were selected by the study's sponsor for evaluation. In addition to storm strength, the accident and incident simulation stochastically varied location, duration, and the assigned times of events between scenarios. Each scenario tested included multiple runs, each using a different random seed for stochastic selections.

Forty simulation runs were completed for hurricane category 2, the storm strength used for decision-model testing in this dissertation. The average time after the start of the evacuation required for 95% of evacuees to clear the region was just under 32 hours with the typical accident/incident option selected.

Selection of the worst-case accident/incident scenario increased the time required for 95% of all evacuees to clear the Hampton Roads region by just one hour. However, significant queuing occurred at event locations and individual evacuation times for those directly affected by the simulated incidents increased significantly, but as this impact was not assessed in the study, no detailed analysis was completed.

3.6. EVACUATION SIMULATION LIMITATIONS

The hurricane evacuation simulation forecasts traffic flows that might be expected in advance of a hurricane. Significant simplifications and assumptions were made during its development and should be understood before using its results to plan evacuations for Hampton Roads or extending its findings to other regions. These limitations include:

- No hurricane has made landfall in Hampton Roads in more than 25 years and no mandatory mass evacuation has ever occurred. Participation rates reflect those seen in other states more prone to hurricanes and are likely significantly greater than would actually be seen.
- The simulation uses origin-destination pairings from survey results that underrepresented residents of some areas. This may significantly impact travel times. However, evacuation routes are assigned based on the origin location and volumes in the immediate Hampton Roads vicinity should be little changed.
- Response rates are predicted based on responses seen in other areas. The simulation assumes a slow response by those living in permanent structures – the majority of the region's residents. If an evacuation order was not issued until just a few hours before a storm's arrival, a rapid response would be required. This would place many more vehicles on the road network at the same time and significantly increase congestion.
- The evacuation plan assessed assumes all evacuees clear the area prior to the arrival of tropical storm force winds. The simulation does not directly adjust the

frequency or severity of accidents and incidents due to adverse weather likely to be seen in advance of a hurricane.

- Road capacities on signalized routes are increased using hypothetical changes to green cycle times. Direction to maximize flows on these roads is included in the state's evacuation plan, but signal light cycle time values have not been assigned.
- Arterial roads that feed traffic onto the designated evacuation routes were not included in the modeling and analysis. Congestion on these roads resulting from high traffic volume would likely extend travel times.

4. SURVEY CONTENT, DISTRIBUTION, AND ANALYSIS

The objective of this portion of the study was to understand the route choices made by hurricane evacuees when faced with congestion and how these choices impact the traffic network under evacuation conditions. The three intermediate goals of the study were to:

1) Identify the key factors considered when evacuees decide whether to take an alternate route when faced with significant traffic congestion during an evacuation;
2) Develop a decision-making model of these decisions; and
3) Integrate the decision-making model into a traffic simulation to assess the impact on evacuation traffic of vehicles using alternate routes and bypassing congestion.

A behavioral survey was conducted to gain insight into the key factors considered. This information was used to support the decision-making model. Synthetic data could have been created using insights from the literature review, but this information was reflective of routine situations and not the expected stress-filled conditions of a hurricane evacuation. As was subsequently revealed by the survey, applying previous results to evacuation situations would have produced erroneous results.

A diagram of the survey flow process is provided as Figure 5. Survey development, including selection of variables of interest, a description of scenarios, and an explanation for how survey respondents learned of the study are provided in the following section. Subsequent sections provide results. Section 4.2 addresses the relationship between selected variables of interest and the decision to take an alternate route. Section 4.3 describes the relationship between variables of interest and respondents' gender and age group. Section 4.4 discusses the correlation between time in congestion, information sources and/or level available, and the diversion decision.

4.1. SURVEY DEVELOPMENT

Using information gleaned from the literature review, factors expected to influence potential evacuee decision-making were identified. Most prior studies of evacuation decision-making have focused on the decisions made in advance of a hurricane evacuation. Studies of the influence of Advanced Traveler Information Systems (ATIS)

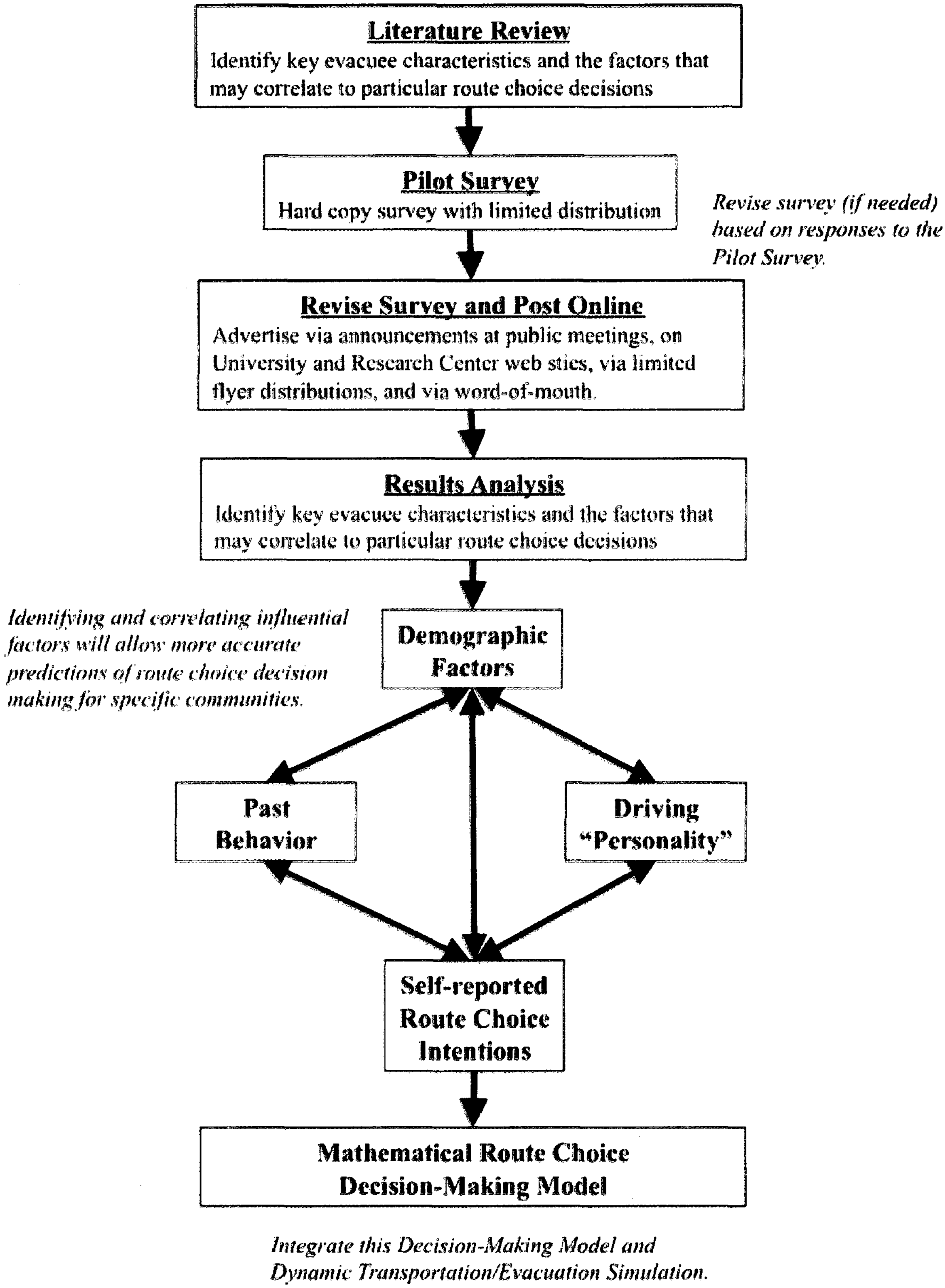


FIGURE 5 Survey flow process.

on decisions made when drivers are faced with traffic delays have assessed routine conditions, not emergency evacuations. In lieu of other information, the influencing factors identified in these efforts were hypothesized to apply to the decisions made during the course of an evacuation and used as a basis for questions in the survey.

Using stated and revealed preference questions, the surveys gathered information on potential evacuees and the influence of these factors. Participants were asked approximately 50 questions. A pilot survey was distributed to assess the adequacy of the survey questions and suggested responses and to identify areas requiring modification. Fifty hard copy pilot surveys were distributed; 32 were completed and returned. The survey was refined and a final survey was made available in both hardcopy and electronic form using a commercial Internet survey product, SurveyMonkey.com. The final version is provided as Appendix A. Results were analyzed using SPSS and Microsoft® Excel® statistical software. Summarized results are provided as Appendix B.

4.1.1 Variables of Interest

Literature reviews identified several variables likely to influence evacuee decision-making. Variables included demographic factors, an individual's past use of traffic information sources and frequency of route adjustments, special needs (lodging requirements, medical requirements) for oneself or members of the evacuation party, and self-assessments of driving behavior and tendencies. The identified variables are listed by general category in Table 3. Each was targeted in the survey.

The survey was used to identify the information types and sources most frequently used by potential hurricane evacuees, allowing development of a decision-making model and assessment of the impact of decisions that might be made on evacuation traffic flow. It also gathered information on the extent of potential evacuees' preparedness for a future evacuation and obtained a self-assessment on how they might respond to congestion during an evacuation when provided with different levels and types of traffic information.

4.1.2 Decision Scenarios

An individual's intended decision whether to divert to an alternate route when faced with congestion during an evacuation was assessed using stated preference questions. Four primary scenarios were tested, each addressing the same progression of increasing congestion, but with either different amounts of information being provided or

TABLE 3 Variables Expected to Influence Evacuee Route Choice Decisions

VARIABLES	EXPECTED IMPACT
Demographics	
Age	The tendency to divert was expected to be inversely related to age with younger drivers more willing to use alternate routes.
Gender	Males were expected to divert at higher rates than females.
Annual income level and education level	Higher incomes and education levels were expected to be related to greater access to and use of ATIS and ability to alter plans (lodging costs).
Household size, traveling with children, and number of vehicles in household	The greater cumulative risk to larger groups and the difficulty of keeping parties together in separate vehicles was expected to reduce the tendency to divert.
Evacuating Party Concerns	
Traveling with others	Cumulative risk was expected to decrease diversions.
Self-reported familiarity with road network	Greater familiarity was expected to increase willingness to divert.
Special lodging requirements and special health concerns for member(s) of evacuating party	Special needs and requirements were expected to decrease willingness to divert from planned routes.
Expected length of individual evacuation trip/evacuation destination	Some association was expected but the type of association was undefined. Those with short trips might be less concerned with delays and refrain from diverting; those with longer trips might be less familiar with local roads, but also less willing to endure long delays.
Planned evacuation destination type (hotel/motel, private residence, shelter, etc.)	Those traveling to public lodging were expected to be more willing to divert.
Personal Characteristics and History	
Self-assessed aggressive driver	Higher aggression was expected to be associated with greater willingness to take alternate routes.
Past history of altering routes to avoid congestion and frequency	Greater past use of alternate routes was expected to be related to greater willingness to divert in an evacuation.
Traffic information sources typically used	Use of traffic information sources was expected to lead to more diversions. Radio and VMS were expected to dominate.
Self-reported willingness to take unfamiliar routes	Associated with greater use of alternate routes.
Past adult participation in an evacuation for hurricanes or other natural disaster	An association was anticipated, but the type of association was not defined.
Confidence in accuracy of traffic information sources	Greater confidence was expected to relate to higher use of alternate routes.
Self-reported familiarity with evacuation route	Greater familiarity was expected to relate to higher use of alternate routes.
Diversions Due to Traffic Information (Stated Preferences)	
Recommendations of alternate routes by police or other public authority on site	Official recommendations were expected to produce higher rates of alternate route use.
Recommendations of alternate routes carried by Variable Message Signs (VMS)	VMS information was expected to produce higher rates of alternate route use.
Recommendations of alternate routes and services availability (food/fuel/lodging) carried by VMS	More complete information messages were expected to produce higher rates of alternate route use.
Recommendations of alternate routes announced via radio messages	Use of public radio announcements was expected to produce higher rates of alternate route use.

using a different source for information transmittal (VMS, on-site State Police, or radio). Each respondent was asked the likelihood of diverting or remaining on the current route for each situation and information scenario.

While evacuees could face traffic congestion at any time during their trip, the survey scenarios specified that congestion was encountered two hours after evacuations began. The two hour mark was chosen as this is the approximate time required to travel from the center of the region to its outskirts under heavy traffic conditions, such as those seen on weekends or holidays, that approximated expected hurricane evacuation traffic conditions. No adjustment was made for the expected duration of the individual respondent's evacuation.

The four scenarios included:

1) VMS suggest an alternate route;
2) VMS suggest an alternate route and say "Gas/Food/Lodging Available";
3) VMS say "Alternate route guided by State Police"; and
4) Public radio suggests and describes an alternate route.

The scenarios and associated variable names are listed in Table 4. Responses for each scenario were assigned variable names in the format "DlyTraf___." The first variable, DlyTrafSlow, is labeled to indicate traffic had just begun to slow. Numbers following the "X" in a variable name indicate the length of the congested period in minutes and the type of information provided. In all scenarios, no information was provided when congestion was first encountered at time "0"; information was provided at times 30, 60, and 120 minutes after congestion was encountered.

4.1.3 Survey Awareness

Other than those who participated in the pilot survey, survey respondents participated by logging onto the Internet and accessing the specific web location on an online website (SurveyMonkey.com). Survey participants were found by word of mouth, via flyers distributed on the university campus and handed out at public venues, announcements posted on the research center and university websites, and via an e-mailed encouragement to respond sent by the Hampton Roads Planning District Commission Metropolitan Planning Organization (MPO). Respondents do not represent a random sampling of the regional population. No information on home addresses was collected.

TABLE 4 Traffic Situations and Information Provided Scenarios

Situation	Information Scenario
Assume traffic has slowed to less than 10 mph and the next exit is visible, but you have seen no information signs.	No situational information provided. (DlyTrafSlow)[1]
Traffic has continued to move very slowly for over 30 minutes.	The next exit is visible. ATIS say "Accident Ahead." (DlyTrafX30_acc)
	ATIS offer alternate route. (DlyTrafX30_alt)
	ATIS suggest an alternate route and say "Gas/Food/Lodging Available." (DlyTrafX30_svc)
	ATIS say "Alternate route guided by State Police." (DlyTrafX30_SP)
Traffic has continued to move very slowly for over one hour.	The next exit is visible. No additional information is provided. (DlyTrafX60_no)
	ATIS offer alternate route. (DlyTrafX60_alt)
	ATIS suggest an alternate route and say "Gas/Food/Lodging Available." (DlyTrafX60_svc)
	ATIS say "Alternate route guided by State Police." (DlyTrafX60_SP)
	Public radio suggests and describes an alternate route. (DlyTrafX60_rad)
Traffic is still extremely congested and has continued to move very slowly for over two hours.	ATIS offer alternate route. (DlyTrafX120_alt)
	ATIS suggest an alternate route and say "Gas/Food/Lodging Available." (DlyTrafX120_svc)
	ATIS say "Alternate route guided by State Police." (DlyTrafX120_SP)
	Public radio suggests and describes an alternate route. (DlyTrafX120_rad)

[1]Variable names for each information scenario are provided in parentheses.

4.2. SELECTED SURVEY VARIABLES AND THE DIVERSION DECISION

Approximately 900 survey responses were received. After excluding those responses that failed to answer a substantial number of key questions, 841 valid surveys were used in the study. A summary of sampled population characteristics and comparable regional values are provided in Table 5, as well as survey response results for

TABLE 5 Survey Respondents' and Hampton Roads Region Demographics

Gender	Male	Female
Number in gender group (55 did not report gender)	392	394
Percent of total reporting gender	48.4	51.6
Regional gender breakdown	49	51
Age	**Survey**	**Region**[1]
18-24	2.4%	15%
25-35	11.4%	18%
36-45	19.3%	20%
46-55	29.8%	19%
56-65	23.4%	13%
>65	10.0%	15%
Not reported	3.7%	
Education Level		
Up to High School Graduate	5.1%	34%
Some College	18.9%	29%
College Graduate	36.3%	14%
Advanced College Degree	35.9%	11%
Not reported	3.7%	
Approximate Annual Income		
Less than $20,000	1.1%	6%
$20,000 - $50,000	13.7%	37%
$50,000 - $75,000	18.5%	23%
$75,000 - $100,000	58.0%	35%
More than $100,000	8.7%	
Responses to Selected Survey Questions:		
Plan to evacuate with group (not alone)	82.6%	
Have planned evacuation (route, possessions, destination)	57.4%	
Comfortable driving all night if necessary	78.0%	
Will detour to avoid congestion (no services information)	61.1%	
Member of group requires special lodging	19.7%	
Member of group requires special assistance at destination	5.6%	
Member of group requires special medical assistance	6.8%	
Consider self to be the head of household?	66.4%	
Have participated in an evacuation as adult	25.0%	

[1]Regional values were obtained from the Virginian-Pilot summary of *The Scarborough Report* 2006, Rel. 2, at http://thevirginianpilot.com/advertising/demoLife.html, last accessed July 24, 2009.

selected questions. Subsequent sections provide more detailed summaries of results in groups by gender and age range. When responses to particular questions were assessed, all 841 valid samples were considered. When the diversion decision was assessed, 75% of the valid responses were considered and the remaining 25% of responses held in reserve. This separation was done to allow development and testing of a decision-making model using the larger sample group and validation of the model developed using those responses held back.

As seen in Table 5, the respondent population was older, better educated, and had higher annual earnings than found in the general population. One way to partially overcome whether the sample is representative is to use weights in statistical analysis. Therefore, to explore the implications of differences in socioeconomics between the survey and regional population, respondents were segmented into demographic groups and responses were statistically weighted by age and annual household income. This was intended to more accurately reflect each group's fraction of the total regional population. The results showed that demographic factors appeared to have little impact on the decisions made (e.g., divert or not). In fact, the single largest difference between weighted and non-weighted choices for the divert decision was just 1.3% with most differences less than 0.5%. This result was contrary to expectations at the study's outset. The consistency of compared weighted and non-weighted responses may support use of results as an approximation of the region's residents. However, Mehndiratta et al. (25) note that users of ATIS tend to be wealthier and better educated than the general population, and this group is over-represented in this study's respondents. Survey respondents who were wealthier and better educated also tended to be older. This association may counter the lesser use of ATIS and more "modern" communications methods (Internet, cellular phones, GPS systems) by older respondents that one might have anticipated and give an inaccurate perception of the use of these methods by more typical members of the community.

As shown in the following calculations, accurately representing the population of Hampton Roads, a region of approximately 1.6 million residents, would require approximately 384 survey participants using W.G. Cochran's formula for determining sample population sizes as shown in Bartlett (54). The formula uses two key factors: (1)

the risk the researcher is willing to accept in the study, commonly called the margin of error, and (2) the alpha level, the level of acceptable risk the researcher is willing to accept that the true margin of error exceeds the acceptable margin of error (54, p. 44).

$$n_0 = \frac{t^2 * variance_{est}}{d^2} = \frac{1.96^2 * (0.5)^2}{.05} = 384$$

$$n_1 = \frac{n_0}{1 + n_0/population} = \frac{384}{1 + 384/1.5M} \cong 384$$

Where:

- n_0 is the required number of survey responses;
- n_1 is the required sample size if the value of n_0 is greater than 5% of the total population;
- The value of t corresponds to a margin of error (alpha value) magnitude of 0.05;
- Variance is estimated for a population proportion of 0.5 (maximizing the resulting value of n_0); and
- The value of d reflects an acceptable margin of error for the proportion being estimated of 0.05.

The calculation of n_1 is necessary only when the value of n_0 exceeds 5% of the total represented population; it is provided here only to show how it would be used when warranted.

This study's total sample population (841) exceeded the 384 necessary, but calculations of required sample sizes assume respondents are randomly selected from the community, representing each demographic and social group in appropriate proportions. This standard was not met in this study due to funding constraints. Though weighting results by category may increase confidence in results, results cannot be asserted to be representative of the entire region. Additionally, forecasts of evacuating driver route choices were made using responses to questions on driving tendencies and expected decisions in response to congestion during a hypothetical hurricane evacuation. This assumes that self-reported anticipated actions were completely accurate and that no events that might have changed a driver's decision occurred between stating intentions and carrying out the action. This may lead to conflict with one of the three critical conditions of Ajzen's Theory of Planned Behavior (14), that intentions and perceived behavioral control must remain stable in the interval between their assessment and observation of the behavior. Intervening events may produce changes in intentions or in perceptions of behavioral control, with the effect that the original measures of these variables are no longer accurate predictors of behavior. Finally, the decisions made by evacuees are obviously influenced by their own past experiences with hurricane evacuations, the effectiveness of their local evacuation procedures, and the local transportation network. Residents of other regions may respond differently to the same hypothetical situations. Any use of survey results must be tempered by the knowledge that survey results were obtained from a single region and were not intended to provide a stochastic representation of that region.

4.2.1 Summary Information on Potential Evacuee Responses

Approximately 50 specific questions were asked and response frequencies recorded. Of the survey respondents, 11% indicated that they would likely evacuate in advance of a Category 1 hurricane while slightly less than 40% reported that they would expect to evacuate for a Category 2 hurricane. Additionally, 25% said they had previously evacuated for a hurricane (while they were of adult age), with 40% of these having evacuated within the past five years. Approximately 40% of respondents reported that their planned destination was some form of commercial lodging, 54% planned to go to the home of a friend or relative, and the remainder intended to use public shelters or other accommodation. All respondents were asked to assume that they had already made the decision to evacuate prior to answering questions related to a detour decision.

4.2.2 Diversion Likelihood and Demographic Variables

Survey responses were analyzed for potential correlation between respondents' anticipated likelihood of taking an alternate route when confronted with congestion and with the reported demographic factors such as age, gender, annual income, household size, and education level. The degree of correlation was assessed using Welch's t-test and chi-squared testing with p-value significance values of 0.05. No correlation was found between the likelihood of diverting and any of the variables with the exception of age group, for which limited correlation was identified. Age group correlations are discussed in Section 4.3.2.

Compared to the total sample population, the 36 – 45 year old age group was more likely to divert (88% vs. 81%) and the over 65 year old group was less likely to divert (69% vs. 81%) when only information on an alternate route was provided at the one hour point. In the same scenario at time 120, the 46 – 55 year old group was less likely to divert than others (81% vs. 85%). No other age groups at any time in any scenario reported anticipated diversions at rates significantly different from the remaining sample population. If available demographic data provided detailed age group breakdowns for different flood zones or evacuation routes, it could be possible to better forecast the route choice and decision timing for evacuees with congestion.

4.2.3 Diversion Likelihood and the Destination Type and Distance

The type of intended destination (residence, shelter, motel, or other) was suspected of being an important factor in the detour decision. Approximately 40% of survey respondents planned to go to a hotel or motel and the hypothesis was made that these evacuees would be more likely than others to choose to detour if VMS indicated that lodging was available. However, while a slightly higher percentage of evacuees traveling to hotels or motels said they would take an alternate route to bypass congestion (73.8%), the difference was not statistically significant from the percentage of all evacuees who would detour (72.1%) using Welch's t-test and Chi-squared tests at a 5% significance level. A relationship between the likelihood of an evacuee choosing to detour and the total planned distance of the evacuation from origin to destination was suspected. However, when survey results were segmented into those expecting to travel less than 75 miles and those traveling greater than 75 miles, the respective likelihoods of choosing to take an alternate route differed by less than 0.1%. Thus, both the type of destination and the distance of the total evacuation were discounted as key contributors to the detour decision, based on statistical evidence.

4.2.4 Diversion Likelihood and Previous Evacuation Experience

Approximately one-fourth of sample respondents had evacuated during their adult years. A summary of respondents' real world evacuation experience and the expectation of diverting when faced with congestion during an evacuation is provided in Table 6. For survey respondents, previous evacuation experience was not associated with the likelihood of anticipated diversions and could not be used in this study as a predictor of route diversions. In fact, the likelihood of diverting due to congestion was slightly lower for those with previous evacuation experience than for the response population in general, but with a difference too small to be statistically significant. All respondents who had evacuated within just the previous three years indicated that they would divert, but this represented too few respondents (2% of all respondents) to use this for forecasting.

TABLE 6 Associations of Past Evacuations (as an Adult) with Anticipated Detour Decision

Time Frame =>	Evacuated w/in last 3 years	Evacuated w/in 3-5 years	Evacuated w/in 6-10 years	Evacuated greater 10 years ago	Never Evacuated
Percentage of all evacuees	1.7%	11.1%	4.9%	7.8%	74.5%
Percentage evacuating in time frame who anticipated diverting	100.0%	92.9%	90.3%	93.2%	94.0%

4.2.5 Diversion Likelihood for Those with Past Route Changes to Avoid Congestion

Analyses sought to relate respondents' past tendency to take alternate routes to avoid congestion and the decision to divert when faced with congestion during an evacuation. Just under 2/3 of survey respondents (62.4%) reported having detoured in the previous month to avoid congestion. Of these, 74.4% anticipated that they would detour in the evacuation scenario. This differed by less than 2.5% from the results for all respondents, a difference statistically insignificant using Chi-squared and t-tests with significance (p) values of 0.05.

Survey data also allowed isolating the responses of those who reported that they detoured to avoid congestion at least weekly. This segment composed 35.3% of the total. Of this segment, 72.1% anticipated detouring in the questioned scenario, a result exactly equal to the percentage of all respondents who would detour, regardless of whether they frequently altered routes to avoid congestion. Therefore, past driving characteristics could not be used to forecast the decision expected in the congested evacuation scenario.

4.2.6 Diversion Likelihood for Those Having Past Diverted Due to VMS Information

The relationship between previous route changes made as a result of VMS prompting and the reported intention to detour during an evacuation as reported in the survey was tested. Coincidentally, the exact same number of respondents in the analysis group reported having previously detoured as a result of VMS prompting as expected to detour during a congested evacuation (72.1% of all respondents). However, the compositions of these two decision groups differed by 25%. This disparity prevented use of the VMS influence marker from being used to forecast decisions in the congested evacuation scenario. However, the significant difference in the two groups calls into question what causes the difference in decisions. What leads the same drivers to make contrary decisions in the routine and crisis circumstances? Information gathered in the survey was not sufficient to provide this answer; the question is deserving of further investigation.

4.2.7 Mode of Transport

Only three of 841 responses indicated the intention to evacuate in other than a private vehicle, either the respondent's own or one belonging to another member of the evacuating party. These three had no common characteristics identified by the survey. Two were female; one was male. One had an advanced college degree; two had bachelor's degrees. Each indicated a different income level band. Each had different number of vehicles. Each was from a different age group. No further insight on diversion likelihoods could be gained by analysis of reported transport mode data. Data indicates that almost all who are able will evacuate by car.

4.3. SELECTED VARIABLES AND THE RELATIONSHIP WITH GENDER AND AGE

As noted previously, few associations between demographic variables and the decision to take an alternate route when confronted with congestion were found. However, analysis identified several variables with significant correlation to respondents' gender or age. The following two sections discuss these relationships. Statistical significance was tested using three methods: confidence intervals, Chi-squared distribution testing, and Welch's t-test.

4.3.1 Correlations of Gender with Survey Responses (Exclusive of the Diversion Decision)

Table 7 summarizes all survey responses that produced statistically significant differences in response rates for males and females using the three test methods applied. The percentage (rounded to the nearest whole percent) of each gender responding in the affirmative to the query is also listed. Table 8 provides gender responses to (primarily) objective questions related to demographics and evacuation intentions. Tables 26 and 27 in Appendix C provide each gender's responses to stated preference questions. Results of significance testing are provided in Appendix C Tables 28 and 29. When calculating the statistical significance of the stated preference responses, "Strongly Agree" and "Somewhat Agree" were grouped together and "Strongly Disagree" and Somewhat Disagree" were grouped together, providing a binary result. Seven preference questions were asked at two or more points throughout the survey with each generating slightly different responses. When testing for significance, comparisons were made between responses to the questions at the same points in the survey.

TABLE 7 Survey Responses with Statistically Significant Differences Between Gender Groups with Percentage of Group Responding in the Affirmative

Survey Query or Statement	Percent of Males	Percent of Females
Average annual income between $20,000 and $50,000	6	22
Average annual income greater than $100,000	47	28
Possess advanced college degree	46	29
I have planned how I would evacuate, including routes and possessions or necessities I would bring.	61	54
I would feel comfortable and safe driving all night to reach my destination.	85	71
I would be comfortable leaving my planned route for an alternate route even without services information.	66	57
Either I or a member of my evacuating group will require special lodging.	15	24
I am the head of my household.	94	43
I am an aggressive driver.	36	26
I am more comfortable waiting out a delay to ensure I reach my destination.	29	40
I usually like to stay on the main roads to keep from getting lost.	43	58
I am willing to try alternate routes to avoid traffic delays. (Asked 3 times, significant all 3 times.)	88	78
I am suspicious about the delays reported on highway message signs. (Asked twice; significant 1 of 2 times.)	68	58
I am reluctant to leave main roads and take other routes. (Asked twice, significant both times.)	40	54
I am comfortable reading and following highway maps. (Asked twice, significant both times.)	94	82

TABLE 8 Survey Results Analyzed by Gender Group

Gender	Male	Female
Number in Gender Group	392	394
Percent of Total Reporting Gender (55 Did Not Report)	48.4	51.6
Percent Planning to Evacuate to:		
Hampton Roads	5.9	10.7
Williamsburg	0	0
Richmond area	18.4	18.5
Northern VA	12.0	11.9
Western VA	27.3	27.2
Southern VA	10.7	10.7
Plan to Evacuate with Group	82.4	82.2
Have Planned Evacuation	61.5	53.6
Comfortable Driving All Night	85.2	70.8
Will Detour to Avoid Congestion (no services information)	65.6	57.4
Member of Group Requires Special Lodging	4.6	6.6
Member of Group Requires Special Assistance	14.8	25.4
Member of Group Requires Special Medical Assistance	4.4	7.1
Head of Household?	94.1	42.6
Past Evacuation as adult?	26.5	26.1
Education Level		
Some High School	0	0.5
High School Graduate	4.3	5.3
Some College	16.3	23.1
College Graduate	33.4	41.4
Advanced College Degree	45.7	28.7
Approximate Annual Income		
Less than $20,000	0.3	2.0
$20,000 - $50,000	6.1	22.1
$50,000 - $75,000	18.4	20.1
$75,000 - $100,000	23.2	21.6
More than $100,000	47.4	27.7

In general, males appeared significantly less concerned that they might lose their way on alternate routes, reporting a significantly higher propensity to take risks, greater comfort reading and following maps, and less unease about leaving major roads. Females were also much more likely to say that they usually try to stay on main roads to avoid becoming lost. Despite these differences, males and females indicated an equal propensity to divert when placed in an evacuation scenario with congestion.

4.3.2 Correlations of Age Group with Survey Responses (Exclusive of the Diversion Decision)

Table 9 lists age group responses that were statistically significantly different from responses for all survey participants. Few responses indicated significance using all three tests used; therefore, responses that showed significance on any one of the tests are shown and listed in the column titled with the appropriate test. Age group ranges formatted in the columns with left justification indicate the group frequency for the response was lower than that for all respondents; ranges shown right justified indicate a response frequency higher than that for all respondents. For example, the percentage of

TABLE 9 Survey Responses with Statistically Significant Differences Between Age Groups and all Respondents Using the Indicated Test

Survey Query or Statement	[1]Confidence Intervals	[1]Welch's t-Test	[1]Chi-Squared Test
Average annual income between $20,000 and $50,000		25-35 56-65	25-35
Average annual income between $50,000 and $75,000		25-35	
Average annual income between $75,000 and $100,000		56-65	
Average annual income greater than $100,000	25-35	25-35 36-45 56-65	25-35 56-65
Some College	25-35	25-35	25-35
College Graduate	25-35	25-35 56-65	25-35 56-65
Possess advanced college degree	56-65	56-65	56-65
I plan to evacuate with a group (not alone).	>65	>65	>65
I have planned how I would evacuate, including routes and possessions/necessities I would bring.	25-35 >65	25-35 >65	25-35 >65
I am an aggressive driver.		>65	
I am willing to try alternate routes to avoid traffic delays.[2]		56-65	

[1] Groups shown left justified responded with lower frequency percentages than the frequency percentage of all samples analyzed; groups shown right justified responded with higher frequency percentages than the frequency percentage of all samples analyzed.
[2]This question was asked three times. The difference between any age group and the value for all analyzed responses was statistically significant only once.

survey respondents in the 25-35 year old age group who said that they were college graduates was higher than the percentage of all survey participants. The difference was statistically significant when assessed using all three test methods. Conversely, the 56-65 year old age group reported a percentage lower than that of all percentages, but this difference was only statistically significant when assessed using the Welch's t-test and Chi-squared methods; confidence intervals for the age group and for all participants slightly overlapped. Survey results included only 20 participants from the 18-24 year old group. These responses are included in total population analyses, but due to the small number, group significance testing was not conducted.

As done for gender analyses, "Strongly Agree" and "Somewhat Agree" were grouped together and "Strongly Disagree" and Somewhat Disagree" were grouped together, providing a binary result. Seven preference questions were asked at two or more points throughout the survey with each generating slightly different responses. When testing for significance, comparisons were made between responses to the questions at the same points in the survey.

Demographic differences between age groups (salary, education) are likely explained by time and opportunity; older respondents are more experienced and have risen to more senior and well-paid employment and also have had more time to pursue advanced education. Likewise, those with more advanced education earn higher salaries. However, three responses that were found to be significant by all three applied tests warrant further discussion.

A significantly larger fraction of responders over 65 years of age expected to evacuate alone as opposed to evacuating as part of a group. This was first suspected of being the result of more respondents over 65 years of age living alone, but the fraction of those living alone who were over 65 was almost exactly equal to the fraction observed in the total sample. However, of those living alone, a larger fraction of those over 65 expected to evacuate alone than seen in the total sample. A comparison was also made between all respondents who did not share the household with someone less than 18 years old and those over 65 years old meeting this criteria. Again, the fractions from the groups who evacuated alone (as opposed to in a group) were essentially equal. No correlation between the higher tendencies of those over 65 to evacuate alone was identified.

A significantly higher percentage of respondents in the over 65 age group reported having planned their evacuation, including the route to be driven and the personal belongings that would be taken. In contrast, just 38% of those in the 25-35 year old group reported having planned their evacuation, approximately 2/3 the percentage of all respondents combined. These responses fit stereotypes of increased caution coming with age, but may also be the result of the older adults having evacuated in the past or having peers who have done so.

Table 10 provides age group responses to (primarily) objective questions related to demographics and evacuation intentions. Tables 30 through 35 in Appendix C provide responses to stated preference questions for each group. Results of significance testing are provided in Appendix C Tables 36 through 42. Note that 31 survey respondents (4%) did not mark an age group on the survey.

4.4. CORRELATION BETWEEN SURVEY FACTORS AND THE ROUTE CHOICE DECISION

Identifying and quantifying correlation between the demographic characteristics, behavioral tendencies, or self-assessed descriptive variables collected in the survey and the anticipated route choice decision was strongly desired and a major focus of this research. The ability to objectively pre-assess an evacuating population and assess how drivers might respond when confronted with congestion in a future event could be of great value to emergency planning and real-time emergency management. The methods used to attempt identification of correlated variables that influenced anticipated route choice decisions are discussed below.

4.4.1 Cross Tabulation

Cross tabulation uses frequencies of paired variables to create tables that can then identify trends in data responses. SPSS® software was used to create these tables using the Crosstabs function. Tests were run comparing all variables with the route choice decisions for each scenario. Though relationships between demographic variables and the other factors previously discussed in this report were identified (using linear

TABLE 10 Survey Results Analyzed by Age Group

Age (years)	18-24	25-35	36-45	46-55	56-65	Over 65
Number in Age Group	20	96	162	251	197	84
Percent of All Respondents	2.3%	12.4%	20.1%	28.8%	22.8%	10.0%
Percent Male	30.0	35.4	46.9	45.0	55.3	64.3
Percent Female	70.0	64.6	51.2	49.8	40.1	33.3
Percent No Gender Reported	0	0	1.9	5.2	4.6	2.4
Percent Planning to Evacuate to:						
Hampton Roads	15.0	14.6	4.9	9.6	7.1	6.0
Williamsburg	0	0	0	0	0	0
Richmond area	10.0	14.6	14.2	19.9	23.4	16.7
Northern VA	0	14.6	11.1	9.6	9.1	13.1
Western VA	25.0	22.9	28.4	23.5	25.9	22.6
Southern VA	5.0	9.4	10.5	9.6	9.6	11.9
Percent with Member of Evacuating Group Requiring:						
Plan to Evacuate with Group	85.0	83.3	90.1	83.7	84.3	70.2
Have Planned Evacuation	30.0	37.5	55.6	59.8	64.0	72.6
Comfortable Driving All Night	85.0	77.1	75.3	78.9	79.7	76.2
Will Detour to Avoid Congestion (no services information)	30.0	67.7	65.4	62.2	59.9	58.3
Member of Group Requires Special Lodging	15.0	26.0	22.2	20.3	17.8	11.9
Member of Group Requires Special Assistance	0	3.1	7.4	6. 4	6.1	3.6
Member of Group Requires Special Medical Assistance	0	4.2	7.4	6.8	6.6	8.3
Head of Household?	50.0	61.5	72.8	68.1	69.0	76.2
Past Evacuation as adult?	0	20.8	27.8	26.3	26.9	31.0
Education Level						
Some High School	0	1.0	0	0	0.5	0
High School Graduate	0	3.1	3.1	7.6	4.6	6.0
Some College	40.0	7.3	19.8	21.5	18.8	25.0
College Graduate	35.0	60.4	42.0	35.1	28.9	29.8
Advanced College Degree	25.0	28.1	34.6	35.5	46.2	38.1
Approximate Annual Income						
Less than $20,000	5.0	2.1	1.2	1.2	0	0
$20,000 - $50,000	10.0	21.9	14.8	12.4	11.7	15.5
$50,000 - $75,000	5.0	14.6	20.4	19.5	16.2	20.2
$75,000 - $100,000	25.0	19.8	18.5	21.9	24.4	22.6
More than $100,000	45.0	35.4	37.7	33.9	37.6	31.0

regression, chi-squared, and confidence interval techniques), no trends in the route choice decision and other factors were found.

4.4.2 Factor Analysis

Twenty-two statements sought the level of user agreement to statements regarding normal driving behavior and patterns. Factor analysis was used to reduce the relatively large number of variables to a smaller number of unrelated variable groups. Factor analysis identifies relationships between different responses and groups those responses most strongly associated with one another into a few components, each of which represents the combined influence of the related variables. This can simplify analysis and make it easier to recognize and understand the full impact of related variables. Factor analysis makes extensive use of matrices and matrix algebra. Eigenvalues are used to represent the amount of data set variance that can be represented by a single value.

There are two basic types of factor analysis: exploratory and confirmatory. Exploratory factor analysis is used when the researcher does not know how many factors are necessary to explain the interrelationships in a data set. Confirmatory factor analysis is used to assess the extent to which the hypothesized organization of factors and interrelationships fit the data. Its use presumes some knowledge about the underlying associations between factors (55, pp. 3-4). Exploratory factor analysis was used in this study to enable identifying either positive or negative correlations between surveyed factors.

Using SPSS®, factor analysis was conducted for survey participant responses to a series of questions on individual characteristics and past driving tendencies. Survey participants were asked to indicate their level of agreement to 22 statements in terms of strongly agree, somewhat agree, somewhat disagree, strongly disagree, or neutral. Neutral responses and non-responses were excluded from the analysis.
Table 11 provides the results of the factor analysis.

The Primary Component Extraction analysis method was used. This method begins with a matrix of all components' relationships with one another, the correlation matrix. Values in cells represent the Pearson r values obtained for the two queries represented by the column and row headings, where

$$r_{x,y}=covariance\ (X,Y)/[var(x)var(y)]^{1/2}.$$

A matrix was conducted with the 22 queries creating both the row and column headers. The matrix diagonal thus represents the correlation of each query with itself; all values on the diagonal equal 1. A series of calculations were next completed to determine the degree of influence of the first principal component on each queried response. The result of these calculations is an eigenvector with cell values equal to the percentage of variance of each item that is accounted for by the principal component. To obtain the eigenvectors for the second principal component, a residual matrix representing the remaining variance not explained by the first principal component is created and then the same series of calculations are repeated. The entire process is then repeated for all principal components. Step-by-step calculations of a principal component extraction for a relatively small matrix with explanatory comments is included as an appendix in reference (55).

The SPSS® software allows users to limit the number of principal components determined by assigning a total number or by considering only components with eigenvalues greater than a predetermined value. For this study, initial component selection was made by filtering for eigenvalues greater than 1.0 and confirmed by assessing the scree plots provided. These plot extracted factors against their eigenvalues in descending order of magnitude and can be used to determine which components are significant by identifying when distinct breaks occur in the slope of graphed values. Five components were suggested by both methods; the fifth component was dropped because it represented only one survey statement and was better matched with the first suggested component. Component values are shown in Table 11 with values less than 0.4 suppressed for display.

Components were rotated using the Varimax option in SPSS®. The calculated Bartlett's Test of Sphericity chi-squared value was 6194, far greater than the corresponding value for a significance value $p=0.05$. This confirms that the SPSS correlation matrix is not an identity matrix. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy value was 0.814, a value considered "meritorious" for factor analysis (55). The two results strongly support the use of factor analysis and validity of results.

TABLE 11 Factor Analysis Component Matrix

	Component Name			
Statement	**Experienced & Cautious (21%)**	**Confident & Prepared (15%)**	**Information Seeking (10%)**	**Aggressive (6%)**
I have previously diverted using info from VMS	.647		~~.465~~	
I have previously diverted using info from temporary VMS	.618			
I have previously diverted using info from radio	.612			
I am wiling to take risks and divert to avoid delays	~~.556~~	.461		
I watch for traffic info on VMS	~~.546~~		.517	
Radio reports should provide delay estimates	.534			
I am comfortable diverting if State Police are present	.530			
I enjoy finding new routes to my destination	.508			
VMS information is usually accurate	~~.507~~		.453	
I usually stay on main roads to avoid getting lost	-.500		~~.467~~	
I usually outwait jams to avoid getting lost	-.469		~~.435~~	
I am comfortable reading highway maps	.467			
I check radio reports for traffic info before starting trips	.456			
I prefer VMS provide delays using time, not distance	.444			
I am willing to divert to avoid delays		.731		
I am uneasy leaving main roads without knowing service availability		-.677		
I am reluctant to divert from main highways		-.660		
I always have a map in the car		.534		
I get impatient quickly when stuck in traffic		~~.453~~		.428
I am an aggressive driver		~~.445~~		.444
I watch for traffic info on VMS		~~.404~~	.651	
I am suspicious of traffic delays reported on VMS				.477

Factor analysis groups are assigned names by the user. The names assigned these groups are subjective, but generally provide a means of summarizing the identifying characteristics of each group with the goal of increasing understanding. Names should suggest the key characteristics or identifiers of the group. After reviewing responses to all 22 statements by members of each group, the four component groups found were separated as four driver types and titled:

1) Experienced and Cautious;
2) Confident and Prepared;
3) Information seeking; and
4) Aggressive.

The four components combined account for 52% of the total variance for the 22 statements. The percentage values following each component's name indicate the percentage of all variance accounted for by the individual component.

As can be seen in Table 11, several statements had high values for factor loadings (correlations between the variable and the factor) (greater than 0.400) when associated with two components. Negative values indicate negative correlation. As most factors in the group tend in one direction, those with negative values trend in the opposite direction. Using Pett's suggested method (55), these component assignments were made where each statement most reasonably fit and not necessarily where the highest magnitude was calculated. To clarify statement assignments to components, values where the statement was not assigned are crossed out (e.g., ~~.465~~).

"Experienced and Cautious" drivers tend to stay on main roads, but are willing to divert to alternate routes when provided information via ATIS. "Confident and Prepared" drivers have little hesitation about leaving main roads for alternates. They carry maps and appear to rely on their own abilities rather than on external information sources, though sources may be considered if available. "Information Seekers" look for traffic information, but generally do not adjust plans in response to information received. Obtaining information may perhaps relieve anxiety, but is unlikely to impact the traffic situation. "Aggressive" drivers quickly grow impatient with congestion and apparently have little confidence in VMS information. They do not tend to act on information any differently than the overall population. Perhaps these are the drivers who constantly shift lanes in congestion, but arrive at their destinations no sooner than others; this aspect of driving and their success at reducing travel times as compared to others was not questioned by the survey.

The majority of drivers claim to seek and use ATIS-provided information to decide on or alter routes in routine travel and also expect to use ATIS under emergency conditions. Responses indicated a greater likelihood of diversion when information was provided that increased drivers' confidence in both the route and available services. However, a significant portion of the sample population (22%) reported having little confidence in traffic information provided via VMS when questioned on the survey. Results show that actions and information that enhances evacuees' sense of security and confidence in alternate routes may increase their likelihood of taking alternate routes. Results also show targeting two of the identified four groups with ATIS may provide the best results. Experienced and Cautious drivers pay attention to traffic information and want to know how long delays are expected to persist. Given good information, they are very likely to follow guidance provided. Confident and prepared drivers use traffic information to augment their own resources. VMS messages that add to or reinforce personal resources might be beneficial. Since relatively few members of the sample population had ever participated in a large scale hurricane evacuation and none had done so in Hampton Roads, this means that more attention must be paid to VMS accuracy in day-to-day operations. Emergency management and transportation officials may use this knowledge to provide (or withhold) information to prompt desired driver actions. Emergency planners might find it useful to provide tailored information for female drivers to better prepare them for what might be required in an actual evacuation.

4.4.3 Coefficient Correlation

One of the most commonly used correlation methods is the product moment correlation coefficient or Pearson r method. This method assumes a linear relationship between two variables, each of which is normally distributed about some interval. The degree of correlation varies between r-values of 1 (perfectly correlated) and -1 (perfectly negatively correlated). An r-value of zero identifies two completely uncorrelated variables. The value of the correlation coefficient r is calculated as:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{(n-1)\sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}\sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}}} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 (y_i - \bar{y})^2}}.$$

Correlation coefficients between all variables questioned in the survey and in particular between variables and the route choice decision were determined using the CORREL function in Microsoft® Excel® (which uses the format on the right in the above equation). No significant correlation between other variables and the route choice decision was identified. The largest correlation identified with the route choice decision was just 0.35.

4.5. INFORMATION SOURCES, INFORMATION LEVELS, AND THE DIVERSION DECISION

Five traffic information sources were listed on the survey and respondents were asked to indicate all that they used while driving. The five sources listed included radio, mobile phones, highway message signs, in-car Global Positioning Systems (GPS), and the Internet. Respondents were also asked if they had altered course because of information obtained using the indicated sources. These answers were compared with the respondents' self reported likelihood of altering course during an evacuation to avoid congestion.

Essentially all (99.7%) respondents reported using traffic information sources. Radio reports were easily the most popular source used with just over 90% of respondents using radio traffic information reports. Variable message signs were used by approximately 70% of respondents, while one-half used cellular phones and approximately one-third used GPS and the Internet. Information shared via radio, VMS, or phone systems were used by 98.3% of all respondents. The vast majority of respondents reported using multiple sources of traffic information with 88.9% using two or more, 59.4% using three or more, and 29.6% using four or more. Figure 6 shows the percentage of respondents who reported using each of the five sources individually.

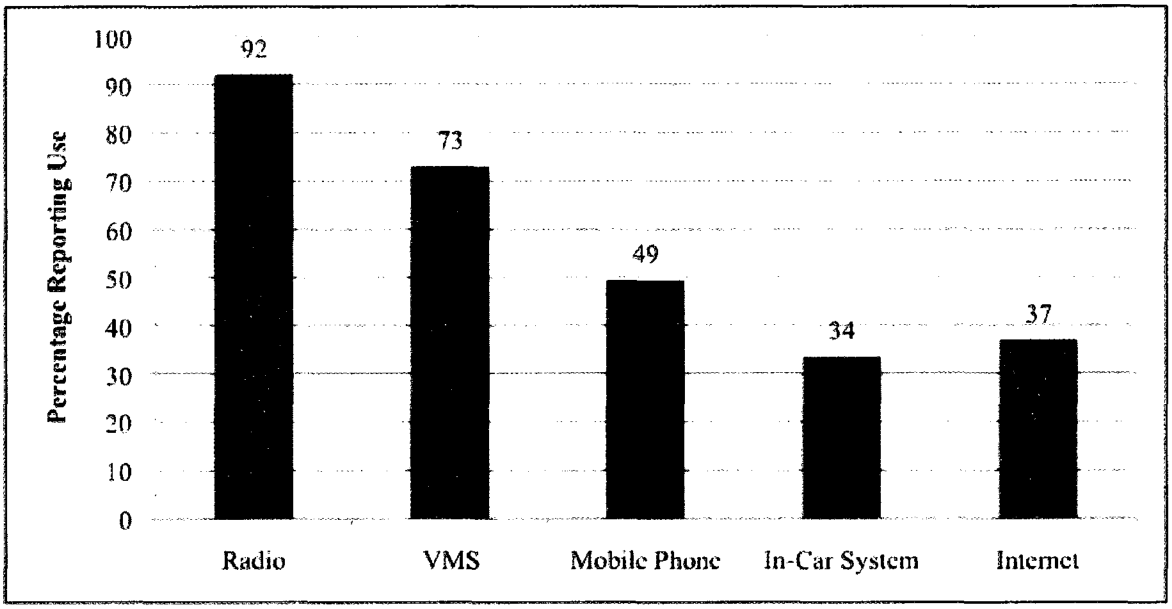


FIGURE 6 Percentage of all potential evacuees reporting use of indicated traffic information sources.

Table 12 indicates the percentage of respondents who reported using both information sources in all possible pairings. For example, 92.1% of all respondents received traffic information via the radio and 73.0% received traffic information via VMS; 67.5% of all respondents received information via both the radio and VMS.

TABLE 12 Reported Use of Traffic Information Sources and Paired Source Combinations (Percentage of All Respondents)

	Radio	VMS	Mobile Phone	In-car GPS	Internet
Radio	92.1	67.5	45.2	30.1	31.2
VMS	67.5	73.0	39.6	21.6	28.4
Mobile Phone	45.2	39.6	49.4	25.5	19.8
In-car GPS	30.1	25.5	21.6	33.5	14.1
Internet	31.2	28.4	19.8	14.1	37.0

Figure 7 show the reported use of each information source by gender group. Males and females reported previous diversions in response to traffic information received from temporary and permanent highway message signs in equal proportions; males tended to be more suspicious of the information's accuracy. Though considerable variability is shown in the figure, differences between gender groups were not statistically significant (see Appendix C Tables 33 and 34).

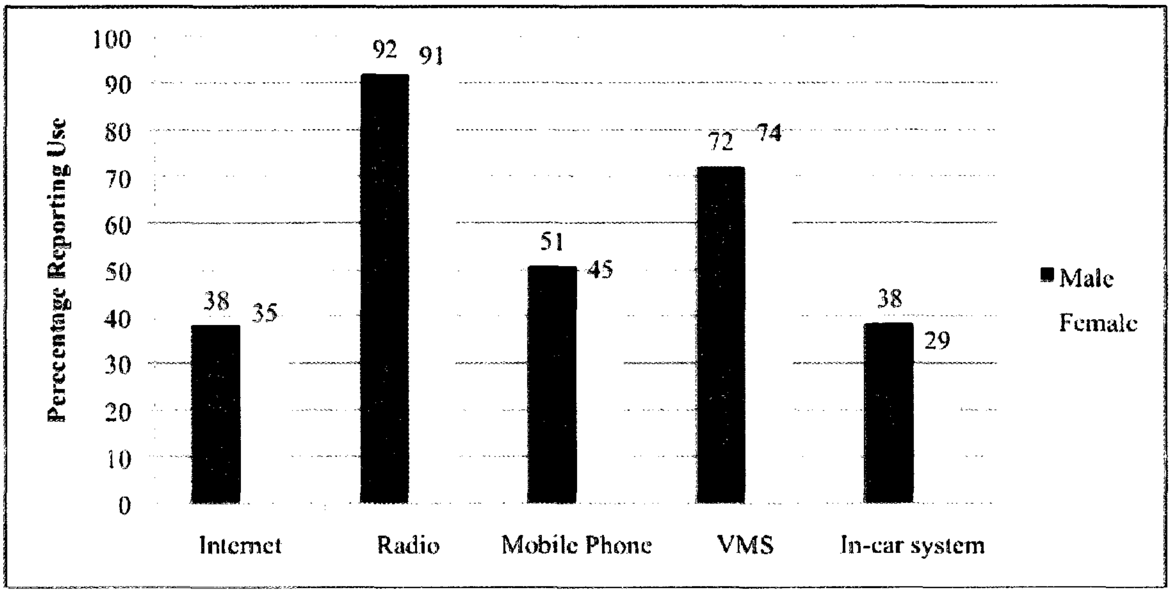


FIGURE 7 Reported use of traffic information sources by gender (percent use).

Figure 8 shows the percentage of each age group reporting use of particular information sources. Again, the dominance of radio and VMS use is easily seen. As indicated in the figure, only the 36-45 year old group used all sources with greater frequencies than the entire survey group. Despite the apparent variability in results, none of the differences within individual age groups were statistically significant (see Appendix C Tables 35 through 41).

Figure 9 shows the percentage of each household annual income group reporting use of information sources. Radio and VMS were used much more frequently than other sources, followed by mobile phones. Though the lowest income group used the Internet much more frequently than other groups, the small number of data points prevents assessing the statistical significance. Despite the variability in results, none of the differences between group values were statistically significant.

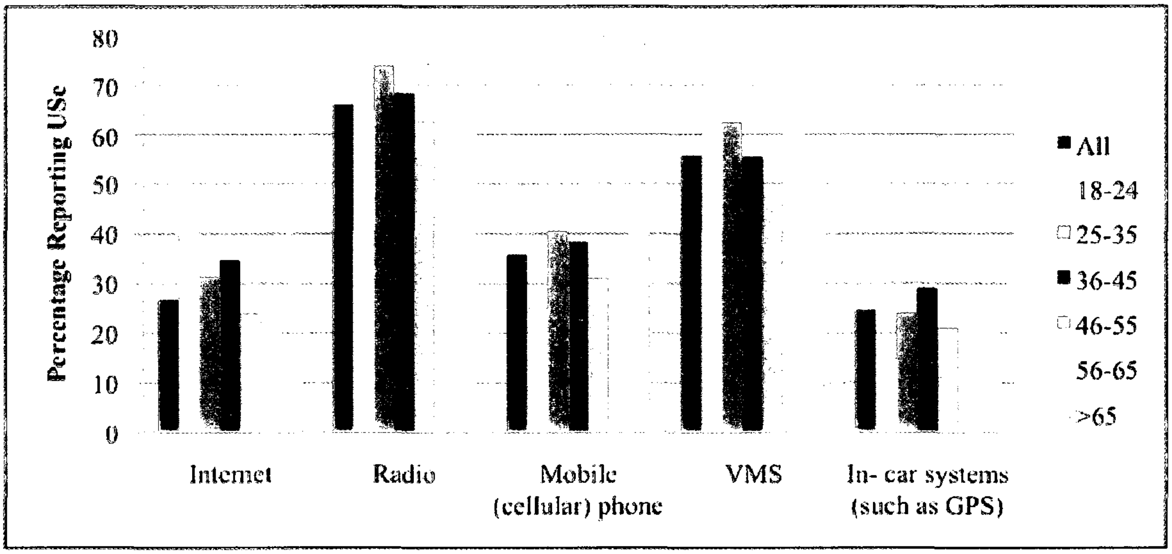
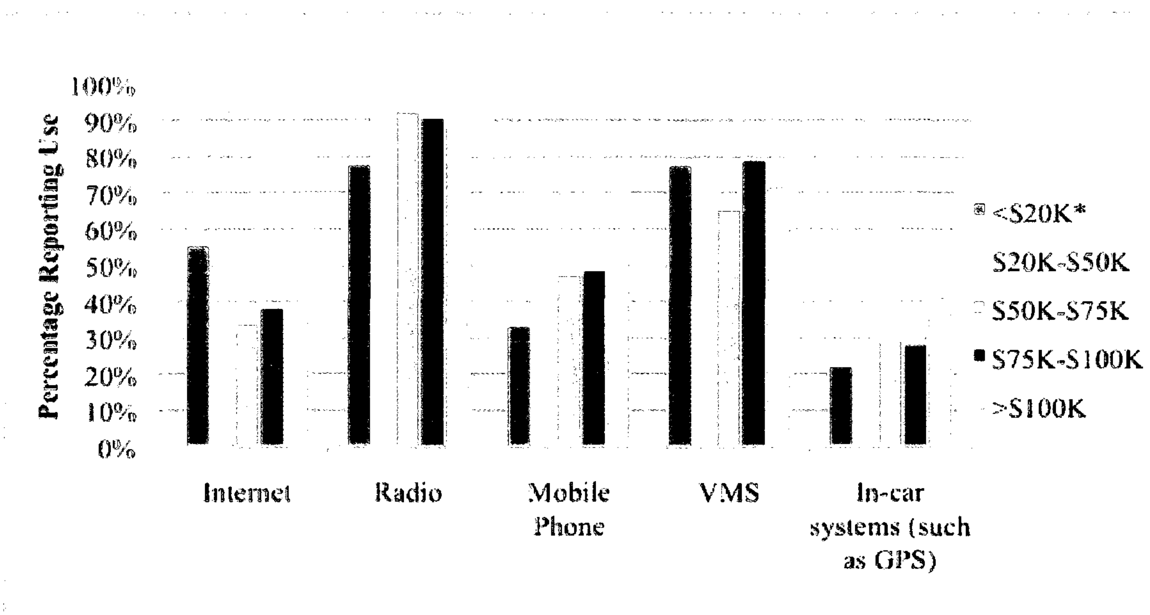


FIGURE 8 Reported use of traffic information sources by age group (percent use).



*only 9 survey participants (1.1%) reported incomes less than $20K/year

FIGURE 9 Reported use of traffic information sources by annual household income (percent use).

The extent of respondents who reported using traffic information sources was significantly higher than found in previous studies, such as those by Mehndiratta et al.

(25) and Yim et al. (33). Additionally, as shown in Table 13, the influence survey participants ascribed to information sources was also higher than found in the earlier studies. This was especially true for "higher tech" sources -- cellular phones, GPS, or the Internet. The increased usage and influence may be a result of the more critical situation

TABLE 13 Percentage of Evacuees Reporting Use of the Indicated Information Source Anticipating Diverting at Each Time Increment (DlyTrafX_alt Scenario)

Time (min)	Overall	Radio	VMS	Cell Phone	GPS	Internet
0	30.7	30.4	30.8	28.3	35.2	30.6
30	77.4	75.9	77.6	80.3	79.9	74.5
60	81.6	81.0	81.5	81.4	81.9	83.3
120	85.9	85.3	86.0	84.5	86.9	88.0

(previous studies looked at routine commutes, not evacuations), but could also be a reflection of the increased use of technology by individuals in the time since the earlier studies. The Virginia "VA511" telephone and website traffic information program was upgraded during the timeframe of the survey and the upgrade was accompanied by a large public awareness campaign. This may also have led to an increase in users of mobile phone and Internet information.

Figure 10 shows the relationship between reported use of each information source in routine driving and the intention to divert when faced with congestion during an evacuation for the DlyTrafX_alt scenario, in which evacuees are provided information on an alternative route via VMS. For all information sources, the percentage of users expecting to detour when faced with congestion during an evacuation was approximately equal for all time increments. For example, in the DlyTrafX_alt scenario, 81.6% of all respondents who said they routinely used traffic information sources while traveling anticipated they would divert to avoid congestion during an evacuation after 60 minutes. When evacuees were separated into groups by traffic information source used, each information source group fell with 2.5% of this value with all but one within 1%. This similarity in rates of influence was noted for each time increment and for each of the questioned scenarios. This indicates that all sources of information have essentially equal credibility amongst their users. Figure 10 also shows that for all information sources, the

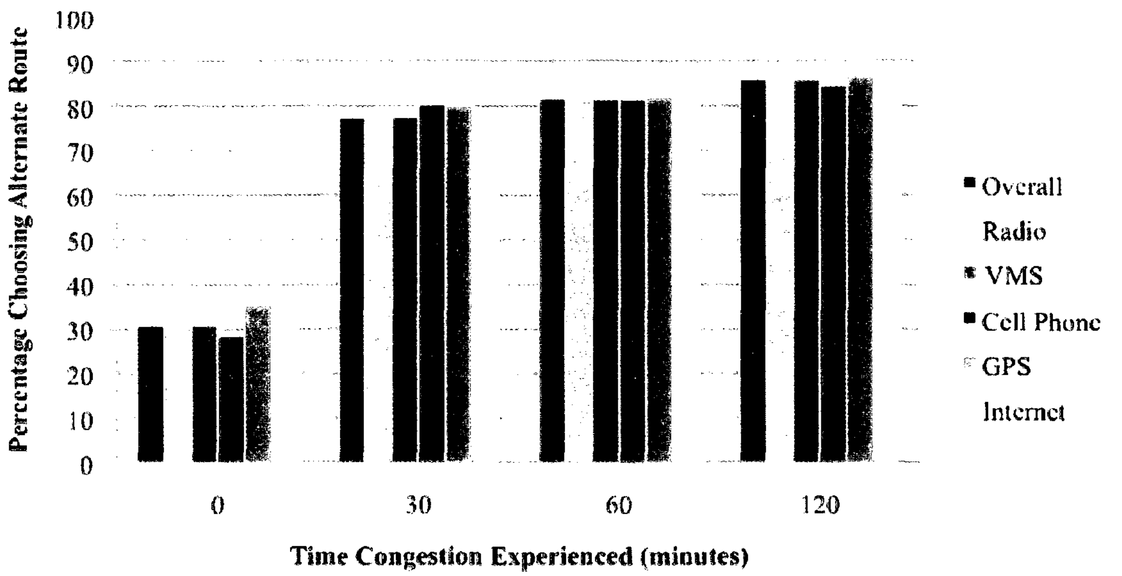


FIGURE 10 Percentage of evacuees reporting use of the indicated information source anticipating diverting at each time increment (DlyTrafX_alt scenario).

probability of users taking an alternate route increases the longer the congested period is faced.

Results reveal that evacuees' decision whether to take an alternate route when faced with traffic congestion was associated with two primary factors:

1) The length of time congestion was experienced (or expected); and
2) The source of congestion information provided to drivers and its detail.

As one would expect, respondents said they would be more likely to take an alternate route the longer they had been in congested traffic. Even without any information on alternate routes being provided, if congestion continued for first an additional one half hour and then one full hour of delay, the percentage of evacuees who would alter routes increased by almost half to just over 45%.

Responses indicated a greater likelihood of diversion when information was provided that increased drivers' confidence in both the route and available services. Note that when time equals zero (when congestion is first encountered) nearly one-third of evacuees anticipated choosing an alternate route even without any additional information. By comparison, when after 30 minutes of congestion VMS suggested an alternate route, fully 75% of respondents said they would take it and after one hour, suggestion of an alternate route resulted in 80% of respondents expecting to detour. When information on services along the alternate routes was provided, the likelihood of diverting increases even more. Overall, the results indicate substantial observed heterogeneity in response to length of delay and various information sources.

4.6. CONCLUSIONS FROM SURVEY ANALYSIS

An evacuee's decision of whether to take an alternate route when faced with congestion was associated with two primary factors:

1) The length of time congestion was experienced (or expected); and
2) Whether information on the congestion was provided to drivers and its detail.

The longer an evacuee was confronted with congestion, the more likely he or she believed they would be to take an alternate route. Likewise, the more information provided an evacuee that might increase his or her confidence in safety or well being, the more likely they believed they would be to take an alternate route. For example, at all time increments questioned, when information on services was provided in addition to alternate route suggestions, participants reported likelihood to take an alternate route increased. Figure 11 shows the relationships between time, information source, and the intention to divert to an alternate route as reported by survey participants.

When asked what they would do if during an evacuation traffic first became congested and slowed to less than 10 mph, 30% of sample respondents indicated they would take an alternate route immediately. If congestion continued for first one half hour and then one full hour of delay but no information on alternate routes was provided, the percentage of evacuees that would alter routes increased by almost half to just over 45%. As one would expect, respondents said they would be more likely to take an alternate route the longer they had been in congested traffic. Responses indicated a higher chance to divert when information was provided that increased drivers' confidence in both the route and available services. By comparison, when after 30 minutes of congestion ATIS suggested an alternate route, fully 75% of respondents said they would take it and after one hour, suggestion of an alternate route resulted in 80% of respondents expecting to detour. When more than just alternate route information was provided, the likelihood of altering routes increased even more.

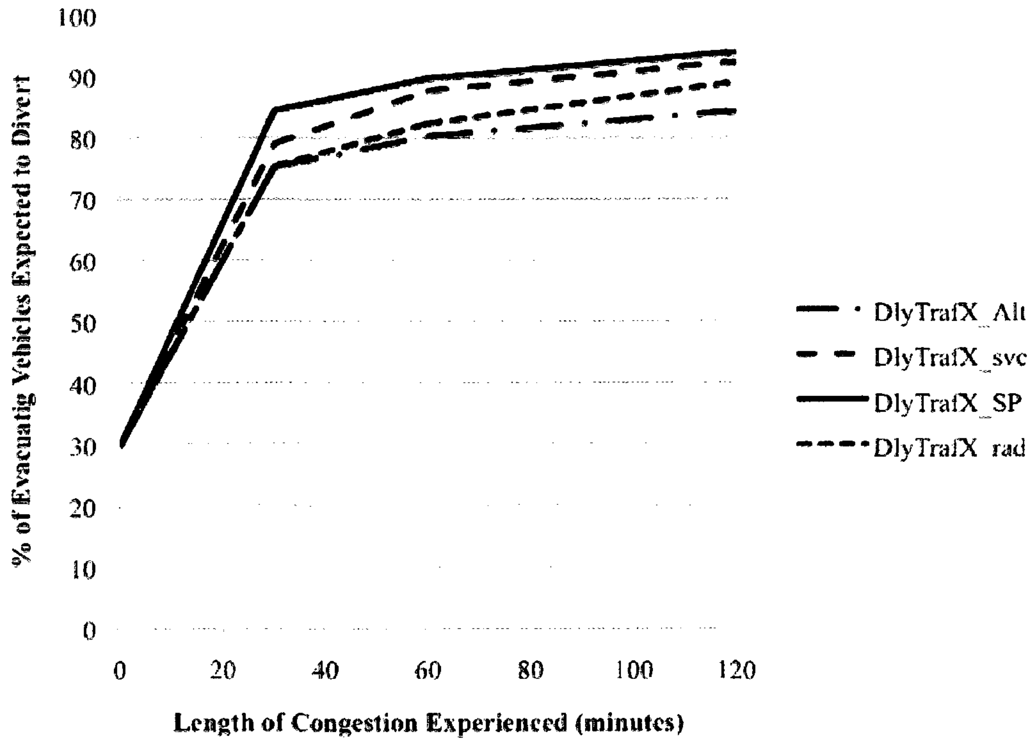


FIGURE 11 Relationships between time length in congestion, traffic information source, and the decision to take an alternate route.

Gender was significant to several factors related to the evacuation, but not significant to the anticipated route-choice decision when confronted with congestion. Male survey respondents were significantly more likely to exhibit behaviors reflective of risk taking (e.g., driving all night, leaving planned routes for alternatives). Males were also more likely to claim advanced evacuation preparation and to be more comfortable reading and following highway maps. Emergency planners might find it useful to target female drivers to better prepare them for what might be required in an actual evacuation. Though both males and females anticipated diverting at the same rate (in hypothetical scenarios), route choice decision forecasts could benefit by having all drivers equally well prepared.

Respondent age was associated with some evacuation factors, but like gender, had little impact on the route-choice made for the sample population. Significant age group impacts were seen at three of the 24 points in the scenario in which only alternative route information was provided, but did not affect overall results. Older potential evacuees (over 65 years of age) were significantly more likely to have prepared for an evacuation than were younger adults (25-35 years of age). In view of the large portion of the population comprised of this younger group (18%), it is important that planners be able to reach this group with information that convinces them of the importance of advance preparations.

Contrary to expectations, the likelihood of an individual choosing to take an alternate route was not related to the immediacy of information availability. Potential evacuees who expected to receive traffic information via GPS or mobile phones indicated the same likelihood of diverting as did those receiving information via VMS or radio. Responses to questions concerning traffic information sources support previous studies related to routine commuting, but also appear to show an evolution in habits. While radio remains the most frequently used source of information, significant increases in the use of more "modern" sources, such as GPS, the Internet, and mobile telephones were reported. Almost all respondents used more than one source of information with either radio, VMS, or phone systems used by 98%. Efforts to ensure good information distribution should clearly target these three modes.

The theory of planned behavior (12) provided three critical conditions that must be met for accurate predictions of future actions to be made. These requirements were that measures must be compatible with behavior predicted (routine behavior must be compatible with evacuation behavior); conditions must be between the time of stated intentions and observed behavior; and the individual's ability to control behavior in the future event must be accurately anticipated. The second condition is assumed in simulation testing because no changes are made to individual characteristics or preferences after an intention is provided. The third condition, perceived control, is partially met since evacuees may divert to an alternate route only if access to the route is available. As seen in the simulation testing discussed in Section 6, the transportation network significantly limited individuals' ability to act on intentions.

Comparisons between survey respondents' reported routine behavior (frequency of taking an alternate route to avoid congestion during non-evacuation situations) and their stated intentions were inconclusive. Those reporting higher frequencies of routine diversions were no more likely to indicate the intention to take an alternate route during an evacuation than were others. For those with past evacuation experience, there was no statistically significant difference in expected route choices between those with recent evacuation experience and those whose evacuations were made in the more distant past.

4.7. SURVEY LIMITATIONS

It is important to note the scope and assumptions of analysis:

- The survey was intended to gather sufficient information to provide data for behavior-based testing. Given resource constraints, a representative sample of the region's population could not be obtained. A cross-sectional survey was conducted and results included some selection bias in the sample population. In particular, younger and lower income citizens were underrepresented. The high number of survey responses provides some mitigation, but before employing these results in a real world situation, a regionally specific, demographically accurate survey must be conducted.
- Comparisons were made between survey respondents' past driving tendencies, current route selection behavior, and anticipated actions in a future hypothetical evacuation. The intervening time period between stated intentions and actually taking action is unclear. This length of time and the potential occurrence of real world events may alter the decisions that would be made.
- As with most cross-sectional studies, analysis may show an association between factors, but causality cannot be asserted.
- Analyses were completed assuming that particular information scenarios continued throughout the examined period. If the type of information provided changes during an evacuation (for example, signs shift from providing only alternate course information to also providing information on services), users can only apply the new decision percentages to the number of drivers still "in play."
- Respondents were asked whether they would divert to avoid congestion without regard to its expected continuing duration. Drivers who expected that congestion would clear soon may have been less inclined to divert.
- In any survey questioning the future intentions of respondents, one must keep in mind that intentions may differ from the actions that are actually taken during an event.

5. A MODEL OF THE ROUTE CHOICE DECISION

The results obtained from the survey did not support use of potential evacuees' demographics, past behavior, or self-assessed driving "personality" as factors in a quantitative decision-making (D-M) model. Though clear correlation was found between these variables, no correlation was found between these variables and evacuees' anticipated route choice decisions when faced with congestion during an evacuation. However, clear correlation was found between the frequencies at which evacuees anticipated taking alternate routes depending on the length of time they were in congestion and the level of traffic information provided or its source. A decision-making model was therefore sought that used these variables in lieu of those initially planned. Figure 12 illustrates this change.

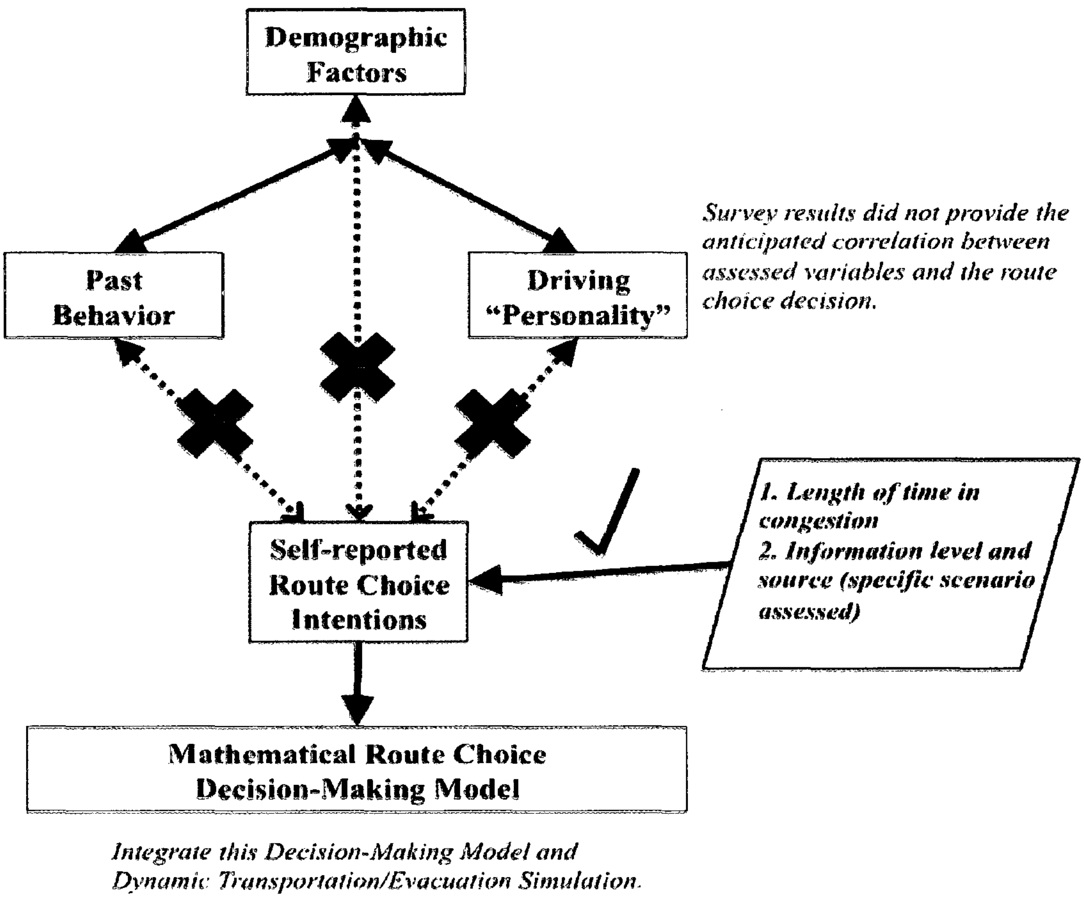


FIGURE 12 Revised variables used in route choice decision-making model.

Valid survey information was received from 841 respondents. Of these, 631 (75%) were randomly selected for analysis and use in the development of a mathematical decision-making (D-M) model. The remaining 210 (25%) were reserved for validation testing of the D-M model. The following sections provide analyses of the influence of information sources and levels on the decision to divert considering only the 631 randomly selected responses.

5.1. EMPIRICAL ANALYSIS OF ROUTE CHOICE RESPONSES

Survey respondents were asked if they would take an alternate route when faced with congestion two hours after beginning a hurricane evacuation. The two-hour point was selected because this is the approximate amount of time required to reach the edges of the Hampton Roads region from its center during periods of heavy traffic. Four different scenarios were provided with each including the provision of different levels of information or using a different medium of information transmission (VMS, radio, on site State Police). Participants were asked to report their anticipated choice at first encountering the congestion and again after being in congestion for 30, 60, and 120 minutes.

Table 14 reports the percentage of respondents who anticipated that they would take an alternate route after congestion of the shown duration when VMS provided information on alternate routes (DlyTrafX_alt), when VMS provided information on alternate routes and services available (DlyTrafX_svc), when route guidance was also provided by State Police (DlyTrafX_SP), and when alternate route information was provided via public radio (DlyTrafX_rad). Services on the alternate route listed in the DlyTrafX_svc scenario included gas, food, and lodging.

TABLE 14 Percentage of Respondents Who Would Divert After the Given Congestion Length When Provided the Information Shown

Information Scenario	Percentage Diverting for Given Unexpected Congestion Period (in minutes)			
	0	30	60	120
DlyTrafX_alt	29.8	75.1	80.1	84.2
DlyTrafX_svc	29.8	78.9	87.5	92.2
DlyTrafX_SP	29.8	84.3	89.5	93.8
DlyTrafX_rad	29.8	(not checked)	82.2	88.9

5.2. DATA RESAMPLING

A mathematical model of evacuee decision-making was desired to allow replicating decisions in a dynamic transportation simulation. However, analyses including only the response averages shown in Table 14 would provide only a single value for each measurement time. The accuracy of a selected mathematical model's representation of evacuee tendencies could not be assessed using a curve of what essentially became a single sample. A modified bootstrapping technique was used to overcome this limitation.

Bootstrapping is a type of data resampling in which subsets of a larger sample are randomly selected with replacement to increase the total number of sample sets. This increased number of sets allows estimation of the range and deviation of data, providing a better understanding of the value of forecasts made. For this study, a modified bootstrapping technique was used. Ten bootstrap data sets were created from the 631 responses with each including 100 responses. The likelihood that evacuees would divert to alternate routes was then calculated for each scenario and time period. Table 15 provides these results with averages and standard deviations.

5.3. CREATING THE MATHEMATICAL MODEL

5.3.1 Model Selection

Using the data points obtained by resampling, a mathematical equation was sought which accurately represented the survey results for each scenario. Though each scenario was assessed individually, a single mathematical model capable of representing all scenarios was desired. Online curve-fitting software was used and the best fitting curves for each scenario (based on calculated R-squared and root mean square error values) examined. Any curves with discontinuities, unrealistic reductions in the cumulative fraction having diverted over time, and those that did not have time zero values near the empirically determined average of 30% were dropped from consideration. After this filtering, six curves were selected for further testing. Using results from the resample data, each curve was assessed from time zero to time 120 minutes in one minute intervals, compared to each of the ten resample runs individually, and the standard deviation between curve values and measured values calculated. Figure 13 illustrates the process used to select the mathematical model.

TABLE 15 Chance (%) of Evacuees Deciding to Take an Alternate Route When Confronted with Congestion for Each Tested Scenario at Each Time Step Using Ten Sets of 100 Samples Randomly Selected from the Analysis Set (with Replacement)

	DlyTrafX_alt				DlyTrafX_svc				DlyTrafX_SP				DlyTrafX_rad		
SET	t=0	t=30	t=60	t=120	t=0	t=30	t=60	t=120	t=0	t=30	t=60	t=120	t=0	t=60	t=120
1	31.0	75.0	82.0	84.0	31.0	84.0	88.0	94.0	31.0	87.0	90.0	93.0	31.0	86.0	89.0
2	39.6	81.0	81.0	90.0	39.6	82.0	89.0	94.0	39.6	90.0	93.0	98.0	39.6	83.0	90.0
3	33.4	78.0	81.0	87.0	33.4	85.0	90.0	95.0	33.4	91.0	92.0	95.0	33.4	87.0	91.0
4	38.0	76.0	78.0	81.0	38.0	78.0	88.0	93.0	38.0	89.0	91.0	95.0	38.0	84.0	90.0
5	32.5	77.0	85.0	89.0	32.5	76.0	92.0	96.0	32.5	89.0	92.0	96.0	32.5	83.0	90.0
6	28.6	71.0	72.0	79.0	28.6	73.0	83.0	89.0	28.6	79.0	86.0	89.0	28.6	77.0	80.0
7	37.4	70.0	78.0	84.0	37.4	77.0	88.0	92.0	37.4	82.0	89.0	92.0	37.4	78.0	87.0
8	30.8	79.0	82.0	86.0	30.8	79.0	93.0	92.0	30.8	82.0	88.0	94.0	30.8	85.0	89.0
9	36.0	81.0	81.0	90.0	36.0	82.0	89.0	94.0	36.0	90.0	93.0	98.0	36.0	83.0	90.0
10	31.0	78.0	81.0	87.0	31.0	78.0	81.0	87.0	31.0	91.0	92.0	95.0	31.0	87.0	91.0
AVE	33.8	76.6	80.1	85.7	33.8	79.4	88.1	92.6	33.8	87.0	90.6	94.5	33.8	83.3	88.7
STD DEV	3.7	3.7	3.5	3.7	3.7	3.8	3.7	2.8	3.7	4.4	2.3	2.7	3.7	3.4	3.3

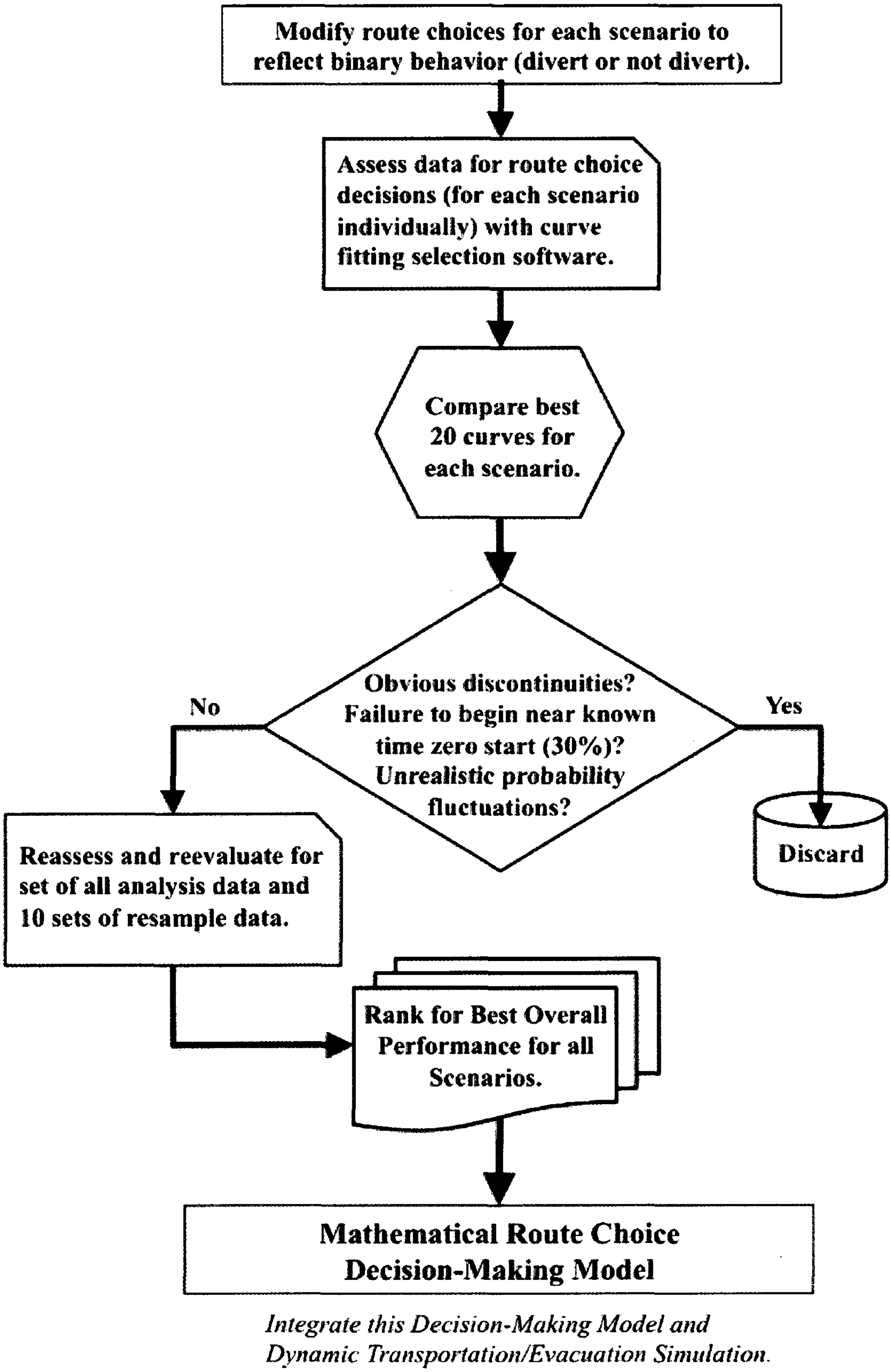


FIGURE 13 Decision-making model selection process.

Table 16 lists the final curves considered, the equation for each curve, and the standard deviation calculated when the model curve was compared to results of the ten sets of resampled data. The Michaelis-Menten offset (MM-O) equation had the smallest average standard deviation. Each curve had low high values for R-squared (indicating the amount of variability accounted for by the equation) and low values for RMSE. Values for the MM-O equation were:

Scenario	R-squared	RMSE
DlyTrafX_alt	0.971	0.00358
DlyTrafX_svc	0.983	0.00309
DlyTrafX_SP	0.983	0.00323
DlyTrafX_rad	0.983	0.00329

The MM-O equation consistently provided good modeling of data and the relative simplicity of the mathematics has the additional benefit of being easy to visualize and understand the impact of changes to variables. The equation is written:

$$y(t) = \frac{a * t}{b + t} + c \quad \text{where}$$

- $y(t)$ gives the percentage of evacuees expecting to divert at a time t for the given scenario;
- t provides the time length of congestion in minutes (the "x-axis value");
- a is a coefficient determined by analysis;
- b is the value of time occurring when $y(t)=1/2*[y_{max}-y(0)]$; and
- c is the value of y at $t=0$. (the y-axis intercept)

Figure 14 is a plot of the DlyTrafX_alt scenario (in which VMS provides information on an alternate route) using calculated coefficient values from the curve fitting analysis. Approximately one-third of respondents indicated that they would divert even with no information; this results in a value of 33.8% when t is equal to zero. Note that the value of the b coefficient can be found on the graph as the value of time when the probability of diverting is midway between its value at time zero and its maximum.

TABLE 16 Equations Tested for Curve Fitting and Standard Deviations When Compared to Results from 10 Sets of Resample Data

	Equation[1]	Calculated Standard Deviation			
		DlyTrafX_alt	DlyTrafX_svc	DlyTrafX_SP	DlyTrafX_rad[2]
Inverse Inverted Offset Exponential with Offset	$= \frac{t}{ae^{(b/(x+c))}} + d$	4.29	4.28	4.25	NA
Scaled Log Transform with Offset	$= \frac{t}{a * \log(bt + c)} + d$	4.27	4.28	4.04	NA
Weibull	$= a(1 - e^{(-b(t-c)^d)})$	4.27	4.26	4.04	NA
Exponential with Offset	$= ae^{bt} + c$	4.50	4.30	4.22	4.36
Michaelis-Menten with Offset	$= \frac{at}{b + t} + c$	4.31	4.00	4.06	4.33
Negative Exponential with Offset	$= a(1.0 - e^{-bt}) + c$	5.37	4.28	4.20	4.33

[1]The variable "t" is the time since congestion began in minutes. Values for other coefficients were obtained using curve-fitting software.

[2]Due to a sampling error, no probability of diverting was reported for the DlyTrafX_rad scenario at time 30, resulting in values for just three points (times 0, 60, and 120). Equations with more than three coefficients could not be fitted to this scenario.

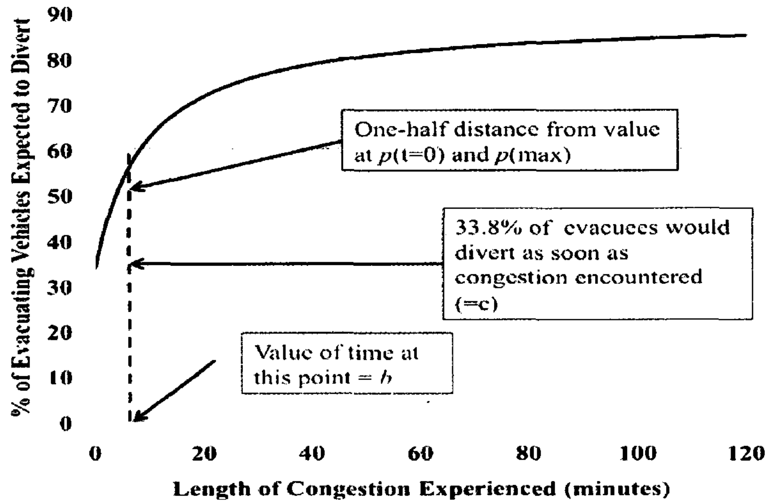


FIGURE 14 DlyTrafX_alt plot using Michaelis-Menten (with offset) equation.

Table 17 provides the coefficient values for each scenario as calculated using the bootstrapping technique with ten data sets of 100 responses each. Using these coefficient values, continuous decision-model curves were created to predict the rates at which evacuees would choose to use alternate routes when confronted with congestion.

TABLE 17 Michaelis-Menten Equation Coefficient Values for Each Scenario

Information Scenario	Coefficient values for each scenario		
	A	b	C
DlyTrafX_alt	54.88	9.06	33.84
DlyTrafX_svc	66.21	12.69	33.82
DlyTrafX_SP	63.12	5.82	33.83
DlyTrafX_rad	61.59	14.70	33.83

5.3.2 Sample Decision-Making Estimate

Suppose the simulation user selects the provision of alternate route information via variable message signs 30 minutes after the congestion event occurs, adds public radio distribution to the information distribution at time 60, and then additionally provides service information at time 90. Using the Michaelis-Menten equation and factor values provided, the percentage of evacuees choosing to use an alternate route from time zero to time 60 is calculated as:

$$y = \frac{a*t}{b+t} + c = \frac{54.88*t}{9.06+t} + 33.84$$ where t is the time in minutes since the event began.

By time 30, 76.0% of evacuees expect to choose to divert; by time 60, 81.5% will make this decision. At time 60, radio begins being used as a means of information distribution. The calculation then becomes:

$$y = \frac{a*t}{b+t} + c = \frac{61.59*t}{14.70+t} + 33.83$$

There is an immediate slight increase (to 81.7%) in the number of evacuees likely to take the alternate route because of the greater number of evacuees using information received via the radio to make decisions on alternate routes. By time 90, 86.8% of evacuees would be expected to choose the alternate route. At this time, services information is also provided and the variables again change. The equation is now:

$$y = \frac{a*t}{b+t} + c = \frac{66.21*t}{12.69+t} + 33.82$$

More travelers are inclined to take the alternate route when this additional information becomes available with 91.8% of evacuees likely to divert to the alternate route. This value continues to rise with 93.7% likely to divert two hours after the event began. While evacuees stuck for more than two hours would likely continue to divert if able, decision trends are quite stable at this point and study analysis did not consider congestion periods of greater than two hours.

5.3.3 Comparison of Model Results with Complete Analysis Data Set

After calculating the MM-O model coefficients for each scenario, the model curve was compared with all 631 survey responses used for analysis. Table 18 provides the predicted values, the standard deviation values for the percent diverting, and the empirical results using all 631 responses as a single data set. Note the strong agreement between predicted values using the developed equation and the relatively small standard deviation. It is important to understand that estimates on diversions report the survey participants' intentions to take an alternate route. The high fraction of evacuees willing

TABLE 18 Predicted Values Compared to Complete Sample Data (631 Responses)

Information Scenario	Percentage Diverting for Given Congestion Period (in minutes)					
		0	30	60	120	Std Dev
DlyTrafX_alt	Predicted	33.8	76.0	81.5	84.9	3.74
	Survey data	29.8	75.1	80.1	84.2	
	Difference	-4.0	-0.3	-0.9	-0.1	
DlyTrafX_svc	Predicted	33.8	80.3	88.5	93.7	3.28
	Survey data	29.8	78.9	87.5	92.2	
	Difference	-4.0	-0.7	-0.6	-1.4	
DlyTrafX_SP	Predicted	33.8	86.7	91.4	94.0	3.34
	Survey data	29.8	84.3	89.5	93.8	
	Difference	-4.0	-1.6	-1.2	0.3	
DlyTrafX_rad	Predicted	33.8		83.3	88.7	3.05
	Survey data	29.8		82.2	88.9	
	Difference	-4.0		-0.7	0.6	

to take an alternate route would likely very quickly exceed the route's capacity, shifting congestion from the primary route to the alternate. In the dynamic traffic simulation described in the following section, this overloading is mitigated because the alternate route travel time (and route cost) increases with congestion, making staying on the primary route a better option.

5.4. VALIDATION TESTING

The Hampton Roads, Virginia, region where this work was conducted has not experienced a full force hurricane in over 20 years. The region has never had a mandatory evacuation, and when Hurricane Isabel struck the region with tropical storm strength in 2003, few residents evacuated the region. Models of evacuee behavior therefore must depend on testing of data reserved for this purpose. Of the 841 valid survey responses received, 25% were randomly selected and reserved for validation testing. The model previously described was first tested against the complete reserved data, then four sets of bootstrapped data, each of which included 70 responses randomly selected with replacement each time from the full reserve set.

Predictive equation results were compared to the full set of 25% of all responses selected at random and reserved for validation from the complete data set, then compared to the average values obtained from the four bootstrap data runs, and finally compared to the averaged results of the four bootstrapped runs and the full reserved data set. Results from this comparison and the standard deviations calculated from the bootstrapped data analysis are provided in Table 19.

TABLE 19 Predicted Values Compared to Values from Reserved Data (210 Responses)

Information Scenario	Percentage Diverting for Given Congestion Period (in minutes)					
		0	30	60	120	Std Dev
DlyTrafX_alt	Predicted	33.8	76.0	81.5	84.9	3.63
	All Reserved data	31.3	77.5	80.4	82.7	
	Difference	-2.5	1.5	-1.4	-2.2	
	Ave 4 bootstrapped runs	30.2	76.3	78.6	81.8	
	Difference with predicted	3.6	0.3	2.9	-3.1	
	Average 5 V&V runs	30.4	76.5	79.0	82.0	
	Difference	3.4	-0.5	2.6	2.9	
DlyTrafX_svc	Predicted	33.9	80.4	88.5	93.8	3.13
	All Reserved data	31.3	79.9	86.6	91.9	
	Difference	-2.6	-0.5	-1.9	-1.9	
	Ave 4 bootstrapped runs	30.2	81.1	84.7	92.5	
	Difference with predicted	3.7	0.7	-3.8	-1.2	
	Average 5 V&V runs	30.4	80.8	85.1	92.4	
	Difference	3.4	0.4	-3.4	-1.4	
DlyTrafX_SP	Predicted	33.8	86.7	91.4	94.0	3.28
	All Reserved data	31.3	88.0	90.9	94.2	
	Difference	-2.5	1.3	-0.5	0.2	
	Ave 4 bootstrapped runs	30.2	84.0	87.2	94.3	
	Difference with predicted	3.6	-2.7	-4.2	0.3	
	Average 5 V&V runs	30.4	84.8	87.9	94.3	
	Difference	3.4	-1.9	-3.5	0.3	
DlyTrafX_rad	Predicted	33.8		83.3	88.7	3.35
	All Reserved data	31.3		82.8	89.0	
	Difference	-2.5		-0.5	0.3	
	Ave 4 bootstrapped runs	30.2		82.2	89.7	
	Difference with predicted	3.6		-1.1	1.0	
	Average 5 V&V runs	30.4		82.3	89.5	
	Difference	3.4		-1.0	0.8	

Predicted values compared very favorably with values calculated from the complete set of reserved data with all following within +/- 2.5%, well within the calculated standard deviations. The smaller bootstrapped data sets, as would be expected, was slightly less well defined, but still trended well with predicted values.

The study began with the expectation that demographic and behavioral traits would be identified and correlated with the route choice decisions made when evacuees were confronted with congestion. For example, if a higher proportion of all young adult males anticipated taking an alternate route than did older females, then it would be possible to refine the model and anticipate decisions made with greater accuracy. Knowing in detail the makeup of an evacuating population would provide simulations with the tools needed to more accurately model the behavior that might be expected. However, the data obtained in the survey does not support this hypothesis. Although demographic groups could be correlated with particular behavioral tendencies, only time, information level, and information source could be correlated to anticipated decisions. For example, 36% of male respondents considered themselves to be aggressive drivers as compared to just 26% of females. The 10% difference was assessed as statistically significant by testing using confidence intervals, Student t tests, and Chi Squared tests. However, when route choice decisions made by the group of male aggressive drivers and the group of female non-aggressive drivers were compared for each time step (0, 30, 60, and 120 minutes), there was no statistically significant difference in responses (5% level). Data obtained from the survey cannot be used as initially intended. This may be a result of the survey process. As noted previously, respondents do not represent a random sampling of the regional population. The respondent population was older, better educated, and had higher annual earnings than the general population. Though compared weighted and non-weighted responses support use of the results as an approximation of the region's residents, a more stochastic survey inclusive of all parts of the region might return different results. The following section discusses uses of an alternate mathematical model for decision-making and how demographic and behavioral characteristics could be incorporated.

5.5. AN ALTERNATIVE DECISION-MAKING MATHEMATICAL MODEL

Survey respondents were asked if they would take an alternate route or remain on the original route when faced with congestion during an evacuation. Four hypothetical scenarios were presented, each varying from the others by either the amount of information provided or the method of delivery. The four scenarios were:

1) DlyTrafX_alt: Dynamic traffic signs advise evacuees of an accident ahead and suggest an alternate route.
2) DlyTrafX_svc: Dynamic traffic signs, in addition to providing a suggested alternate route, advise that services (gas, food, and lodging) will be available.

3) DlyTrafX_SP: Dynamic traffic signs advise that an alternate route is available and is guided by State Police.

4) DlyTrafX_rad: Public radio suggests and describes an alternate route.

As noted earlier, the MM-O equation described in Section 5.3 provided the best overall replication of survey responses for the four scenarios. However, the structure of the equation does not readily adapt to the use of utility function (discussed below). A negative exponential curve (with offset) (NEC-O) represented response data nearly as accurately as the MM-O equation for three of the four scenarios. Because of the relatively small increase between the time 60 and time 120 values for the DlyTrafX_alt scenario, the NEC-O curve is less pleasing at higher values of time and overall standard deviation is approximately 25% larger than for the MM-O model (see Figure 15). The NEC-O equation is written:

$$y(t) = a(1 - e^{-Ut}) + c .$$

The *y(t)* term yields the fraction of evacuees diverting by time *t* and the *c* term is the offset for the fraction of evacuees who would divert at time *0* when congestion was first encountered. The *a* and *U* variables are functions of the curve fit.

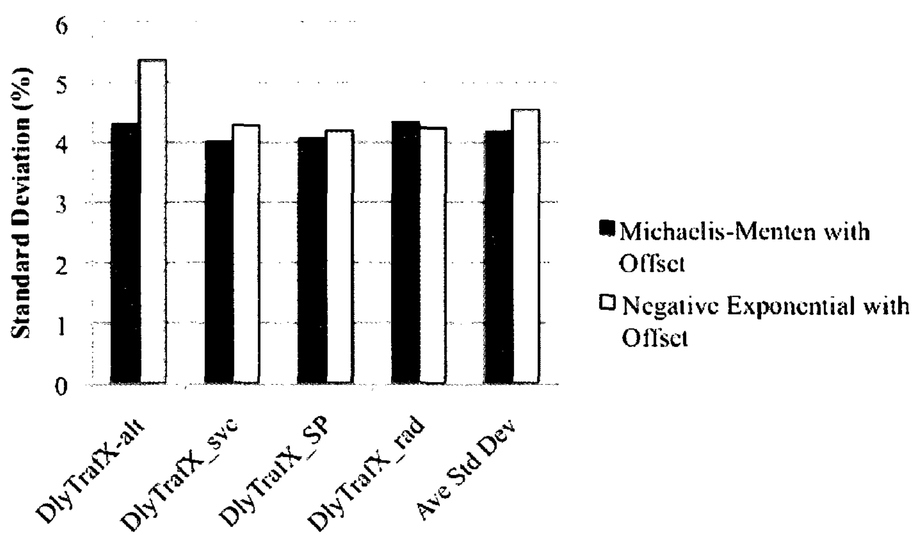


FIGURE 15 Standard deviations comparison for Michaelis-Menten (with offset) and negative exponential (with offset) curve models.

A representative base curve for all scenarios was sought. Two trials were run using average data, first for all four scenarios and then for three scenarios (DlyTrafX_alt values dropped). With these values for *a* and *c* assigned as constants, new NEC-O curve fits for each scenario were obtained and the resulting values for *U* recorded. Each of these model equations was next tested against survey sample data, just as done for the MM-O equation. The smallest average standard deviation as well as the smallest change in any scenario's standard deviation were obtained from the curve found using data averaged without including the DlyTrafX_alt scenario. Table 20 shows the standard deviation for each scenario when plotted using the two NEC-O curves.

TABLE 20 Negative Exponential (with offset) Curve Trials with Constant *a* and *c* Values: Standard Deviation Comparisons

	***a* value**	***c* value**	***U* value**	**Standard Deviation**
Average of survey data for three scenarios (DlyTrafX_alt data omitted)				
DlyTrafX_alt	58.15	29.83	0.04474	5.15
DlyTrafX_svc	58.15	29.83	0.06301	4.80
DlyTrafX_SP	58.15	29.83	0.09410	5.17
DlyTrafX_rad	58.15	29.83	0.03943	4.31
			Average Standard Deviation	**4.86**
Average of survey data for four scenarios				
DlyTrafX_alt	58.61	29.82	0.4359	5.27
DlyTrafX_svc	58.61	29.82	0.06130	4.65
DlyTrafX_SP	58.61	29.82	0.09008	5.00
DlyTrafX_rad	58.61	29.82	0.03810	4.30
			Average Standard Deviation	**4.81**

These results show that a standard NEC-O curve can be used for all four scenarios with only one value (*U*) varying between scenarios. The *U* value represents the influence on evacuees facing congestion of traffic information and delivery methods. Subsequent studies, data from which supported the original hypothesis concerning the influence of demographic and behavior factors on route choice decisions, could use a utility function (described below) with *U* to represent various scenarios and the influence of other factors.

5.5.1 Utility Function

The value of a utility function reflects the importance of its components to the decision maker, for this case the importance of various factors to an evacuees decision to take an alternate route. Many factors contribute; several potential factors are listed in Table 21. Some factors, such as time of day, expected delay time, and the presence of police or other public authority are a function of influences external to an individual evacuee. These factors are represented by X_i, where *i* represents the individual factor. Other factors, such as age, gender, and fatigue, are primarily attributes of the individual making the decision. The factors are represented by S_i. Some factors, such as the length of time an evacuation has been in progress, could potentially be assigned to either X or S. Some factors influencing an evacuee's choice may not be identified and some may not be represented with complete accuracy. This influence is represented by an error term €.

TABLE 21 Factors that May Contribute to Evacuee Decision-Making

Number	Factor	Variable
1	Length of time confronted with congestion	X
2	Familiarity with road network	X
3	Traveling with others (in separate vehicles)	S
4	Health concerns for individual or traveling companions	X
5	Availability of services (gas, food, lodging)	S
6	Presence of police or other public authority recommending route	S
7	Method of traffic information delivery	S
8	Traveling with children	S
9	Economic status	S
10	Education	S
11	Gender	X
12	Age	X
13	Traveling with pets	X

The utility of a decision is thus represented by:

$U_i(X,S,€)= \alpha_0+\beta_0+\alpha_1X_1+\alpha_2X_2+\ldots+\alpha_iX_i+\beta_1S_1+\beta_2S_2+\ldots+\beta_iS_i+€.$

The values for the α and β coefficients are determined after analysis of survey results. As noted in Section 4 (Survey Content, Distribution, and Analysis), survey results did not support the expected association of these factors on an evacuee's decision to take an alternate route. Data obtained from future work may support use of utility functions to predict these decisions with greater population detail.

5.6. APPLICATION OF MODEL RESULTS TO OTHER REGIONS

The MM-O equation used in the D-M model was selected because it provided the best overall representation of data obtained in the survey. Due to funding constraints, a completely random survey of the entire Hampton Roads region was not conducted. It is possible that data from a different survey of potential evacuees in Hampton Roads might lead to the selection of a different equation and model. Surveys of different regions, especially those with more frequent evacuations, might also yield different results since evacuees from these regions act on different factors with different biases than those tested here. However, the D-M model selection process previously described (Section 5.3) and illustrated in Figure 13 remains effective. First, a survey or other information-gathering tool obtains data representative of the evaluated population. Second, this data is analyzed to identify those variables influencing the route choice decision. Next, potential equations fitting the data are identified and tested. Finally, the equation providing the best statistical fit for the data is selected and validation testing conducted.

6. A DYNAMIC EVACUATION SIMULATION WITH INTEGRATED DECISION-MAKING MODEL

The primary goals of the study were to

1) Identify the key factors associated with evacuees' decisions whether or not to take an alternate route when confronted with congestion during an evacuation;
2) Create a decision-making (D-M) model reflecting the influence of these variables;
3) Integrate the D-M model created in a dynamic evacuation simulation and assess the impact of the decisions made.

Influencing variables were identified and analyzed using a survey of potential evacuees. Section 4 described and reported results of the survey. The development of a D-M model was explained in Section 5. A dynamic hurricane evacuation simulation, introduced in Section 3, was used as a test platform. Section 6 now describes the integration of the D-M model with the evacuation simulation, reports results, and evaluates the information gained.

6.1. CONGESTION TEST EVENTS

Evacuee route choice decision impacts on the evacuation transportation network were tested by integrating the decision-making model into the evacuation simulation using Congestion Test Events (CTE) to simulate incidents. CTEs simulate the complete closure of one travel lane for one hour by reducing road capacities. Each CTE was placed on a section of roadway with two lanes in each direction and, using the guidance of the Highway Capacity Manual (2000), capacities were reduced to 35% for the one hour CTE duration.

One CTE was placed on an Interstate (I-64) segment and one on a state highway (US 460). Each CTE was placed to allow vehicles to alter paths to a roughly parallel road until the congested portion of the primary route was bypassed and either the original route rejoined or the next leg of the evacuation trip reached. The survey queried anticipated responses for incidents occurring approximately two hours into an evacuation; the I-64 and US 460 CTE locations approximated this situation.

The Interstate test CTE was selected to allow use of multiple accesses to the alternate route. The combined hourly capacities of the accesses was greater than the maximum expected rate of vehicles expected to divert to the alternate route at any time. Likewise, the Interstate alternate route, US 60, was capable of carrying the maximum volume of diverting traffic expected. (Up to 92% of the sample population anticipated diverting if any congestion 90 minutes, but not all of these would have both the opportunity and motivation to divert. The alternate route was capable of carrying 83% of all vehicles using the Interstate.) The highway CTE was also placed to allow multiple accesses to the alternate route, but with combined access route capacities and alternate route capacity less than the maximum expected volume of diverting traffic.

6.1.1 Interstate Congestion Test Event

The Interstate CTE was placed just prior to I-64 exit 227 (VA 30). Figure 16 shows this location, the alternate route on US 60, and access road connections. This location required congestion to extend for approximately 2 miles before reaching the first available access to the alternate route on US 60 at exit 231 (SR 607). For tests simulating a lack of ATIS, exit 231 was the first location at which evacuating vehicles confronted congestion and were motivated to divert. When the D-M model was used to simulate ATIS contributions, vehicles diverted to the alternate route (US 60) at exit 231 or also at exit 234 via SR 646, at exit 242 via VA 199, or on VA 143 at exit 243. Capacities on SR 607 and SR 646 were approximately 800 vehicles per hour (vph), capacity on VA 199 was 2667 vph, and capacity on VA 143 was 667 vph. The number of available access points and combined capacities of the access road segments (greater than 4900 vph) increased the likelihood vehicles had the opportunity divert.

Traffic diverting to US 60 could rejoin I-64 traffic at either I-64 exit 227 using VA 30, at I-64 exit 205 via VA 249, or by remaining on US 60 until the intersection with I-295, one mile south of the I-64/I-295 intersection. The total length of the alternate route varied from 4.5 miles to approximately 40 miles. At the I-64 CTE location, the two westbound lanes had a total capacity of 4276 vph. The capacity on US 60, also with two westbound lanes, was 3570 vph, 83% of the capacity on I-64.

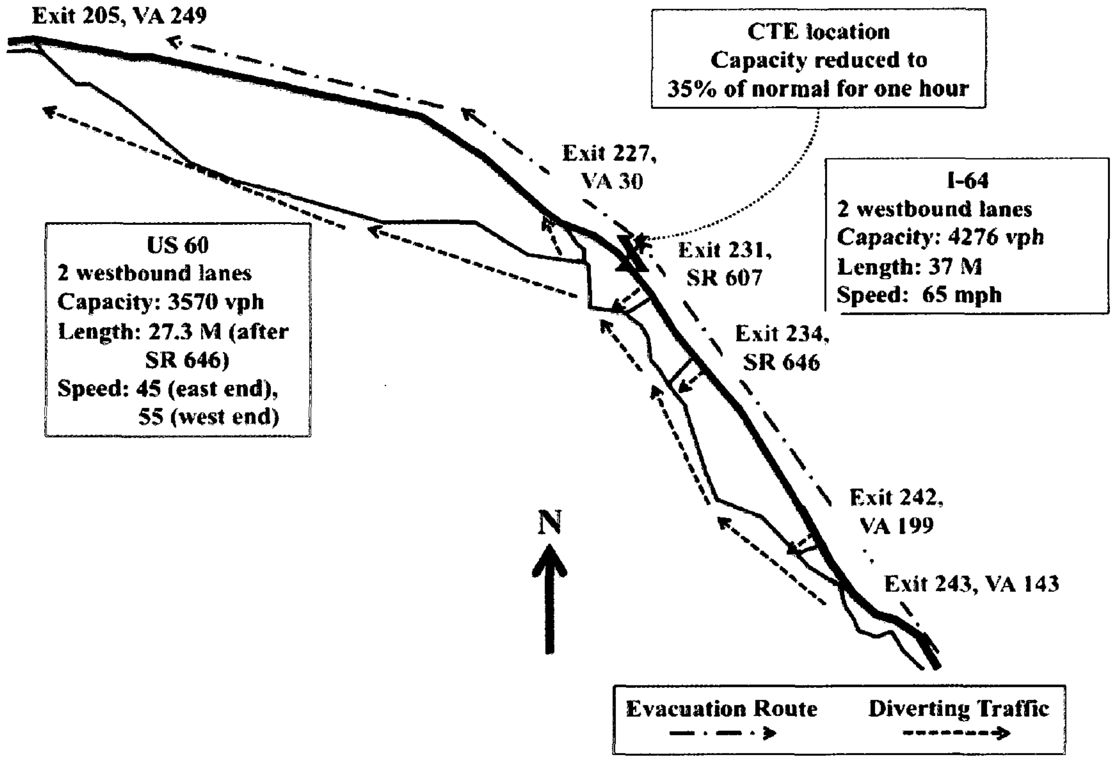


FIGURE 16 I-64 congestion test event location and connections to alternate route US 60.

6.1.2 Highway Congestion Test Event

The CTE on US 460 was approximately 3 miles northwest of Windsor, VA. US 460 is a four-lane highway (two lanes in each direction) with total capacity of 3570 vph. The alternate route is a roughly half-oval bypass south of US 460 using SR 638. Access to the alternate route is one mile southeast of the CTE location and the alternate route rejoins US 460 less than 1/4 mile northwest of the CTE. All evacuating traffic using the alternate route must rejoin US 460; no other routes are available. Total capacity on the alternate route is 312 vph, just 9% of the westbound capacity on US 460. The length of the alternate route was 3.6 miles; it bypassed 2.1 miles on US 460. Some evacuating traffic could also diverted to the alternate route 2.5 miles earlier via SR 603, rejoining SR 638 via SR 657. The length of the modified alternate route was 6.7 miles; it bypassed 4.6 miles on US 460. Figure 17 shows the US 460 section, alternate route, and connections.

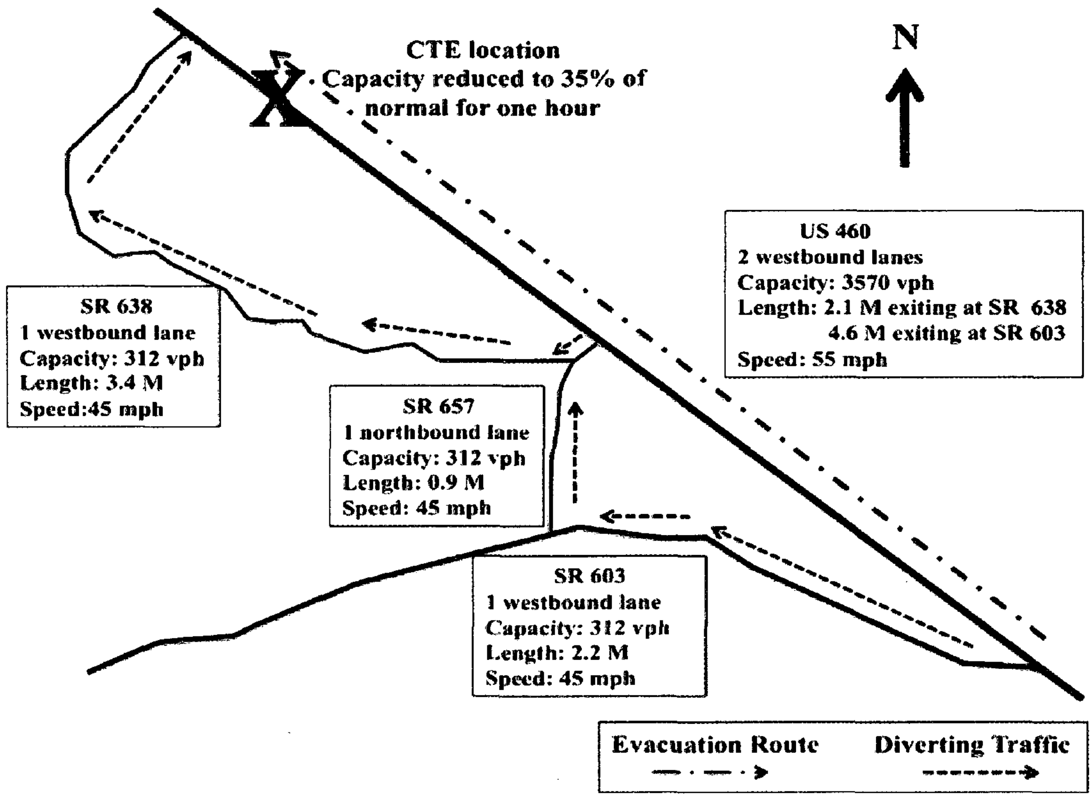


FIGURE 17 US 460 congestion test event location and connections to alternate route SR 638.

6.2. SIMULATING TRAFFIC INFORMATION

The influence of traffic information was simulated using the Michaelis-Menten Offset (MMO) D-M model described in Section 5.3. The effects of the D-M model were added to the evacuation simulation using the variable COST, previously discussed in Section 3.3. The Avenue default COST value equals the sum of travel times over all road segments traversed along the route from origin to destination. Travel times include delays caused by congestion. COST values are calculated prior to vehicles being loaded onto the network and determine a vehicle's route selection. Calculations are made and routes assigned using pre-trip anticipated road segment travel times. No new calculations or route adjustments are made after vehicles have been loaded onto the network. When repeated iterations of the same run are conducted, the system adjusts to previous information, reassigning routes to minimize travel time. The base hurricane evacuation simulation applies a multiplying factor (titled "COSTFACTOR") to COST calculations for road segments not on the designated evacuation routes. The higher COST values prejudice route choice to the designated routes.

Modeling the impact of traffic information required influencing some vehicles to take alternate routes to avoid congestion. This was accomplished by providing selected vehicles a lower cost route, mimicking the real world situation when drivers provided ATIS information may divert to better routes. This was accomplished by applying a second set of multiplying factors, called "DECISION," to the sections of the designated evacuation routes affected by the CTE, raising the associated COST and motivating vehicles to use the alternate route. DECISION was set to a value greater than COSTFACTOR, prompting one-third of evacuees at the appropriate time to take an alternate route. DECISION was gradually reduced as the primary evacuation route cleared and congestion began to cause delays on the alternate route. Without reducing the value of DECISION, vehicles would remain on alternate routes even after the primary route was cleared. This mimicked the shifts of evacuees between routes to minimize travel times. This method allowed vehicles to adjust routes to reduce trip times without affecting the remainder of the network by changing the value of COSTFACTOR. The process is illustrated in Figure 18 and explained below:

1) The overall evacuation rate is represented by a logit equation and is shown as a sigmoid curve, commonly used to model evacuation response, in the left-most graph of Figure 18. Development of this curve is described in Section 3.1. Vehicles affected by the CTE tests are taken from the dynamic load matrix described by this curve and shown by the shaded partitioned quadrangle. Evacuations initiate at the same rate as without the CTE testing. The majority of the vehicles represented by this curve will use other routes than those affected by the CTE or will travel at times not impacted by the CTE. These vehicles are unaffected by the changes made to the system to allow mimicking decision-making behavior.
2) The time duration of the partition had a maximum limit of two hours, the maximum congested time questioned in the study survey. In practice, the partition size was reduced to approximately 90 minutes, the observed duration of congestion.

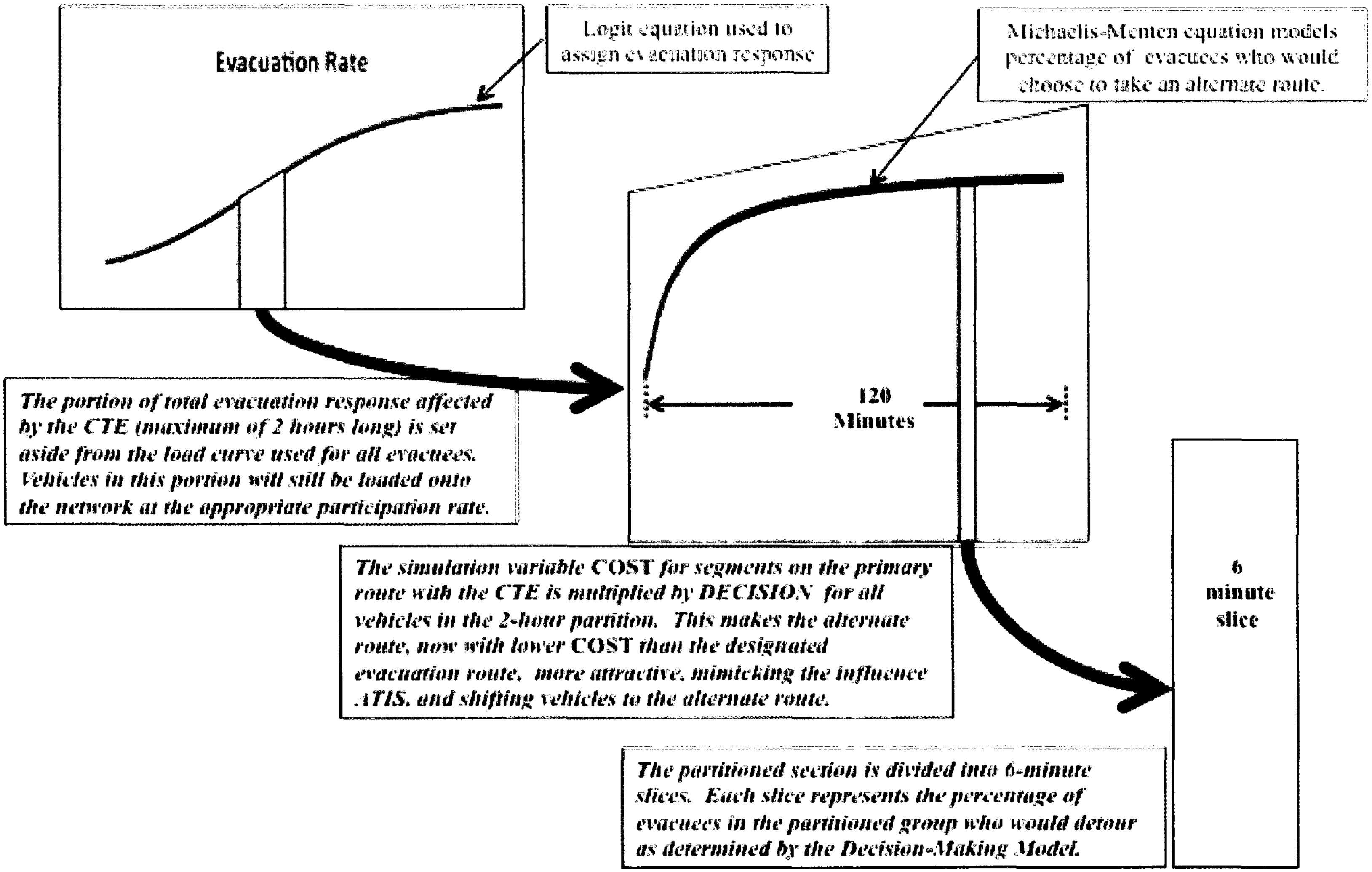


FIGURE 18 Influencing evacuating vehicles to detour using the decision-making model.

3) Just as in real world driving situations, not all vehicles affected by the CTE congestion divert. The percentage of evacuees who would take an alternate route and the rate at which this choice would be made is described by D-M model. The MMO curve for one scenario is shown in the middle graph of Figure 18. The left value of this curve is at 34%, representing the members of the sample population who indicated they would divert when congestion was first confronted, even without ATIS. As time passes, an increasing percentage of the portioned group would be influenced to divert.
4) The simulation time segments used during testing are 6 minutes long and evacuees motivated to take an alternate route are loaded in six-minute increments. This is shown by the right-most graph of Figure 18.

The vehicles under the curve in the middle graph of Figure 18 represent the survey respondents who indicated they would take an alternate route when confronting congestion for increasing lengths of time and provided different levels of traffic information. Since vehicles that will encounter the CTE begin the evacuation prior to its initiation, the dynamic loading of these vehicles "anticipates" the future CTE, and the values considered when these vehicles make route choices must be timed correctly. Applying the decision-making model too early causes vehicles to begin altering routes to avoid congestion not yet present. Applying the model too late allows the CTE caused congestion to form long queues extending beyond available exits, reducing the potential effectiveness of ATIS. The following section describes the process used to implement the MMO decision-making model results in the dynamic hurricane evacuation simulation.

1) Vehicles within the partitioned area were initially predisposed to remain on primary evacuation routes by applying the multiplying factor COSTFACTOR to COST calculations for road segments not on the primary routes, essentially raising the calculated length of time required to travel from origin to destination on alternate routes. To now prompt vehicles in the partition area to use the alternate route, COST on the primary route segments affected by the CTE was raised by applying a second multiplying factor, DECISION, to

calculations made by those vehicles in the partitioned group under the curve representing evacuee route-choice decisions.

2) Determine volume addition rate on the CTE affected segment immediately following the CTE start. For I-64, this rate was approximately 4300 vph.
3) Use the volume addition rate and the expected outflow rate (35% of normal capacity) to estimate the rate of queue growth. For I-64, outflow rate was approximately 1505 vph and queue growth rate was 2795 vph.
4) Using a storage value of 300 vehicles per lane per mile and two lanes, the initial queue growth rate for I-64 was: (2795 vph)/(600 vehicles/mile)=4.66 mph.
5) Using this rate, calculate the length of time required to the queue to extend upstream to the first available alternate route access. For I-64, this distance was 2 miles, so the time required for the queue to grow backwards and reach the first alternate route access was: (2 miles)/(4.66)=0.43 hr (approximately 25 minutes). This time, termed "BLINDTIME," was the length of time after a CTE was initiated that the first route changes to an alternate route were expected.
6) Determine when vehicles reaching the appropriate road segments at the end of BLINDTIME initiate travel. Since evacuees along I-64 and, to a lesser extent, along US 460 begin travel from across Hampton Roads, this necessitated assigning dynamic vehicle load matrices for several parts of the region:
    a. Williamsburg,
    b. Newport News and Hampton,
    c. Norfolk,
    d. Virginia Beach (north and south),
    e. Chesapeake and portions of Suffolk, and
    f. Portsmouth and remaining portions of Suffolk.
7) Several evacuation simulation runs were conducted while monitoring vehicles from each of these regions. Using results of these runs, dynamic load matrices (represented by the middle section of Figure 18) were applied for each region. These matrices ensured that the proper number of vehicles was

loaded onto the system at the right time to arrive at congestion with a predisposition to use alternate routes.

Vehicles beginning travel before or after the selected group have COST variables assigned which bias remaining on the designated route and only use the alternate route if calculated COST values (using the multiplying factor COSTFACTOR) are less on the alternate route.

6.3. SIMULATION TESTS

Four primary sets of simulation runs were connected:

1) I-64 CTE without and with ATIS simulated and each of the four information variants;
2) US 460 CTE without and with ATIS simulated and each of the four information variants;
3) I-64 CTE with ATIS using three combinations of traffic information content and sources; and
4) US 460 CTE with ATIS using two combinations of traffic information content and sources.

Sets 1 and 2 each consisted of 82 separate runs for each of the four information scenarios, with 41 each without and with ATIS simulation. Each run included two iterations, an initial run and a second run with rerouting by the Avenue software to respond to congestion seen in the first iteration. Each pair of runs (with and without ATIS cases) used a different random seed in the stochastic selection of origin-destination pairs in Avenue; both runs within a pair used the same random seed allowing direct comparison of the two situations. Altogether, these sets included approximately 700 simulation runs. Sets 3 and 4 also required 41 runs for each information scenario, but the "no ATIS" cases were not repeated since the same sequence of random seed assignment were used and results would repeat those already observed. These two sets required 410 simulation runs. Each run required approximately 75 minutes of dedicated computer processing time using HP xw4400 Workstation computers using the Windows XP® operating system and equipped with Intel Core2 Quad 2.66GHz processors and 3.2 GB memory.

The first five time intervals in the simulation were one-hour each. Intervals six through 45 were 0.1 hours long; subsequent interval lengths returned to one hour. The simulation was run for five hours to establish steady state conditions with primary evacuation routes at or near maximum volume loading. The CTE was inserted at the 5.8 hour point and reduced primary route capacity for one hour. At the 6.8 hour point, full capacity was restored. Volume and queue measurements were taken until the 9 hour point (3.3 hours of data). The evacuation network was not at equilibrium prior to, during, or after insertion of the CTE. Vehicles were prejudiced to either the primary evacuation routes or alternate routes. After the CTE was inserted, on runs where no traffic information was provided, all vehicles continued on the primary evacuation route until confronting congestion at which time vehicles moved to alternate routes at rates representative of survey responses as limited by the transportation network. Many vehicles representing evacuees who anticipated diverting were unable to do so because no alternate route access was available or the available accesses were extensively congested. When traffic information was provided, all vehicles were assumed to have this information. Vehicles responded to the information received in accordance with the D-M model for the scenario being tested as limited by the transportation network.

The maximum possible evacuating vehicle volume was dependent on road segments upstream of the CTE. For both the Interstate and highway tests, this limit was the maximum volume for two lanes of traffic operating at capacity.

6.4. SIMULATION RESULTS FOR INDIVIDUAL SCENARIOS

Simulation assessments used the Avenue animation and quantitative measurements for each of the four test sets. Results for the first two sets are provided below.

6.4.1 Interstate Congestion Test Event Animation Analysis

Figures 19 and 20 display results for one alternate route decisions on the I-64 segment used for the CTE. Figure 19 shows the traffic queue building up to the east (right) of the road segment where the CTE occurred. A limited amount of traffic, representative of the sample population respondents who anticipated diverting even without traffic information, is on the alternate route. Some traffic (35%) is able to pass through the restricted segment, but most begins to queue. Figure 20 shows the same scenario, but with D-M model integration modeling the impact of traffic information. Queue growth continues, but at a reduced rate. A large volume of vehicles has diverted to the alternate route. Note that almost all diverting vehicles exit at the first opportunity (VA 143); in all tests, relatively few vehicles used any of the three other accesses to the alternate route.

On I-64 in the no-ATIS case, vehicles began diverting to US 60 within four to five time segments (24 – 30 minutes) at exit 231 (SR 607). However, the queue quickly extended upstream and restricted access to the I-64 off ramp, preventing many vehicles that would choose to use the alternate route from exiting. Congestion continued to extend until the next access at exit 234 (SR 646). This exit became the primary alternate route access in the no-ATIS case. Queues caused by the CTE lasted for an average of 196 minutes. When modeled ATIS influence was added, vehicles began to divert to the alternate route at exit 243 using VA 143. This was approximately 16 miles upstream of the CTE. Additional shifts to the alternate route were made at the remaining three exits, but VA 143 remained the primary access to the alternate route for all simulations with ATIS. The large number of vehicles exiting well before the CTE is in agreement with the real-world behavior observed by Huo and Levinson (56), who used empirical data from loop detector systems to assess drivers' responses to VMS information and noted that drivers prefer to start diverting at several exits prior to the incident. In the no-ATIS case, approximately 25% of all evacuees rejoined I-64 at the first opportunity (exit 227, VA 30) with most of the remainder rejoining I-64 prior to the intersection with I-295 at exit 205. When ATIS was simulated, a smaller portion (<10%) rejoined at I-64, with remaining vehicles rejoining at exit 205 or continuing on the alternate route until reaching the major leg of the evacuation journey at I-295. When ATIS was simulated, approximately six times as many vehicles used alternate routes as when no ATIS was simulated. After the CTE ended on I-64, the queue shrank with queues on downstream segments clearing first when no ATIS was simulated and upstream clearing first when ATIS was simulated. This occurred because without ATIS, incoming traffic volume was only slightly greater than outgoing volume so that the upstream segments stayed very congested. When ATIS was simulated and a large portion of evacuating traffic used the alternate route, the volume arriving at congested segments on I-64 was significantly less than the outflow volume at the head of the queue. Queue duration was more than twice

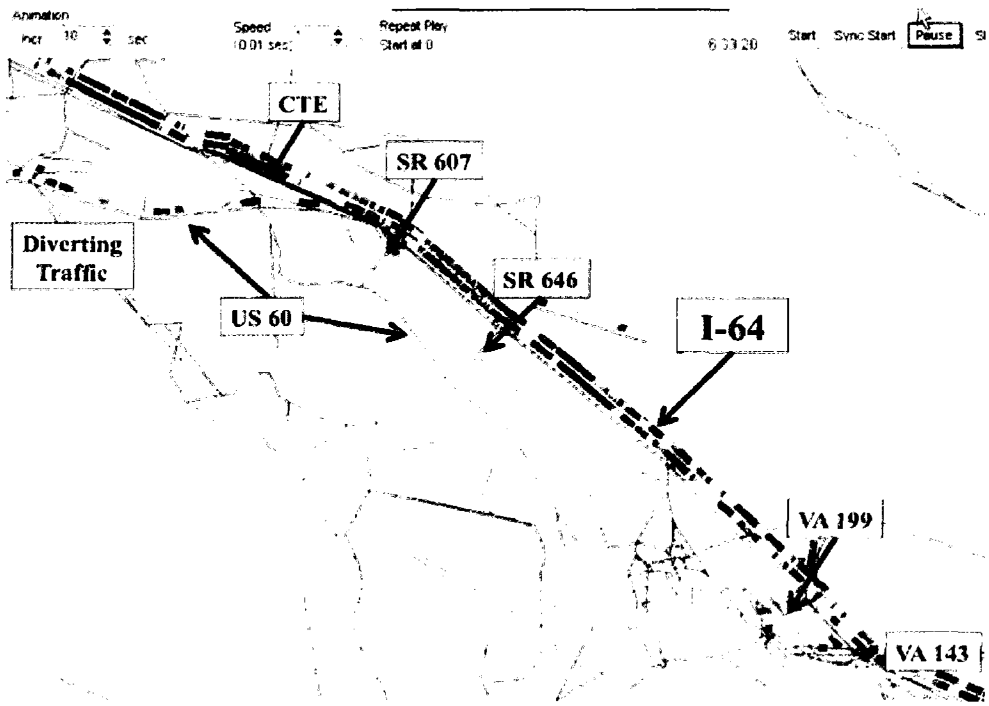


FIGURE 19 Example interstate segments with no decision-making model integration (congested traffic in queue on primary route, limited traffic using alternate route).

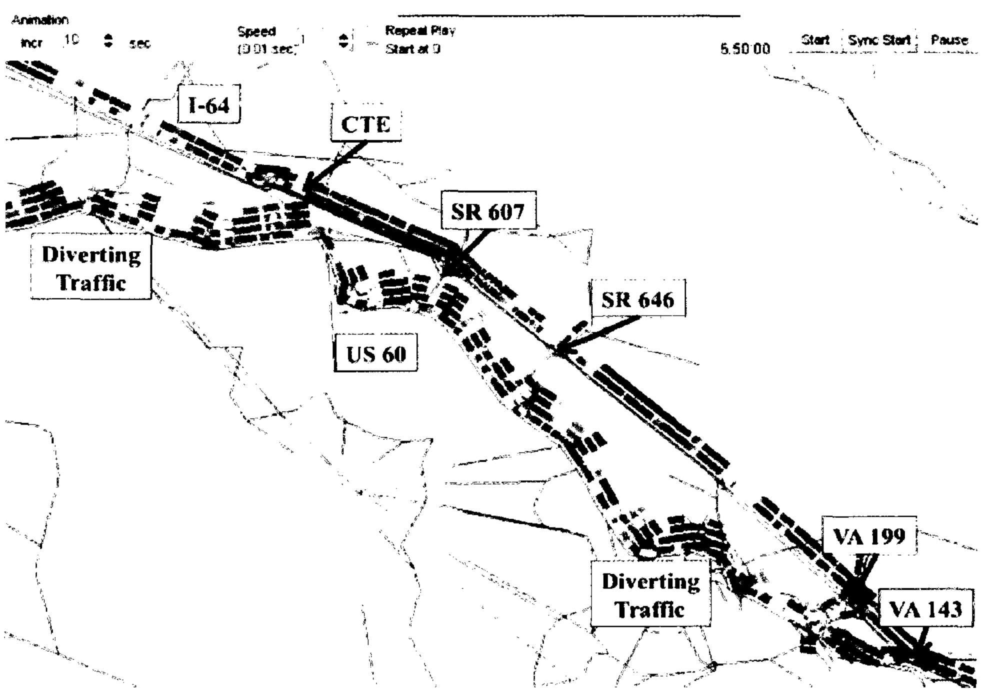


FIGURE 20 Example interstate segments with decision-making model integration (congested traffic in queue on primary routes, extensive traffic using alternate route).

as long when no ATIS was provided (196 minutes) as when ATIS was provided (87 minutes).

When congestion was first encountered, before any ATIS was received, one-third of all evacuees (approximately 1500 vph on I-64) were forecast by the D-M model to use an alternate route. When ATIS was provided, within just eight minutes, this rate was expected to double. During simulation testing, after a CTE was initiated, queues quickly formed at the CTE segment and at alternate route accesses and the number of vehicles that actually diverted was thus less than expected from considerations of the D-M model alone.

6.4.2 Highway Congestion Test Event Animation Analysis

Example graphics from the simulation at the Highway CTE are shown in Figures 21 and 22. Key roadways are labeled on the figure. The near vertical lines crossing both figures are connections to TAZ centroids for the simulated network and are not part of the evacuation routes.

At the US 460 CTE, the queue extended to the first upstream exit (SR 638) in just 15 minutes. Vehicles attempted to access the alternate route on SR 638, but congestion quickly blocked most from reaching the exit. For those vehicles able to exit, the low capacity of the alternate route was soon reached and it became congested as well. When ATIS was simulated, some vehicles diverted at SR 603, rejoining the alternate route via SR 657. The limited capacity of these segments and delays caused by merging traffic caused additional queuing. As a result, far fewer vehicles actually used the alternate route than forecast by the sample population. Provision of ATIS more than doubled the alternate route volume, but still just 13% of evacuees in the test period used the alternate route. The difference in queue clearance times between the "with" and "without" ATIS scenarios were not statistically significant. With ATIS on US 460, queues further upstream cleared slightly more quickly than those nearer the CTE, just as seen on I-64.

When congestion was first encountered, before any ATIS was received, one-third of all evacuees (approximately 1270 vph on US 460) were forecast to use an alternate route. This rate was significantly greater than the capacity on either alternate route access or on the alternate route itself. After a CTE was initiated, queues quickly formed

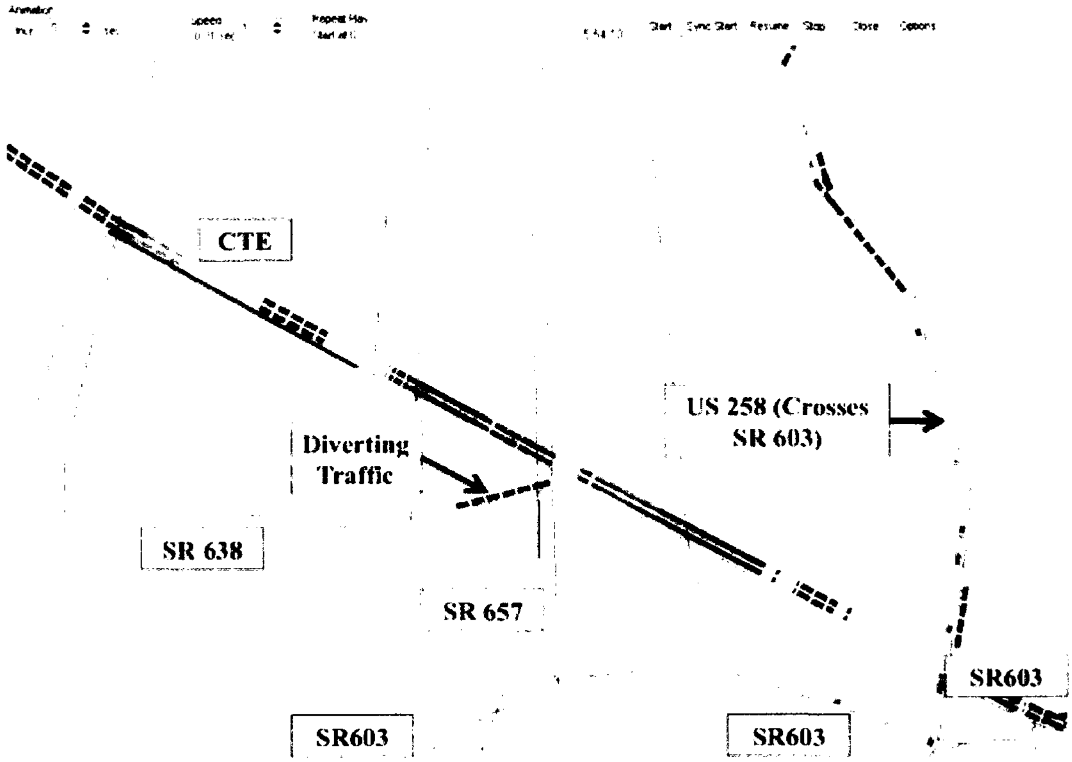


FIGURE 21 Example highway segments with no decision-making model integration (congested traffic in queue on primary route, little traffic on alternate route).

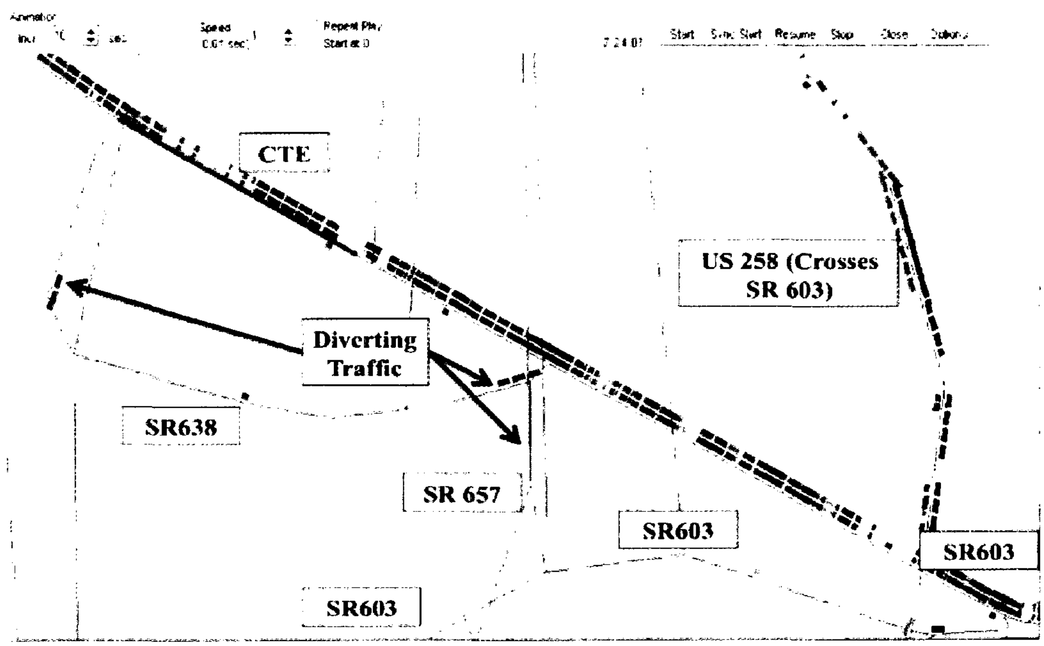


FIGURE 22 Example highway segments with decision-making model integration (congested traffic in queue on primary route, slight traffic on alternate route).

at the CTE segment and at alternate route accesses. The extent of congestion at these points significantly reduced total traffic flow even after the CTE ended and full capacity was restored.

6.4.3 Quantitative Results

The AVENUE simulation significant data for all individual segments of a tested network for all individual time segments in a simulation run. The impact of the D-M model and ATIS influence was assessed by comparing the results of simulation runs when a CTE was injected with and without the D-M model integration using volume and queue data. Data was assessed after 41 runs for each of the four information scenarios (DlyTrafX_alt, DlyTrafX_svc, DlyTrafX_SP, and DlyTrafX_alt) and also for progressive combinations of the information sources. Two sets of cumulative volume data, measured over a 3.3 hour period beginning with the start of the CTE, were used to assess the effect of route choices:

1) The number of vehicles using the alternate route to bypass the CTE and then continuing on the alternate route until the next major leg of their journey. This value applied only to the CTE on I-64 and most vehicles counted were those which remained on US 60 until connecting with I-295 near Richmond, Virginia. No parallel alternate route was available on US 460; all who used the alternate route returned to US 460.
2) The total number of vehicles reaching the next leg of the primary route downstream of the CTE.

Queue measurements were made on the two simulation network road segments immediately upstream of the CTE. Though queue sizes were recorded, the information of most use was each queue's persistence – how long (in minutes) vehicles remained queued after a CTE was inserted. The longer of the two durations is recorded as total queue duration.

6.4.3.1 Interstate CTE quantitative results. The total volume of vehicles evacuating on I-64 and passing the CTE section are shown in Figure 23 for each tested basic scenario. Also provided for comparison are the vehicle volumes which would pass this section if no CTE were inserted (labeled "No CTE, No diversions"), the volume if a CTE were inserted but no diversions occurred (even by those who said they would divert without traffic information) (labeled "CTE, No diversions"), and the total volume with a CTE, but no traffic information provided (labeled "Diversions but no D-M model. As can be seen in Figure 23, relatively few vehicles use the alternate route without the D-M model. Using the same headings, the maximum queue durations on the link are shown in Figure 24. Even with no CTE inserted, a queue of average length 42 minutes occurred. When the CTE is inserted, an average 198-minute duration queue is formed. Other scenarios are shown on the figure and quantitative results provided in Table 22. When route choice decisions by evacuating vehicles are influenced by ATIS using the D-M model, the volume of evacuees using alternate routes and the volume reaching the next leg of the evacuation trip significantly increased. Six times as many vehicles used the alternate routes. The volume of evacuees passing the CTE and completing the affected link of the evacuation during the measured time period increased by an average of 5.5%. The most dramatic influence was in queue duration where average times dropped from 196 minutes with no ATIS to 87 minutes with ATIS. (Note that a 42 minute delay occurred even with no CTE injected.)

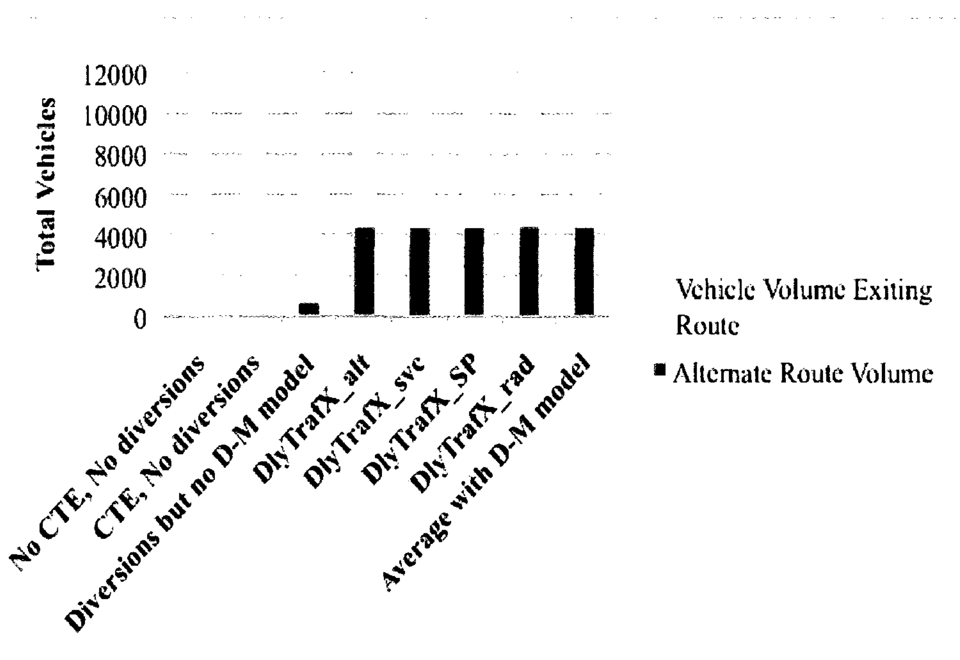


FIGURE 23 Interstate congestion test event site total evacuating vehicle volumes over 3.3 hours.

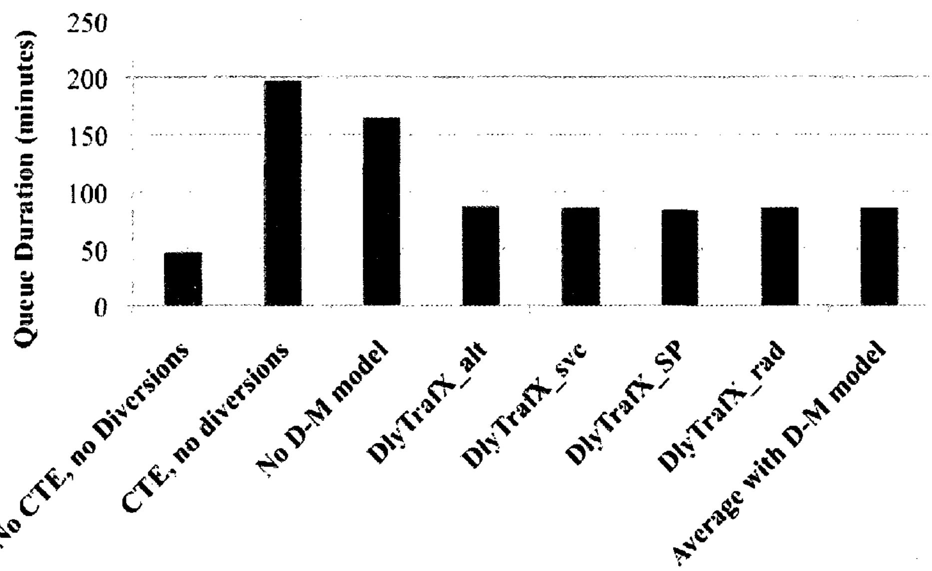


FIGURE 24 Interstate congestion test event site maximum queue durations.

Some additional items of interest can also be seen in Table 22.

1) There was no significant difference between the values for the four tested scenarios for any of three key values. Chi-squared and t tests results for significance value p=0.05 cannot affirm that the tests are from different samples.
2) The largest increases in total vehicles reaching the next leg of the evacuation was seen in the two scenarios having lower rates of forecast diversions, DlyTrafX_alt and DlyTrafX_rad. The increases were not statistically significant, but may provide insight on the value of ATIS investments.
3) Data values for all scenarios were remarkably consistent. All standard deviation values for total evacuations were within 2.5% of the scenario average and the standard deviations for total alternate route vehicles was even more focused, with all within 1.3% of the scenario averages. Queue clearance times were similarly consistent; all standard deviations were within 5% of the scenario average.

TABLE 22 Interstate Congestion Test Event Evacuating Traffic Volumes and Queue Durations Without and With Traffic Information (N=41 for Each Event Location, Time Period = 3.3 hours)

Scenario	Measurement	Total Vehicles on Alternate Route	% Increase (Over No D-M case)	Total Vehicles on I-64	% Increase (Over No D-M case)	Vehicles on Route Exiting Region[1]	% Increase (Over No D-M case)	Maximum Queue Duration (minutes)	% Increase (Over No D-M case)
No CTE (max flow)	*Average*	***0***	*NA*	***12341.8***	*NA*	***12341.8***	*NA*	***48***	*NA*
No D-M Simulation	**Average**	741.2		11882.8		12066.5		165.8	
	Std Deviation	17.5		40.9		40.5		11.4	
DlyTrafX_alt	**Average**	4441.7	499.6%	8811.8	-25.8	12833.6	6.4%	87.7	47.1%
	Std Deviation	54.7		323.3		48.9		4.2	
DlyTrafX_svc	**Average**	4434.4	498.3%	8680.0	-27.0	12717.1	5.4%	87.4	47.3%
	Std Deviation	48.9		291.8		175.5		4.0	
DlyTrafX_SP	**Average**	4436.3	498.5%	8455.4	-28.8	12550.6	4.0	85.0	48.7%
	Std Deviation	38.2		309.1		286.6		4.4	
DlyTrafX_rad	**Average**	4464.8	502.4%	8812.8	-25.8	12831.7	6.3	87.2	47.4%
	Std Deviation	57.6		284.3		264.3		4.4	
Average of All Runs with Traffic Information	**Average**	4444.3	499.6%	8690.7	-26.9	12733.9	4.7	86.8	47.6%
	Std Deviation	51.4		333.6		305.6		4.4	

[1]Total of all vehicles using I-64 as the initial evacuation route that bypass the CTE on I-64 or reach the next leg of the evacuation trip.

4) The number of vehicles using the alternate route was significantly less than anticipated by the D-M model. The maximum average alternate route use frequency observed was 35% of all evacuees; the model forecast more than 80% of evacuees would use alternate routes after one hour of congestion. This difference was caused by the restricted capacity on alternate routes, especially where first accessed. Delays caused by the queues at the accesses increased travel times on the alternate routes so much that remaining on the primary routes was the better choice

6.4.3.2 Highway CTE quantitative results. In contrast to the results seen on I-64, when ATIS influence was added to the traffic simulation using the D-M model, conditions worsened instead of improving. Figures 25 and 26 display these results graphically; Table 23 provides the quantitative values.

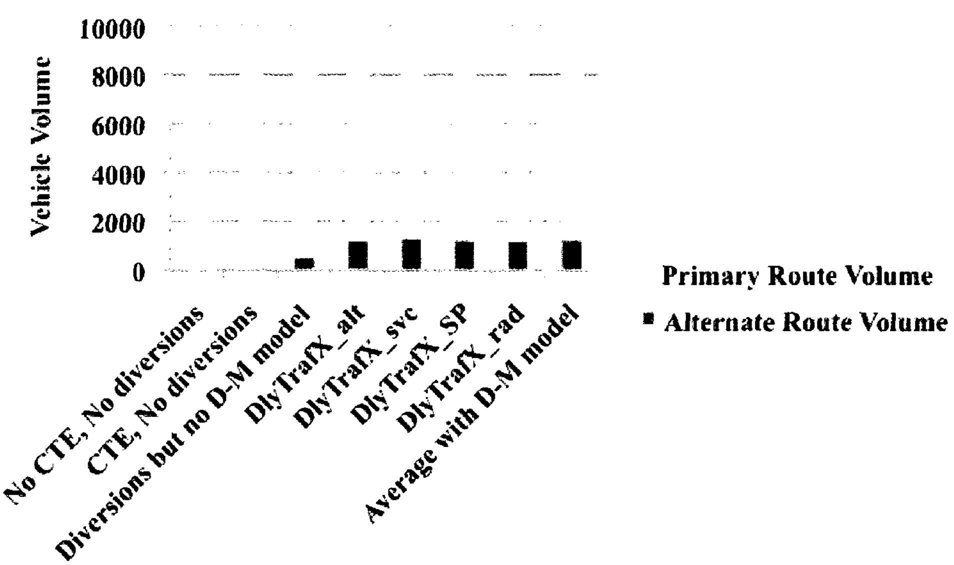


FIGURE 25 Highway congestion test event site total evacuating vehicle volumes over 3.3 Hours.

CTE were inserted (labeled "No CTE, No diversions"), the volume if a CTE were inserted but no diversions occurred (even by those who said they would divert without traffic information) (labeled "CTE, No diversions"), and the total volume with a CTE, but Just as done for I-64, the total volume of vehicles evacuating on US 460 and passing the CTE section are shown in Figure 25 for each tested basic scenario. Also provided for comparison are the vehicle volumes that would pass this section if no traffic information was provided (labeled "Diversions but no D-M model"). As can be seen in Figure 25, relatively few vehicles use the alternate route without the D-M model. Using the same headings, the maximum queue durations on the link are shown in Figure 26. Of note, virtually no queue occurred when no CTE was inserted on US 460.

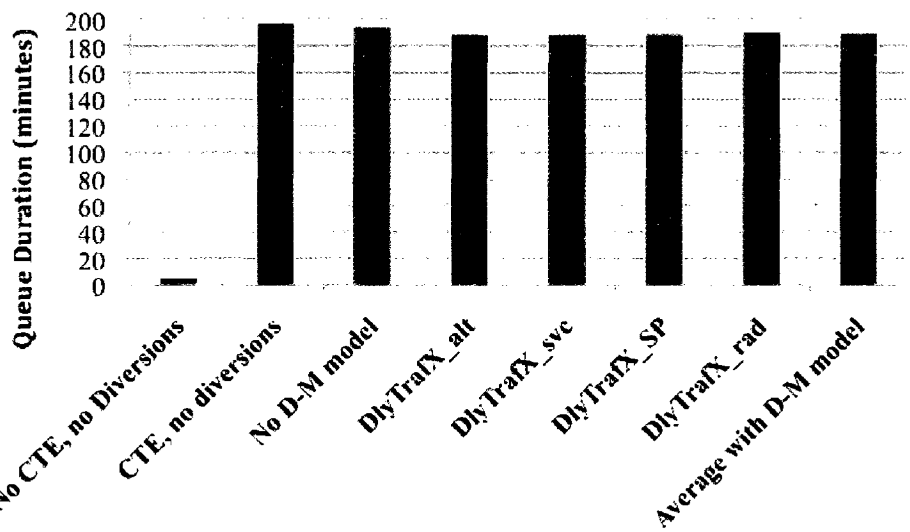


FIGURE 26 Highway congestion test event site maximum queue durations.

Though all scenarios with ATIS showed an increase in the number of vehicles on the alternate route, there was no corresponding increase in the number of evacuees reaching the next leg of their journeys. In fact, in two of the four scenarios, total evacuees decreased when ATIS addition was simulated and the average number of evacuees with ATIS was slightly less than without ATIS. Though the differences seen were not statistically significant, the fact that there was no improvement in performance

TABLE 23 US Highway Congestion Test Event Evacuating Traffic Volumes and Queue Durations Without and With Traffic Information (N=41 for Each Event Location, Time Period = 3.3 hours)

Scenario	Measurement	Total Vehicles on Alternate Route	% Increase (Over No D-M case)	Total Vehicles on US 460	% Increase (Over No D-M case)	Vehicles on Route Exiting Region	% Increase (Over No D-M case)	Maximum Queue duration (minutes)	% Increase (Over No D-M case)
No CTE (max flow)	*Average*	*0*	*NA*	*9708.1*	*NA*	*9708.1*	*NA*	*6*	*NA*
No D-M Simulation	Average	528.7		8901.0		9429.7		194.8	
	Std Deviation	146.8		678.8		756.7		14.5	
DlyTrafX_alt	Average	1230.0	132.6%	8291.7	-6.8	9521.7	1.0	189.5	2.7%
	Std Deviation	130.22		850.4		962.8		23.1	
DlyTrafX_svc	Average	1328.4	151.3%	7895.6	-11.3	9224.0	-2.2	189.5	2.7%
	Std Deviation	273.1		1048.7		992.3		23.2	
DlyTrafX_SP	Average	1248.5	136.1%	8243.1	-7.4	9491.6	0.7	189.8	2.6%
	Std Deviation	232.7		837.9		935.2		22.4	
DlyTrafX_rad	Average	1212.6	129.4%	8164.2	-8.3	9376.8	-0.6	191.4	1.7%
	Std Deviation	189.3		877.0		1006.6		20.1	
Average of All Runs with Traffic Information	Average	1255.17	137.6%	8148.6	-8.5	9403.71	-0.3	190.1	2.4%
	Std Deviation	215.80		912.3		972.47		22.0	

[1]Total of all vehicles using US 460 as the initial evacuation route that bypass the CTE on I-64 or reach the next leg of the evacuation trip.

despite ATIS addition and route changes by more than twelve hundred vehicles is important. CTE queue duration was an average of 2.5% (approximately 5 minutes) less when ATIS was provided than without ATIS. Both volume and queue duration data showed much more variance for the US 460 tests than seen on I-64. Whereas I-64 standard deviations differed from averages by 2.5% - 5%, US 460 differences were 10% - 12%. This was a result of the small capacities on the alternate route and its accesses amplifying the effects of even small changes in the arrival times of vehicles with different D-M route choice tendencies.

6.5. SIMULATION RESULTS WITH DECISION-MAKING MODEL INTEGRATION AND MIXED TRAFFIC INFORMATION SOURCES

Additional simulation iterations were conducted using five combinations of information scenarios. Either the source or content was changed during the scenario at set times after congestion was confronted; changes are shown in Table 24. Just as was

TABLE 24 Mixed Information Source Scenarios and Times Source in Effect

Time	AltAltSP	AltSvcSP	AltRadSvc	RadSvcSP	AltRadSP
0	No Traffic Information Provided				
30	VMS suggests alternate route	VMS suggests alternate route	VMS suggests alternate route	Alternate route information provided via radio	VMS suggests alternate route
60	VMS suggests alternate route	VMS says services available on alternate route	Alternate route information provided via radio	VMS says services available on alternate route	Alternate route information provided via radio
120	On site State Police guide route	On site State Police guide route	VMS says services available on alternate route	On site State Police guide route	On site State Police guide route

done for individual information scenario tests, each was compared to a run using the same random number seed but without D-M model integration. Forty-one iterations of each combination were conducted. Table 25 provides the results of these runs. None were statistically distinguishable from the runs made without adjustments to the information sources or content. This result was expected since differences between scenarios were relatively small for the first half of the model periods and previously

TABLE 25 Evacuating Traffic Volumes and Queue Durations Without and With Traffic Information (N=41 for Each Event Location) Using Mixed Information Scenarios

Scenario	Event Location	Measurement	Total Volume Using Alternate Route	Percent Increase (Compared to No D-M case)	Vehicle Volume Exiting Region	Percent Increase (Compared to No –D-M case)	Maximum Queue duration (minutes)	Percent Increase (Compared to No –D-M case)
No D-M Simulation	US 460	Average	528.7		9429.7		194.8	
		Std Deviation	146.8		756.7		14.5	
Alt-Svc-SP	I-64	Average	4435.73	498.5%	12647.5	4.8%	85.8	48.3%
		Std Deviation	53.32		284.41		4.1	
Alt-Rad-Rad	I-64	Average	4438.5	498.3%	12849.14	6.5%	87.4	47.3%
		Std Deviation	48.9		298.9		4.3	
Svc-Rad-SP	I-64	Average	4445.7	499.8%	12719.2	5.4%	87.4	47.3%
		Std Deviation	59.0		277.6		4.3	
No D-M Simulation	I-64	Average	741.2		12066.5		165.8	
		Std Deviation	17.5		40.5		11.4	
Alt-Svc-SP	US 460	Average	1310.4	47.8%	9411.5	-0.2%	190.8	2.1%
		Std Deviation	285.1		857.0		22.5	
Svc-Rad-SP	US 460	Average	1269.6	40.1%	9226.2	-2.2%	186.6	4.2%
		Std Deviation	287.5		1097.7		25.6%	

results using individual information scenarios had shown that the value of ATIS integration was mitigated by limits in the road network itself.

6.6. CONCLUSIONS

Results show that a decision-making model forecasting evacuees' propensity to choose alternate routes when confronted with congestion can be integrated into a dynamic traffic simulation and demonstrate the impact of anticipated ATIS use in a hypothetical hurricane evacuation. The impact of ATIS was represented by a decision-making model developed using the stated preference and revealed preference responses of over 800 survey participants.

Analyses of results show that by directing traffic to alternate routes after an incident, ATIS has the potential to mitigate the impact of congestion caused to evacuation rates and can also significantly reduce the duration of resulting queues. However, results also indicate that ATIS cannot be considered a "one size fits all solution."

Two test sites were used. The first, located on a major interstate, made use of multiple accesses to an alternate route with capacity equal to 80% of the capacity of the primary route. The alternate route also provided multiple ways for vehicles to rejoin evacuating traffic. As a result, even though the alternate route was never loaded to capacity, over 1/3 of all evacuating traffic made use of it and queue durations were significantly shortened. In a real world situation, these conditions would significantly improve the ability to maintain emergency responder capabilities by maintaining or quickly restoring access. Of note, emergency responder access on alternate routes was never curtailed. Though not tested, rapid queue reductions may also offer the benefit of reducing the impact of secondary incidents. If a secondary incident had occurred near the "tail" of a queue, overall queue lengths could have extended for several miles and blocked additional accesses to the alternate route. Though there a statistically significant increase in the number of vehicles reaching the next leg of the journey, the average improvement of approximately 670 vehicles was equivalent to just six minutes of evacuation time. This small difference was expected. Upstream of the CTE location, the number of lanes was reduced from three to two, both of which were at near capacity throughout the test period. Capacity at the CTE was reduced to 35% of maximum for one hour, then fully restored. Traffic did not begin to use the alternate routes for almost one-half hour and the volume able to pass the CTE in the remaining one-half hour before congestion cleared was limited to approximately 800 vehicles. This compares well with the average improvement of 670 vehicles (and maximum improvement of 767 vehicles) seen when ATIS was simulated. The consistency of data values is an important aspect of results. The ability to estimate with a high degree of accuracy the effectiveness of evacuation plans and understand the impact of unplanned events can improve emergency management and public safety. The second test site was on a state highway. Only two accesses to the alternate route were available and both the accesses and the alternate route itself had significantly lower capacities than the primary route (less than 10%). Queues formed at the CTE location, at alternate route accesses, at intersections where two access roads met, and at the single location where vehicles using the alternate route could rejoin evacuating traffic. Queues that developed on the alternative routes persisted almost as long as those on the highway itself. As a result, there was no improvement in the flow of evacuating vehicles and emergency responder access would have been reduced due to congestion on all routes. The failure of this site to show an improvement when ATIS was introduced demonstrates the necessity of understanding each situation before investing resources.

Not all ATIS provides a tangible benefit. Successful sites for using ATIS to improve traffic flow following incident induced congestion during evacuations require:

- Multiple accesses to alternate routes;
- Adequate capacity on alternate routes and their accesses;
- Access routes located well in advance of the incident; and
- VMS availability.

When any of the first three conditions are not met, evacuees' intentions to use alternate routes may be thwarted by alternate route availability and capacity and their actions could cause worsening of congestion and travel delays instead of fostering improvement. When the fourth condition, access to VMS, is not met, even with the use of radio announcements, fewer drivers may receive information on alternate routes. While more survey respondents reported use of traffic information obtained via radio than by VMS, the radio message might not be available or be broadcast at a time conducive to influencing the decision, while VMS messages are shown continuously.

Little difference was seen in the results between information scenarios for either of the two test sites. This indicates that the provision of information on an alternate route provides significant motivation to divert, but the increase in influence provided by more complete information or use of different sources was mitigated by the capacity of the traffic network. Likewise, when after first providing alternate route information a different source or additional information was added, little improvement was noted. Though the D-M model forecast an increased percentage of evacuees would choose an alternate route, transportation network limitations negated the increase.

The importance of early identification of congestion and early provision of traffic information to evacuees was seen by varying the time in advance of a CTE that the partition is selected. When alternate route choices were made too late, extensive queue growth blocked alternate route accesses, delayed queue clearance times, and reduced the effectiveness of the evacuation.

7. CONCLUSIONS

7.1. SUMMARY

The goal of this research was to develop a deeper understanding of travel decisions made by (hurricane) evacuees when traffic incidents occur, to model resulting route choice decisions made by evacuees, and to predict the effects of route choice decisions made on traffic flows using modeling and simulation tools. The study successfully implemented a behavioral survey with both stated and revealed preference responses and simulated route-choice decisions by evacuees on a large-scale transportation network in Hampton Roads. The integration of the D-M model into a dynamic hurricane evacuation simulation and its capability to assess route-choice impacts – both positive and negative – is a unique contribution resulting from this study.

7.2. BEHAVIORAL AND DECISION-MAKING CONCLUSIONS

Correlation was found between respondent demographics, extent of evacuation preparedness, willingness to take risks, level of comfort in unfamiliar areas, and other factors. However, analysis failed to show that any of these factors were significant in the route choice decision made by an evacuee when confronted with congestion. Instead, survey results showed that an evacuee's decision of whether to take an alternate route when faced with congestion was associated with two primary factors:

1) The length of time congestion was experienced (or expected); and
2) Whether information on the congestion was provided to drivers and its level of detail.

The longer evacuees were confronted with congestion, the more likely they believed they would be to take an alternate route. Likewise, the more information provided evacuees that might increase their confidence in safety or well being, the more likely they believed they would be to take an alternate route.

Male respondents were more likely to claim having planned for an evacuation, including identifying routes and items to be taken. Male respondents were more comfortable reading and following highway maps and expressed greater comfort with increased risks such as driving all night or leaving main roads. However, males were no more likely than females to say they would take an alternate route to avoid congestion at any of the four times queried in the survey. Both males and females claimed willingness to take an alternate route during a hurricane evacuation with much greater frequency than reported during routine driving.

The primary sources of traffic information used by the sample population were radio and VMS, but more advanced technologies were both being used in routine driving and are expected to be used in an evacuation much more frequently than just a few years ago. This increased use was true for both genders, for all age groups, and for all income groups. A strong majority of drivers (89%) used two or more traffic information sources. A traffic information plan incorporating radio, VMS, and mobile phone messages would reach 98% of the sample population.

Factor analysis of the sample population identified four traffic information use groups. Experienced and Cautious drivers tend to remain on main roads, but seek traffic information and when given information are likely to adjust their routes. Confident and Prepared drivers are self-reliant and have little hesitation leaving main roads for alternate routes. They may consider VMS information when provided. Information Seekers look for traffic information, but rarely make changes to routes using information received. Aggressive drivers quickly grow impatient when confronted in congestion, have little confidence in VMS information, but do not act on information in a way discernible from the overall population. Traffic information communication plans will be more effective at motivating behavior when Experienced and Cautious drivers and Confident and Prepared drivers are targeted; information and training programs that result in a shift of more drivers to these two groups will lead to increased ATIS influence.

A decision-making (D-M) model was created to represent route choices made by drivers for a two-hour period after encountering congestion during a hurricane evacuation. The model was used for four scenarios:

1) DlyTrafX_alt: alternative route information provided via VMS;
2) DlyTrafX_svc: in addition to DlyTrafX_alt information, the availability of services on the alternative route was provided;
3) DlyTrafX_SP: VMS announce an alternative route and note that it is guided by on-scene State Police; and

4) DlyTrafX_rad; in addition to DlyTrafX_alt information; alternative route information provided via radio.

The rate at which evacuees decided to take an alternate route when provided traffic information progressed much more rapidly than seen in evacuation response studies and could not be represented by the logit equation and sigmoid curve common in evacuation studies. The decision also could not be represented by the Probit model proposed by Levinson et al. (2003) who studied decisions in routine driving. An offset Michaelis-Menten equation provided the best fit for the four scenarios when fitted to 75% of the survey responses randomly selected from the all responses. The D-M model developed using the equation was validated using the remaining 25% of the data and produced forecast results within 2.5% of survey data throughout the measured time period.

Results showed that increasing the amount of information provided via ATIS, using more frequently used information sources (VMS or radio), or increasing the number of sources can cause significant dynamic changes to evacuee route choice decisions. The rapidity with which decisions were made and the aggressive choice to use alternate routes in a hypothetical emergency evacuation differ markedly from the results seen in previous studies under routine conditions.

7.3. EVACUATION SIMULATION RESULTS

Simulation results demonstrated the significant benefits that may be achieved by using ATIS to provide alternative route information when congestion restricts traffic flow during an evacuation. Results also showed that these results are not universal. Identical ATIS source use and information simulated at a second site provided no improvement, instead increasing congestion on alternative routes that may have reduced the emergency response capability.

The D-M model was integrated into a dynamic hurricane evacuation simulation developed using commercial traffic simulation software to assess the impact of route-choice decisions and ATIS on an evacuation. Seven information scenarios were tested at two locations. One location was on an Interstate with a near parallel high capacity alternate route with four access points and three methods of returning to the evacuation route. The second location was on a state highway with a low capacity alternate route with two accesses and a single point of return to the evacuation route. More than 800 separate simulation runs were conducted.

Diversions to alternate routes were highly context dependent. As shown in the D-M model, the time in congestion and the amount and source of traffic information were strongly associated with the decision to take an alternate route. However, the desire to divert and the ability to divert were frequently in conflict. Extended congestion queues often blocked accesses to alternate routes. When access was available, the capacity at evacuation route exits was often less than the volume desiring to exit and limited the number of vehicles able to divert. At the Interstate site, the results clearly demonstrate the available benefits of ATIS use during an evacuation as queue durations were drastically reduced and measured evacuation volumes increased by 5%. At the highway site, no significant improvement was noted in either evacuation volumes or queue durations and vehicles using alternate routes caused significant, long-lasting congestion, which would have significantly hindered passage by emergency response vehicles.

7.4. APPLICATION

Transportation planners and emergency managers have worked to create evacuation plans that maximize traffic flow out of endangered regions. Plans take into account expected evacuee participation and response rates, the volume of vehicles expected, roads most likely to be taken, likely end destinations, and even the locations on evacuation routes likely to suffer from accidents and incidents. In short, almost all variables that impact an evacuation and that can be predicted with reasonable accuracy have been considered. What have not been taken into account are the dynamic decisions made by evacuees when confronted with delays during a stressful evacuation. The tools developed in this study provide a method of correcting this.

Prior to a hurricane's arrival, the locations most likely to suffer accidents, incidents, or other delays should be identified. Available alternate routes to bypass these locations should be marked and link characteristics (e.g., capacities, lengths, and speeds) noted. As done in this research, a D-M model to forecast likely evacuee route choices should be integrated in a transportation simulation and the impact on traffic flow assessed. Ideally, the D-M model should be developed using locally acquired survey results. In the absence of such data, the Hampton Roads model, which represents a population of approximately 1.7 million, might be substituted. The impact on the transportation network, such as traffic flows, queue clearance times, arterial road congestion levels, and emergency response vehicle access can then be measured. This allows the benefits (or lack thereof) to be objectively and recorded for future reference. (The time currently required to conduct such assessments prohibits use of this process in real-time.)

7.5. LIMITATIONS

- The survey conducted gathered sufficient information for behavior-based modeling. Given resource constraints, a representative sample of the region's population could not be obtained. In particular, younger and lower income citizens were underrepresented. The high number of survey responses provides some mitigation, but a more demographically representative survey would be valuable to refine results.
- The survey targeted adult drivers in the Hampton Roads region of Virginia and results from other regions, especially those with more frequent evacuations, may differ. However, the methodology and its implications could still be applied.
- The D-M model developed is largely based on stated preference responses.
- As common to all cross sectional survey analyses, this study is subject to selection bias, temporal validity concerns, and inability to prove cause-and-effect relationships.
- The complexity of calculations required to assess accident and incident impacts and the capability of the transportation simulation employed restricted analyses to one location at a time. In reality, the impacts of some accidents and incidents may extend well beyond the immediate area. While improvements in analytical technique and technological advances may allow testing for multiple accidents at once, this was not yet possible.

7.6. FUTURE WORK

7.6.1 Application of Existing Simulation in Hampton Roads

The current version of the simulation may be employed in the Hampton Roads region to assess the potential impacts of hurricane evacuee route choices and to identify in advance of an evacuation those locations within the region likely to benefit from (or be adversely affected by) use of ATIS to prompt route changes. Such use should only be done recognizing the limitations of the cross-sectional survey results used to develop the

D-M model previously discussed in Section 4.7. The following steps should be followed to use the simulation:

1) Identify suitable test sites. Successful sites for using ATIS to improve traffic flow following incident induced congestion during evacuations require:
    a. Multiple accesses to alternate routes;
    b. Adequate capacity on alternate routes and their accesses;
    c. Access routes located well in advance of the incident; and
    d. VMS availability.

    When the first three conditions are met but the fourth is not, the simulation could be used to assist in selection of sites for future VMS assignment.
2) Adjust values for link COST for CTE affected links using the multiplying factor DECISION as described in Section 6.2 to appropriately bias vehicles to leave primary evacuation routes for alternate routes.
3) Determine the strength of the hurricane for which the evacuation will be simulated. (This decision is used to assign the evacuation response rates and participation rates and thus determines the number of vehicles using particular sections of the transportation network at any time.)
4) Conduct a series of simulation runs to determine the average time required for vehicles from various points within Hampton Roads to reach the road segments at which CTEs will be applied during the time the CTEs impact traffic. These times are used to input dynamic vehicle loading to appropriate vehicles as described in Sections 6.1 and 6.2.
5) Determine the CTE characteristics to be used (number of lanes blocked, remaining road segment capacity, and incident duration) and assign appropriate road segment dynamic capacity reductions.
6) Conduct a series of simulation runs to assess the impact of the D-M model and alternate route use on travel times, queue lengths, or other transportation metrics as desired by the individual users. At least 30 runs should be conducted before assuming the validity of results.

7.6.2 Application of Existing Simulation Outside of Hampton Roads

The simulation may be used outside Hampton Roads as described above, but even greater caution must be taken when using the D-M model. As noted in Section 5.6, evacuees from other regions, especially those affected by more frequent or more direct hurricane activity than Hampton Roads, may exhibit different route choice tendencies. The accuracy of the D-M model and the simulation would be improved by reassessing the survey with locally obtained responses or by conducting a survey after an evacuation and obtaining route choice tendencies from actual behavior and not from stated preferences. The new data may result in the selection of a different equation for use in the D-M model, but required revisions necessitate only changing the equation used in the simulation's script file.

7.6.3 Simulation Process Improvements

A key potential benefit system use is the reduction of queue durations and sizes. In addition to the identified system performance improvements, these reductions may also reduce the impacts that might result from secondary accidents occurring while extensive queuing remained from a primary accident. Future work will incorporate the impacts of secondary accidents and assess this potential benefit of ATIS use.

In the existing simulation, two CTEs used were placed at specific locations to support analysis of D-M model integration and assess the potential benefits of ATIS used to influence evacuee route choices. Preparations in advance of testing required numerous simulation runs to ensure timely dynamic vehicle loads from multiple locations throughout the region. These dynamic vehicle load times were manually determined and validated, requiring significant hands-on testing. Future work will seek to automate this process, allowing quicker injection of incidents and more rapid evaluation of driver response. Additionally, automation will seek to enable testing of multiple coincident events on various evacuation routes.

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APPENDIX A

HURRICANE EVACUEE BEHAVIORAL SURVEY (ONLINE SURVEY BODY)

1. From what source do you expect to receive most information on a hurricane's approach, potential danger, and announcements from government authorities? (Please check all that apply.)
    - Cable television systems, including news services such as CNN and Fox News
    - Local television stations
    - Telephone
    - Radio broadcasts
    - The Weather Channel
    - Newspapers
    - Internet
    - Other (please specify)

2. What would be more likely to convince you to evacuate? (Check all that apply)
    - Personal knowledge about the storm and potential danger from winds or flooding
    - Evacuation orders from government officials
    - Advice from others
    - National Weather Service issued Hurricane Watch or Warning
    - Other (please specify)

3. Why might you decide not to evacuate? (Check all that apply.)
    - Fear of being caught in traffic during the hurricane
    - Experience from previous storms
    - Special transportation or care requirements for household members
    - Work requirements
    - Adequate care for household pets
    - Other (please specify)

4. If a category 1 hurricane was expected to hit the region directly, would you plan to evacuate?
    - Yes
    - No

5. If a category 2 hurricane was expected to directly hit the region, would you plan to evacuate?
    - Yes
    - No

6. If you evacuated, where would you go? (Check one only.)
- Williamsburg
- Northern Virginia
- Western Virginia (Roanoke, Blacksburg, Staunton, etc.)
- Safer location in Hampton Roads
- Southern Virginia (Emporia, Danville, etc.)
- Richmond/Petersburg area
- Other (please specify)

7. Would you take a motor home, trailer, or boat?
- Yes
- No

8. Would you or someone else in your household require special assistance?
- Yes
- No

9. If others will travel with you, how many total people will be in your group?
- Not applicable
- Two
- Three or more

10. Are you familiar with the designated hurricane evacuation routes for your region?
- Yes
- No

11. Would you require special lodging facilities at your destination?
- Yes
- No

12. If you evacuated, what main highway(s) would you use? (Indicate up to three.)
- I-64
- I-95
- US 58
- US 60
- VA 10
- US 17
- Other (please specify)

On September 18, 2003, Hurricane Isabel made landfall near Cape Hatteras, North Carolina, and moved north through southeastern Virginia. Hurricane Isabel was a category 5 hurricane with wind speeds over 165 mph one week prior to making landfall in North Carolina. Just three days before landfall, Isabel was still a category 4 storm and a hurricane warning was issued for the North Carolina and Virginia oceanfront. A hurricane watch was posted as far north as New Jersey. Hurricane Isabel caused more than $3.6 billion in damage and caused 35 storm-related deaths. For the purpose of the following questions, assume that a similar storm is now approaching Hampton Roads and a hurricane warning has been issued, meaning hurricane conditions are expected in the next 24 hours. Mandatory evacuation orders have already been issued for coastal and low-lying areas.

13. Would you evacuate?
- Yes
- No

Regardless of your previous answer, please answer remaining questions assuming you decided to evacuate.

14. Would you evacuate alone or as part of a larger group (such as with family or friends)?
- Alone
- With a group

15. Have you planned how you would evacuate, including the routes taken and what possessions and necessities you would bring?
- Yes
- No

16. Would you take household pets (dogs, cats, etc.) with you?
- Yes
- No

17. What would be your mode of transportation? (Select one only.)
- Personal vehicle (traveling alone)
- Commercial transportation (bus, train, plane)
- Public transportation provided specifically for this evacuation
- Personal vehicle (traveling with others)
- Other (please specify)

18. What would be your planned evacuation destination?
- Hotel or motel
- Public shelter
- Friends or relative
- Other (please specify)

19. If traffic conditions were severe or if you began to evacuate late in the day, would you feel comfortable and safe driving all night to reach your destination?

- Yes
- No

20. Would children (0-18 years old) evacuate with you?

- Yes
- No

21. Would anyone in your group require special medical capabilities at your end destination?

- Yes
- No

22. Would you be comfortable leaving your planned route for an alternate route if no information was provided on the availability of fuel, food, or lodging?

- Yes
- No

23. How familiar are you with the designated evacuation route you would expect to take?

- Very familiar
- Comfortably familiar
- Somewhat unfamiliar
- Not at all familiar

24. If your planned evacuation route(s) are blocked or congested, do you have a planned alternate route?

- Yes
- No

25. During an evacuation, would you be willing to take an alternate route to avoid being stuck in traffic?

- Yes
- No

26. Before leaving and while traveling, what sources of information on traffic do you typically use? (Please check all that apply.)

- Internet traffic websites
- Radio
- Mobile phone
- Highway message signs
- In-car system (such as GPS)
- Other (please specify)

27. What would you consider a significant traffic delay during a hurricane evacuation?
- less than 30 minutes
- 30 – 60 minutes
- 1-2 hours
- Over 2 hours

28. Would you prefer highway information signs provide the estimated time delay or the length of the traffic back-up (in miles) for congested areas?
- Estimated time delay
- Size of congestion in miles

29. Would you be confident of information provided by highway information signs (such as the lighted signs above freeways that report congested areas)?
- Yes
- No

30. Assume that you have been on the road for almost 2 hours. Please indicate your choice between staying on your planned evacuation route or diverting when faced with the condition listed.

Conditions on the Planned Evacuation Route	Definitely remain on planned route			Definitely take alternate route	Anticipated Conditions on Alternate Route
Traffic has essentially stopped (less than 10 mph)					The next exit is visible. There are no traffic information signs.
Traffic has continued to move very slowly for over 30 minutes.					The next exit is visible. Traffic information signs say "Accident Ahead"
					Traffic information signs offer alternate route.
					Traffic information signs offer alternate route and say "Gas/Food/Lodging Available"
					Information signs say "Alternate route guided by State Police"

31. You have been completely stopped for the indicated time. Please indicate your choice between staying on your planned evacuation route or diverting.

Conditions on the Planned Evacuation Route	Definitely remain on planned route			Definitely take alternate route	Anticipated Conditions on Alternate Route
Traffic has continued to move very slowly for over one hour.					The next exit is visible. There are no traffic information signs.
					Traffic information signs offer alternate route.
					Information signs suggest an alternate route and indicate "Gas/Food/Lodging Available"
					Information signs say "Alternate route guided by State Police"
					Public radio suggests and describes an alternate route.
Traffic has continued to move very slowly for over two hours.					Traffic information signs offer alternate route.
					Information signs suggest an alternate route and indicate "Gas/Food/Lodging Available"
					Information signs say "Alternate route guided by State Police"
					Public radio suggests and describes an alternate route.

The following questions concern your personal driving habits.

32. While driving for all types of trips, how often do you encounter the following delay lengths?

Delay Length	Daily	Weekly	Monthly	Less than monthly	Never
15 - 30 minutes					
30 - 45 minutes					
45 – 60 minutes					
1 – 2 hours					
More than 2 hours					

33. Have you recently (within the past month) diverted from your normal driving path to avoid unexpected congestion?

- Yes
- No

34. How often do you change your planned driving path and use an alternate route to avoid unexpected congestion?

Daily	Weekly	Monthly	Less than monthly	Never

35. What delay lengths would lead you to take an alternate route to avoid unexpected congestion?

15-30 minutes	30-60 minutes	1-2 hours	More than 2 hours

36.

Please answer the following questions about traffic reports and alternate routes, indicating your level of agreement or disagreement under normal driving conditions (NOT during a hurricane evacuation).	**Strongly Agree**			**Strongly Disagree**
I have taken alternate routes based on information received from overhead highway traffic information signs.				
I have taken alternate routes based on information received from portable, temporary signs placed on the side of the highway.				
I have taken alternate routes based on information received from radio traffic reports.				
I watch for traffic information on overhead highway traffic information signs in order to get the latest information.				
I check the radio broadcast traffic reports before beginning a trip.				
Information on overhead traffic information signs is usually accurate.				
I would prefer that overhead traffic information signs provide estimates of delay time and not the distance traffic is backed up.				
I am suspicious of the accuracy of estimated traffic delays reported on overhead traffic signs.				
Radio traffic reports should provide estimates of expected delay times.				
I am reluctant to leave main highways and take other routes.				
I would be uneasy about taking a route off the main road without knowing if food, gasoline, and lodging would be available.				
I enjoy finding new routes to my destination.				
I am comfortable reading and following a highway map.				
I would be willing to take risks on a new route to avoid having a long traffic delay.				
I would be very comfortable taking an alternate route if recommended by a policeman on the scene, even in an unfamiliar area.				

37.

Please answer the following questions about yourself, indicating your level of agreement or disagreement.	**Strongly Agree**			**Strongly Disagree**
I am an aggressive driver.				
I always have a map of the area in my car.				
I get impatient quickly when stuck in traffic.				
I watch for traffic information on overhead highway traffic information signs in order to get the latest information.				
I am willing to try alternate routes to avoid traffic delays.				
I usually like to stay on the main roads to keep from getting lost.				
I am more comfortable waiting out a traffic delay to ensure I know how to get to my destination.				
I am suspicious of the accuracy of estimated traffic delays reported on overhead traffic signs.				
Radio traffic reports should provide estimates of expected delay lengths.				
I am reluctant to leave main highways for other routes.				
I would be uneasy about taking a route off the main road without knowing if food, gasoline, and lodging would be available.				
I enjoy finding new routes to my destination.				
I am comfortable reading and following a highway map.				
I would be willing to take risks on a new route to avoid having a long traffic delay.				

38. Age?
- 18-24
- 25-35
- 36-45
- 45-55
- 56-65
- Over 65

39. Gender?
    - Male
    - Female
40. Counting yourself, how many people live in your household?
    - One
    - Two
    - Three
    - Four
    - Five
    - Six or more

41. Are any of these children less than 18 years of age?
    - Yes
    - No
    - Not applicable

42. If the answer to the above question was yes, how many are under 18 years of age?
    - One
    - Two
    - Three or more

43. Are you the head of your household?
    - Yes
    - No

44. How many vehicles are in your household?
    - Zero
    - One
    - Two
    - Three or more

45. While an adult (18 years of age or older), have you evacuated because of a hurricane or other natural disaster?
    - Yes
    - No

46. If you have evacuated, how long ago did this occur?
    - Not applicable
    - Less than 3 years
    - 4-5 years
    - 6-10 years ago
    - More than 10 years

47. What category best describes your education level?
    - Some high school
    - High school graduate
    - Some college
    - College graduate
    - Advanced college degree

48. What is your approximate household annual income?
    - Less than $20,000
    - $20,000 - $50,000
    - $50,000 - $75,000
    - $75,000 - $100,000
    - More than $100,000

APPENDIX B

HURRICANE EVACUEE BEHAVIORAL SURVEY ONLINE SURVEY RESPONSE FREQUENCIES

1. From what source do you expect to receive most information on a hurricane's approach, potential danger, and announcements from government authorities? (Please check all that apply.)
   - Cable television systems: 329
   - Local television stations: 673
   - Telephone: 60
   - Radio broadcasts: 431
   - The Weather Channel: 484
   - Newspapers: 122
   - Internet: 430

2. What would be more likely to convince you to evacuate? (Check all that apply)
   - Personal knowledge about the storm and potential danger from winds or flooding: 444
   - Evacuation orders from government officials: 670
   - Advice from others: 93
   - National Weather Service issued Hurricane Watch or Warning: 309

3. Why might you decide not to evacuate? (Check all that apply.)
   - Fear of being caught in traffic during the hurricane: 404
   - Experience from previous storms: 345
   - Special transportation or care requirements for household members: 46
   - Work requirements: 267
   - Adequate care for household pets: 199

4. If a category 1 hurricane was expected to hit the region directly, would you plan to evacuate?
   - Yes: 92
   - No: 741

5. If a category 2 hurricane was expected to directly hit the region, would you plan to evacuate?
   - Yes: 324
   - No: 507

6. If you evacuated, where would you go? (Check one only.)
    - Williamsburg: 0
    - Northern Virginia: 90
    - Western Virginia (Roanoke, Blacksburg, Staunton, etc.): 211
    - Safer location in Hampton Roads: 72
    - Southern Virginia (Emporia, Danville, etc.): 80
    - Richmond/Petersburg area: 156

7. Would you take a motor home, trailer, or boat?
    - Yes: 43
    - No:791

8. Would you or someone else in your household require special assistance?
    - Yes: 47
    - No: 786

9. If others will travel with you, how many total people will be in your group?
    - Not applicable: 80
    - Two: 270
    - Three or more: 490

10. Are you familiar with the designated hurricane evacuation routes for your region?
    - Yes: 631
    - No: 198

11. Would you require special lodging facilities at your destination?
    - Yes: 166
    - No: 670

12. If you evacuated, what main highway(s) would you use? (Indicate up to three.)
    - I-64: 581
    - I-95: 211
    - US 58: 359
    - US 460: 291
    - VA 10: 48
    - US 17: 120

On September 18, 2003, Hurricane Isabel made landfall near Cape Hatteras, North Carolina, and moved north through southeastern Virginia. Hurricane Isabel was a category 5 hurricane with wind speeds over 165 mph one week prior to making landfall in North Carolina. Just three days before landfall, Isabel was still a category 4 storm and a hurricane warning was issued for the North Carolina and Virginia oceanfront. A hurricane watch was posted as far north as New Jersey. Hurricane Isabel caused more than $3.6 billion in damage and caused 35 storm-related deaths. For the purpose of the following questions, assume that a similar storm is now approaching Hampton Roads and a hurricane warning has been issued, meaning hurricane conditions are expected in the next 24 hours. Mandatory evacuation orders have already been issued for coastal and low-lying areas.

13. Would you evacuate?
- Yes: 540
- No: 300

14. Would you evacuate alone or as part of a larger group (such as with family or friends)?
- Alone: 129
- With a group: 707

15. Have you planned how you would evacuate, including the routes taken and what possessions and necessities you would bring?
- Yes: 485
- No: 353

16. Would you take household pets (dogs, cats, etc.) with you?
- Yes: 528
- No: 50

17. What would be your mode of transportation? (Select one only.)
- Personal vehicle (traveling alone): 280
- Commercial transportation (bus, train, plane): 2
- Public transportation provided specifically for this evacuation: 1
- Personal vehicle (traveling with others): 555

18. What would be your planned evacuation destination?
- Hotel or motel: 334
- Public shelter: 17
- Friends or relative: 450

19. If traffic conditions were severe or if you began to evacuate late in the day, would you feel comfortable and safe driving all night to reach your destination?
- Yes: 656
- No: 184

20. Would children (0-18 years old) evacuate with you?
- Yes: 389
- No: 445

21. Would anyone in your group require special medical capabilities at your end destination?
- Yes: 57
- No: 777

22. Would you be comfortable leaving your planned route for an alternate route if no information was provided on the availability of fuel, food, or lodging?
- Yes: 514
- No: 322

23. How familiar are you with the designated evacuation route you would expect to take?
- Very familiar: 339
- Comfortably familiar: 319
- Somewhat unfamiliar: 134
- Not at all familiar: 48

24. If your planned evacuation route(s) are blocked or congested, do you have a planned alternate route?
- Yes: 440
- No: 397

25. During an evacuation, would you be willing to take an alternate route to avoid being stuck in traffic?
- Yes: 818
- No: 19

26. Before leaving and while traveling, what sources of information on traffic do you typically use? (Please check all that apply.)
- Internet traffic websites: 308
- Radio: 766
- Mobile phone: 407
- Highway message signs: 603
- In-car system (such as GPS): 277

27. What would you consider a significant traffic delay during a hurricane evacuation?
- less than 30 minutes: 18
- 30 – 60 minutes: 204
- 1-2 hours: 368
- Over 2 hours: 248

28. Would you prefer highway information signs provide the estimated time delay or the length of the traffic back-up (in miles) for congested areas?

- Estimated time delay: 572
- Size of congestion in miles: 268

29. Would you be confident of information provided by highway information signs (such as the lighted signs above freeways that report congested areas)?

- Yes: 540
- No: 297

30. Assume that you have been on the road for almost 2 hours. Please indicate your choice between staying on your planned evacuation route or diverting when faced with the condition listed.

Conditions on the Planned Evacuation Route	Definitely remain on planned route			Definitely take alternate route	Anticipated Conditions on Alternate Route
Traffic has essentially stopped (less than 10 mph)					The next exit is visible. There are no traffic information signs.
Traffic has continued to move very slowly for over 30 minutes.					The next exit is visible. Traffic information signs say "Accident Ahead"
					Traffic information signs offer alternate route.
					Traffic information signs offer alternate route and say "Gas/Food/Lodging Available"
					Information signs say "Alternate route guided by State Police"

31. You have been completely stopped for the indicated time. Please indicate your choice between staying on your planned evacuation route or diverting.

Conditions on the Planned Evacuation Route	Definitely remain on planned route			Definitely take alternate route	Anticipated Conditions on Alternate Route
Traffic has continued to move very slowly for over one hour.					The next exit is visible. There are no traffic information signs.
					Traffic information signs offer alternate route.
					Information signs suggest an alternate route and indicate "Gas/Food/Lodging Available"
					Information signs say "Alternate route guided by State Police"
					Public radio suggests and describes an alternate route.
Traffic has continued to move very slowly for over two hours.					Traffic information signs offer alternate route.
					Information signs suggest an alternate route and indicate "Gas/Food/Lodging Available"
					Information signs say "Alternate route guided by State Police"
					Public radio suggests and describes an alternate route.

The following questions concern your personal driving habits.

32. While driving for all types of trips, how often do you encounter the following delay lengths?

Delay Length	Daily	Weekly	Monthly	Less than monthly	Never
15 - 30 minutes	298	165	133	161	84
30 - 45 minutes	66	177	197	297	104
45 – 60 minutes	17	52	157	418	197
1 – 2 hours	0	17	70	442	312
More than 2 hours	0	1	20	346	474

33. Have you recently (within the past month) diverted from your normal driving path to avoid unexpected congestion?

- Yes: 539
- No: 292

34. How often do you change your planned driving path and use an alternate route to avoid unexpected congestion?

Daily	Weekly	Monthly	Less than monthly	Never
44	172	161	388	76

35. What delay lengths would lead you to take an alternate route to avoid unexpected congestion?

15-30 minutes	30-60 minutes	1-2 hours	More than 2 hours
331	320	107	26

36.

Please answer the following questions about traffic reports and alternate routes, indicating your level of agreement or disagreement under normal driving conditions (NOT during a hurricane evacuation).	**Strongly Agree**			**Strongly Disagree**
I have taken alternate routes based on information received from overhead highway traffic information signs.	287	408	58	50
I have taken alternate routes based on information received from portable, temporary signs placed on the side of the highway.	257	408	87	257
I have taken alternate routes based on information received from radio traffic reports.	284	385	81	284
I watch for traffic information on overhead highway traffic information signs in order to get the latest information.	431	282	65	26
I check the radio broadcast traffic reports before beginning a trip.	187	271	194	138
Information on overhead traffic information signs is usually accurate.	94	401	211	72
I would prefer that overhead traffic information signs provide estimates of delay time and not the distance traffic is backed up.	308	275	113	84
I am suspicious of the accuracy of estimated traffic delays reported on overhead traffic signs.	174	349	522	75
Radio traffic reports should provide estimates of expected delay times.	321	390	68	14
I am reluctant to leave main highways and take other routes.	46	228	273	127
I would be uneasy about taking a route off the main road without knowing if food, gasoline, and lodging would be available.	136	273	231	155
I enjoy finding new routes to my destination.	163	327	186	110
I am comfortable reading and following a highway map.	532	195	47	33
I would be willing to take risks on a new route to avoid having a long traffic delay.	331	344	89	40
I would be very comfortable taking an alternate route if recommended by a policeman on the scene, even in an unfamiliar area.	460	292	46	13

37.

Please answer the following questions about yourself, indicating your level of agreement or disagreement.	**Strongly Agree**			**Strongly Disagree**
I am an aggressive driver.	35	214	177	154
I always have a map of the area in my car.	275	212	128	102
I get impatient quickly when stuck in traffic.	105	288	150	51
I watch for traffic information on overhead highway traffic information signs in order to get the latest information.	361	344	30	0
I am willing to try alternate routes to avoid traffic delays.	323	386	34	4
I usually like to stay on the main roads to keep from getting lost.	197	318	179	61
I am more comfortable waiting out a traffic delay to ensure I know how to get to my destination.	55	228	238	69
I am suspicious of the accuracy of estimated traffic delays reported on overhead traffic signs.	125	383	114	30
Radio traffic reports should provide estimates of expected delay lengths.	271	408	35	3
I am reluctant to leave main highways for other routes.	39	188	298	111
I would be uneasy about taking a route off the main road without knowing if food, gasoline, and lodging would be available.	94	269	221	72
I enjoy finding new routes to my destination.	183	283	126	35
I am comfortable reading and following a highway map.	527	191	31	10
I would be willing to take risks on a new route to avoid having a long traffic delay.	298	355	47	15

38. Age?
- 18-24: 20
- 25-35: 96
- 36-45: 162
- 45-55: 251
- 56-65: 197
- Over 65: 84
- Not reported: 31

39. Gender?
   - Male: 392
   - Female: 394
   - Not reported: 45

40. Counting yourself, how many people live in your household?
   - One: 96
   - Two: 326
   - Three: 170
   - Four: 154
   - Five: 53
   - Six or more: 15

41. Are any of these children less than 18 years of age?
   - Yes: 305
   - No: 493
   - Not applicable or not reported: 43

42. If the answer to the above question was yes, how many are under 18 years of age?
   - One: 161
   - Two: 109
   - Three or more: 37
   (Note: Two more respondents provided a number for those under 18 than said there those under 18 in the household.)

43. Are you the head of your household?
   - Yes: 559
   - No: 240

44. How many vehicles are in your household?
   - Zero: 31
   - One: 93
   - Two: 404
   - Three or more: 37

45. While an adult (18 years of age or older), have you evacuated because of a hurricane or other natural disaster?
   - Yes: 210
   - No: 597

46. If you have evacuated, how long ago did this occur?
   - Less than 3 years: 17
   - 4-5 years: 93
   - 6-10 years ago: 41
   - More than 10 years: 58

47. What category best describes your education level?
    - Some high school: 2
    - High school graduate: 41
    - Some college: 159
    - College graduate: 305
    - Advanced college degree: 302
    - Not reported: 32

48. What is your approximate household annual income?
    - Less than $20,000: 9
    - $20,000 - $50,000: 115
    - $50,000 - $75,000: 156
    - $75,000 - $100,000: 181
    - More than $100,000: 307
    - Not reported: 73

APPENDIX C

SIGNICANCE TESTS RESULTS BY GENDER AND AGE

TABLE 26 Survey Results: Characteristics Reported by Males

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
I have previously taken alternate routes using overhead message sign information	34.7%	51.5%	5.9%	6.1%
I have previously taken alternate routes using temporary message sign information	31.4%	50.3%	9.9%	5.9%
I have taken alternate routes using radio information	36.2%	43.6%	12.0%	4.8%
I check traffic information on the radio before beginning trips	21.4%	31.4%	27.6%	15.8%
I believe traffic information on overhead signs is usually accurate	8.4%	48.5%	27.6%	10.7%
I prefer overhead traffic information signs provide time delay estimates, not distance traffic is backed up	36.5%	32.4%	14.8%	11.0%
I am comfortable taking alternate routes recommended by policemen on the scene, even in unfamiliar areas	60.7%	34.4%	2.3%	1.5%
I am an aggressive driver	4.6%	31.4%	20.7%	14.5%
I always have a map of the area in my car	34.2%	29.3%	14.5%	7.9%
I usually stay on main roads to avoid getting lost	7.7%	35.5%	25.8%	9.2%
I am more comfortable waiting out a delay to ensure I reach my destination	2.8%	25.8%	33.4%	11.5%
I become impatient quickly when stuck in traffic	14.0%	39.3%	17.3%	3.8%
Radio reports should provide estimated delay lengths	39.3%	46.9%	8.2%	2.3%
Radio reports should report estimated delay times	32.7%	49.0%	4.6%	0.5%
I watch for information on overhead message signs	50.5%	34.9%	8.4%	3.8%
I watch for information on overhead message signs	40.8%	43.9%	4.3%	0.0%
I'm willing to take risks on new routes to avoid delays	43.9%	43.4%	7.1%	3.8%
I'm willing to take risks on new routes to avoid delays	42.1%	44.1%	3.6%	0.3%
I'm willing to take risks on new routes to avoid delays	42.1%	49.2%	2.8%	0.3%
I am suspicious of estimated delays reported on overhead traffic signs	25.3%	42.1%	22.2%	6.4%
I am suspicious of estimated delays reported on overhead traffic signs	18.4%	49.7%	9.9%	2.8%
I am reluctant to leave main roads for other routes	2.8%	26.5%	34.2%	32.7%
I am reluctant to leave main highways for other routes	2.8%	18.9%	39.5%	17.3%
I am uneasy about leaving main roads without knowing the availability of services	12.0%	31.6%	31.1%	23.0%
I am uneasy about leaving main roads without knowing the availability of services	6.6%	29.8%	31.1%	11.2%
I enjoy finding new routes to my destination	20.7%	42.3%	23.2%	9.7%
I enjoy finding new routes to my destination	24.2%	35.7%	13.5%	2.3%
I am comfortable reading, following highway maps	76.5%	17.3%	1.8%	2.8%
I am comfortable reading, following highway maps	76.5%	17.9%	1.5%	0.0%

TABLE 27 Survey Results: Characteristics Reported by Females

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
I have previously taken alternate routes using overhead message sign information	34.8%	47.7%	8.4%	6.3%
I have previously taken alternate routes using temporary message sign information	30.7%	48.7%	11.7%	5.6%
I have previously taken alternate routes using radio report information	33.5%	49.5%	7.9%	5.6%
I check traffic information on the radio before beginning trips	23.6%	35.0%	19.3%	18.0%
I believe traffic information on overhead signs is usually accurate	14.5%	48.0%	24.6%	7.1%
I prefer overhead traffic information signs provide time delay estimates, not distance traffic is backed up	38.6%	33.2%	13.5%	9.9%
I am comfortable taking alternate routes recommended by policemen on the scene, even in unfamiliar areas	51.5%	36.5%	8.9%	1.8%
I am an aggressive driver	4.3%	21.3%	22.1%	23.6%
I always have a map of the area in my car	32.2%	23.4%	17.0%	16.5%
I usually stay on main roads to avoid getting lost	15.7%	41.9%	18.3%	6.1%
I am more comfortable waiting out a delay to ensure I reach my destination	10.2%	29.9%	26.1%	5.3%
I become impatient quickly when stuck in traffic	12.2%	31.5%	18.5%	8.6%
Radio reports should provide estimated delay lengths	39.1%	47.2%	8.9%	1.3%
Radio reports should report estimated delay times	34.5%	49.7%	4.3%	0.3%
I watch for information on overhead message signs	54.6%	33.5%	7.1%	2.8%
I watch for information on overhead message signs	47.0%	41.4%	3.3%	0.0%
I'm willing to take risks on new routes to avoid delays	36.8%	40.6%	14.0%	6.1%
I'm willing to take risks on new routes to avoid delays	31.7%	42.9%	8.1%	3.6%
I'm willing to take risks on new routes to avoid delays	36.8%	45.4%	5.6%	0.8%
I am suspicious of estimated delays reported on overhead traffic signs	17.8%	43.9%	22.1%	11.4%
I am suspicious of estimated delays reported on overhead traffic signs	12.9%	45.2%	16.8%	4.6%
I am reluctant to leave main roads for other routes	7.9%	28.9%	33.0%	24.9%
I am reluctant to leave main highways for other routes	6.9%	26.4%	34.0%	10.2%
I am uneasy about leaving main roads without knowing the availability of services	21.3%	34.0%	24.9%	16.0%
I am uneasy about leaving main roads without knowing the availability of services	16.8%	35.5%	22.6%	6.9%
I enjoy finding new routes to my destination	19.8%	36.8%	21.8%	17.0%
I enjoy finding new routes to my destination	21.3%	32.7%	18.0%	6.1%
I am comfortable reading, following highway maps	52.8%	30.2%	9.4%	5.6%
I am comfortable reading, following highway maps	52.5%	28.9%	6.3%	2.5%

TABLE 28 Confidence Intervals for Selected Characteristics by Gender (Intervals Without Overlap Marked with an Asterisk)

	Male	Female
I am an aggressive driver*	36.0 +/- 4.8	25.6 +/- 4.3
I become impatient quickly when stuck in traffic	53.3 +/- 4.9	43.7 +/- 4.9
Comfortable waiting out delay & ensuring destination reached*	28.6 +/- 4.5	40.1 +/- 4.8
I usually stay on main roads to avoid getting lost*	43.1 +/- 4.9	57.6 +/- 4.9
I check traffic information on radio before beginning trips	52.8 +/- 4.9	58.6 +/- 4.9
I am willing to take risks on new routes to avoid delays*	91.3 +/- 2.8	82.2 +/- 3.8
I am willing to take risks on new routes to avoid delays *	87.2 +/- 3.3	77.4 +/- 4.1
I am willing to take risks on new routes to avoid delays*	86.2 +/- 3.4	74.6 +/- 4.3
I am suspicious about the delays reported on HMS*	68.1 +/- 4.6	58.1 +/- 4.9
I am suspicious about the delays reported on HMS	67.3 +/- 4.6	61.7 +/- 4.8
I am uneasy about leaving main roads for other routes*	43.6 +/- 4.9	55.3 +/- 4.9
I am uneasy about leaving main roads for other routes*	36.5 +/- 4.8	52.3 +/- 4.9
I enjoy finding new routes to my destination	63.0 +/- 4.8	56.6 +/- 4.9
I enjoy finding new routes to my destination	59.9 +/- 4.9	54.1 +/- 4.9
I am comfortable reading, following highway maps *	93.9 +/- 2.4	83.0 +/- 3.7
I am comfortable reading, following highway maps*	94.4 +/- 2.3	81.5 +/- 3.8
Annual Income Levels		
<$20K	0.3 +/- 0.5	2.0 +/- 1.4
$20K - $50K*	6.1 +/- 2.4	22.1 +/- 4.1
$50K - $75K	18.4 +/- 3.8	20.1 +/- 4.0
$75K - $100K	23.2 +/- 4.2	21.6 +/- 4.1
>$100K*	47.4 +/- 4.9	27.7 +/- 4.4
Education Level		
< High School	0	0.5 +/- 0.7
High School Graduate	4.3 +/- 2.0	5.3 +/- 2.2
Some College	16.3 +/- 3.7	23.1 +/- 4.2
College Graduate	33.4 +/- 4.7	41.4 +/- 4.9
Advanced College Degree*	45.7 +/- 4.9	28.7 +/- 4.5

TABLE 29 Selected Characteristics' Student t-test and Chi-squared Test Results by Gender (Significance Is Indicated by p-values ≤ 0.05)

	Male	Female	t-Test	Chi-Squared
I plan to evacuate with a group	323	324	0.952	0.953
I have planned my evacuation*	241	211	0.025	0.042
I am comfortable driving all night*	334	279	0.000	0.001
I will detour to avoid congestion (no services information)*	257	226	0.018	0.034
A member of my group requires special lodging*	58	96	0.001	0.009
A member of my group requires special assistance	18	26	0.221	0.345
A member of my group requires special medical assistance	21	28	0.310	0.385
Head of Household?*	369	168	0.000	0.000
I have participated in a past evacuation as adult?	104	103	0.902	0.904
I consider myself an aggressive driver*	141	101	0.002	0.009
I become impatient quickly when stuck in traffic*	209	172	0.007	0.017
I am more comfortable waiting out delay to ensure my destination is reached*	112	158	0.001	0.005
I usually stay on main roads to avoid getting lost*	169	227	0.000	0.001
I check traffic information on radio before beginning trips	207	231	0.100	0.124
I am willing to take risks on new routes to avoid delays*	342	305	0.000	0.008
I am willing to take risks on new routes to avoid delays *	338	294	0.000	0.003
I am suspicious about the delays reported on HMS*	267	227	0.002	0.010
I am suspicious about the delays reported on HMS	264	243	0.097	0.122
I am uneasy about leaving main roads for other routes*	171	218	0.001	0.006
I am uneasy about leaving main roads for other routes*	143	206	0.000	0.001
I enjoy finding new routes to my destination	247	223	0.067	0.089
I enjoy finding new routes to my destination	235	213	0.095	0.119
I am comfortable reading, following highway maps*	368	327	0.000	0.005
I am comfortable reading, following highway maps*	370	321	0.000	0.002
Annual Income				
$20K - $50K*	24	87	0.000	0.001
$50K - $75K	72	79	0.549	0.566
$75K - $100K	91	85	0.581	0.595
>$100K*	186	109	0.000	0.000
Education Level				
High School Graduate	17	21	0.516	0.583
Some College*	64	91	0.017	0.044
College Graduate*	131	163	0.021	0.038
Advanced College Degree*	179	113	0.000	0.000

*Characteristic has p-values ≦0.05.

TABLE 30 Survey Results: Characteristics Reported by 18-24 Year-Old Group

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
I have previously taken alternate routes using overhead message sign information	25.0%	45.0%	5.0%	25.0%
I have previously taken alternate routes using temporary message sign information	15.0%	50.0%	15.0%	15.0%
I have previously taken alternate routes using radio report information	25.0%	45.0%	10.0%	20.0%
I check traffic information on the radio before beginning trips	15.0%	40.0%	30.0%	10.0%
I believe traffic information on overhead signs is usually accurate	20.0%	50.0%	10.0%	5.0%
I prefer overhead traffic information signs provide time delay estimates, not distance traffic is backed up	25.0%	35.0%	25.0%	5.0%
I am comfortable taking alternate routes recommended by policemen on the scene, even in unfamiliar areas	25.0%	70.0%	5.0%	0.0%
I am an aggressive driver	10.0%	10.0%	30.0%	15.0%
I always have a map of the area in my car	35.0%	10.0%	5.0%	25.0%
I usually stay on main roads to avoid getting lost	15.0%	50.0%	10.0%	0.0%
I am more comfortable waiting out a delay to ensure I reach my destination	5.0%	55.0%	20.0%	5.0%
I become impatient quickly when stuck in traffic	20.0%	20.0%	35.0%	5.0%
Radio reports should provide estimated delay lengths	40.0%	45.0%	5.0%	0.0%
Radio reports should report estimated delay times	50.0%	50.0%	0.0%	0.0%
I watch for information on overhead message signs	65.0%	35.0%	0.0%	0.0%
I watch for information on overhead message signs	60.0%	30.0%	0.0%	0.0%
I'm willing to take risks on new routes to avoid delays	15.0%	55.0%	20.0%	5.0%
I'm willing to take risks on new routes to avoid delays	15.0%	55.0%	10.0%	0.0%
I'm willing to take risks on new routes to avoid delays	15.0%	60.0%	10.0%	0.0%
I am suspicious of estimated delays reported on overhead traffic signs	5.0%	60.0%	20.0%	10.0%
I am suspicious of estimated delays reported on overhead traffic signs	10.0%	25.0%	10.0%	10.0%
I am reluctant to leave main roads for other routes	5.0%	30.0%	35.0%	15.0%
I am reluctant to leave main highways for other routes	10.0%	25.0%	25.0%	0.0%
I am uneasy about leaving main roads without knowing the availability of services	10.0%	55.0%	20.0%	10.0%
I am uneasy about leaving main roads without knowing the availability of services	5.0%	40.0%	30.0%	0.0%
I enjoy finding new routes to my destination	5.0%	50.0%	20.0%	20.0%
I enjoy finding new routes to my destination	5.0%	35.0%	35.0%	0.0%
I am comfortable reading, following highway maps	55.0%	25.0%	10.0%	10.0%
I am comfortable reading, following highway maps	50.0%	30.0%	10.0%	0.0%

TABLE 31 Survey Results: Characteristics Reported by 25-35 Year-Old Group

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
I have previously taken alternate routes using overhead message sign information	35.4%	46.9%	7.3%	7.3%
I have previously taken alternate routes using temporary message sign information	26.0%	54.2%	11.5%	7.3%
I have previously taken alternate routes using radio report information	30.2%	47.9%	10.4%	6.3%
I check traffic information on the radio before beginning trips	26.0%	31.3%	22.9%	18.8%
I believe traffic information on overhead signs is usually accurate	12.5%	51.0%	25.0%	6.3%
I prefer overhead traffic information signs provide time delay estimates, not distance traffic is backed up	27.1%	37.5%	13.5%	18.8%
I am comfortable taking alternate routes recommended by policemen on the scene, even in unfamiliar areas	49.0%	35.4%	13.5%	1.0%
I am an aggressive driver	5.2%	34.4%	24.0%	7.3%
I always have a map of the area in my car	21.9%	26.0%	18.8%	20.8%
I usually stay on main roads to avoid getting lost	12.5%	38.5%	16.7%	10.4%
I am more comfortable waiting out a delay to ensure I reach my destination	4.2%	33.3%	19.8%	10.4%
I become impatient quickly when stuck in traffic	17.7%	34.4%	13.5%	3.1%
Radio reports should provide estimated delay lengths	29.2%	53.1%	13.5%	1.0%
Radio reports should report estimated delay times	24.0%	55.2%	5.2%	0.0%
I watch for information on overhead message signs	51.0%	39.6%	6.3%	2.1%
I watch for information on overhead message signs	41.7%	47.9%	4.2%	0.0%
I'm willing to take risks on new routes to avoid delays	28.1%	49.0%	12.5%	8.3%
I'm willing to take risks on new routes to avoid delays	30.2%	44.8%	7.3%	2.1%
I'm willing to take risks on new routes to avoid delays	36.5%	46.9%	3.1%	0.0%
I am suspicious of estimated delays reported on overhead traffic signs	22.9%	45.8%	19.8%	8.3%
I am suspicious of estimated delays reported on overhead traffic signs	15.6%	47.9%	15.6%	4.2%
I am reluctant to leave main roads for other routes	3.1%	35.4%	36.5%	21.9%
I am reluctant to leave main highways for other routes	4.2%	29.2%	30.2%	13.5%
I am uneasy about leaving main roads without knowing the availability of services	14.6%	35.4%	29.2%	18.8%
I am uneasy about leaving main roads without knowing the availability of services	11.5%	31.3%	17.7%	12.5%
I enjoy finding new routes to my destination	13.5%	51.0%	21.9%	10.4%
I enjoy finding new routes to my destination	17.7%	41.7%	16.7%	4.2%
I am comfortable reading, following highway maps	53.1%	31.3%	9.4%	5.2%
I am comfortable reading, following highway maps	54.2%	27.1%	5.2%	3.1%

TABLE 32 Survey Results: Characteristics Reported by 36-45 Year-Old Group

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
I have previously taken alternate routes using overhead message sign information	32.7%	48.8%	9.3%	6.8%
I have previously taken alternate routes using temporary message sign information	30.9%	51.9%	10.5%	4.3%
I have previously taken alternate routes using radio report information	38.9%	42.0%	9.9%	4.9%
I check traffic information on the radio before beginning trips	18.5%	35.2%	25.3%	17.3%
I believe traffic information on overhead signs is usually accurate	7.4%	45.7%	32.1%	11.7%
I prefer overhead traffic information signs provide time delay estimates, not distance traffic is backed up	34.0%	34.0%	18.5%	9.9%
I am comfortable taking alternate routes recommended by policemen on the scene, even in unfamiliar areas	56.2%	36.4%	5.6%	1.2%
I am an aggressive driver	4.9%	29.6%	25.9%	14.2%
I always have a map of the area in my car	29.0%	27.8%	17.9%	14.8%
I usually stay on main roads to avoid getting lost	9.9%	35.2%	24.7%	9.3%
I am more comfortable waiting out a delay to ensure I reach my destination	6.2%	23.5%	33.3%	13.0%
I become impatient quickly when stuck in traffic	13.0%	40.7%	14.2%	4.3%
Radio reports should provide estimated delay lengths	34.6%	52.5%	8.6%	2.5%
Radio reports should report estimated delay times	30.9%	55.6%	3.1%	0.6%
I watch for information on overhead message signs	45.1%	34.0%	13.0%	6.2%
I watch for information on overhead message signs	35.8%	42.6%	6.2%	0.0%
I'm willing to take risks on new routes to avoid delays	43.2%	40.1%	11.7%	4.3%
I'm willing to take risks on new routes to avoid delays	40.7%	38.9%	7.4%	1.9%
I'm willing to take risks on new routes to avoid delays	43.8%	43.2%	4.3%	0.6%
I am suspicious of estimated delays reported on overhead traffic signs	26.5%	38.9%	20.4%	10.5%
I am suspicious of estimated delays reported on overhead traffic signs	21.0%	45.1%	9.3%	4.9%
I am reluctant to leave main roads for other routes	3.7%	24.7%	34.6%	34.0%
I am reluctant to leave main highways for other routes	3.1%	23.5%	36.4%	19.1%
I am uneasy about leaving main roads without knowing the availability of services	14.8%	27.8%	25.3%	27.8%
I am uneasy about leaving main roads without knowing the availability of services	8.0%	30.2%	32.1%	10.5%
I enjoy finding new routes to my destination	28.4%	35.8%	20.4%	12.3%
I enjoy finding new routes to my destination	27.2%	32.7%	14.8%	4.9%
I am comfortable reading, following highway maps	67.9%	22.2%	3.1%	6.2%
I am comfortable reading, following highway maps	64.2%	24.1%	6.2%	2.5%

TABLE 33 Survey Results: Characteristics Reported by 46-55 Year-Old Group

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
I have previously taken alternate routes using overhead message sign information	37.8%	47.8%	7.2%	5.6%
I have previously taken alternate routes using temporary message sign information	32.7%	49.4%	11.6%	4.4%
I have previously taken alternate routes using radio report information	38.2%	43.4%	11.6%	4.4%
I check traffic information on the radio before beginning trips	20.7%	35.1%	23.1%	19.1%
I believe traffic information on overhead signs is usually accurate	11.6%	48.2%	26.3%	10.0%
I prefer overhead traffic information signs provide time delay estimates, not distance traffic is backed up	35.9%	34.3%	11.2%	13.1%
I am comfortable taking alternate routes recommended by policemen on the scene, even in unfamiliar areas	57.4%	35.5%	4.0%	1.6%
I am an aggressive driver	2.0%	25.9%	20.7%	23.1%
I always have a map of the area in my car	32.3%	26.3%	18.7%	11.6%
I usually stay on main roads to avoid getting lost	13.1%	37.8%	23.9%	5.2%
I am more comfortable waiting out a delay to ensure I reach my destination	8.4%	27.5%	29.9%	4.0%
I become impatient quickly when stuck in traffic	10.8%	31.9%	21.9%	6.0%
Radio reports should provide estimated delay lengths	30.7%	48.2%	4.0%	0.4%
Radio reports should report estimated delay times	36.3%	50.6%	7.2%	2.0%
I watch for information on overhead message signs	48.2%	38.6%	8.8%	2.4%
I watch for information on overhead message signs	42.2%	45.0%	3.6%	0.0%
I'm willing to take risks on new routes to avoid delays	40.2%	43.0%	10.0%	4.4%
I'm willing to take risks on new routes to avoid delays	36.7%	43.8%	5.6%	2.8%
I'm willing to take risks on new routes to avoid delays	38.6%	47.4%	4.4%	1.2%
I am suspicious of estimated delays reported on overhead traffic signs	21.5%	43.4%	23.1%	8.0%
I am suspicious of estimated delays reported on overhead traffic signs	14.7%	49.8%	16.7%	2.0%
I am reluctant to leave main roads for other routes	7.2%	26.3%	34.3%	29.5%
I am reluctant to leave main highways for other routes	4.4%	21.1%	43.4%	11.2%
I am uneasy about leaving main roads without knowing the availability of services	15.9%	35.9%	29.5%	15.5%
I am uneasy about leaving main roads without knowing the availability of services	12.4%	36.7%	28.3%	6.4%
I enjoy finding new routes to my destination	17.1%	41.0%	22.7%	14.7%
I enjoy finding new routes to my destination	22.3%	35.1%	15.9%	4.0%
I am comfortable reading, following highway maps	64.9%	25.9%	5.6%	2.4%
I am comfortable reading, following highway maps	65.3%	24.7%	2.8%	0.4%

TABLE 34 Survey Results: Characteristics Reported by 56-65 Year-Old Group

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
I have previously taken alternate routes using overhead message sign information	35.5%	53.8%	5.1%	4.1%
I have previously taken alternate routes using temporary message sign information	35.0%	47.2%	8.6%	5.6%
I have previously taken alternate routes using radio report information	34.5%	52.3%	8.1%	2.5%
I check traffic information on the radio before beginning trips	27.4%	29.9%	27.9%	11.7%
I believe traffic information on overhead signs is usually accurate	12.7%	53.8%	22.8%	5.6%
I prefer overhead traffic information signs provide time delay estimates, not distance traffic is backed up	42.6%	33.0%	14.7%	4.1%
I am comfortable taking alternate routes recommended by policemen on the scene, even in unfamiliar areas	61.9%	30.5%	4.1%	2.5%
I am an aggressive driver	6.1%	23.4%	20.8%	21.8%
I always have a map of the area in my car	39.6%	25.4%	12.7%	9.1%
I usually stay on main roads to avoid getting lost	9.1%	45.7%	21.8%	8.1%
I am more comfortable waiting out a delay to ensure I reach my destination	6.1%	25.9%	29.9%	9.6%
I become impatient quickly when stuck in traffic	13.7%	34.0%	22.8%	6.1%
Radio reports should provide estimated delay lengths	47.7%	42.6%	6.6%	0.5%
Radio reports should report estimated delay times	42.1%	46.7%	3.6%	0.0%
I watch for information on overhead message signs	61.9%	28.9%	4.1%	3.0%
I watch for information on overhead message signs	50.8%	40.6%	2.5%	0.0%
I'm willing to take risks on new routes to avoid delays	45.7%	37.6%	11.7%	3.6%
I'm willing to take risks on new routes to avoid delays	37.1%	46.2%	3.6%	0.0%
I'm willing to take risks on new routes to avoid delays	39.6%	52.8%	3.0%	0.0%
I am suspicious of estimated delays reported on overhead traffic signs	17.3%	44.2%	24.4%	9.6%
I am suspicious of estimated delays reported on overhead traffic signs	10.7%	48.7%	12.7%	4.1%
I am reluctant to leave main roads for other routes	5.6%	26.9%	33.5%	28.9%
I am reluctant to leave main highways for other routes	5.1%	23.9%	34.0%	13.7%
I am uneasy about leaving main roads without knowing the availability of services	18.3%	29.9%	32.0%	17.8%
I am uneasy about leaving main roads without knowing the availability of services	13.7%	29.4%	30.5%	9.6%
I enjoy finding new routes to my destination	21.3%	36.5%	24.4%	12.7%
I enjoy finding new routes to my destination	20.3%	33.0%	16.2%	3.6%
I am comfortable reading, following highway maps	68.0%	20.3%	4.6%	4.1%
I am comfortable reading, following highway maps	69.0%	20.8%	1.5%	1.0%

TABLE 35 Survey Results: Characteristics Reported by Over 65 Year-Old Group

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
I have previously taken alternate routes using overhead message sign information	33.3%	50.0%	8.3%	3.6%
I have previously taken alternate routes using temporary message sign information	32.1%	44.0%	9.5%	7.1%
I have previously taken alternate routes using radio report information	27.4%	50.0%	8.3%	8.3%
I check traffic information on the radio before beginning trips	21.4%	33.3%	11.9%	19.0%
I believe traffic information on overhead signs is usually accurate	14.3%	42.9%	22.6%	9.5%
I prefer overhead traffic information signs provide time delay estimates, not distance traffic is backed up	48.8%	28.6%	8.3%	8.3%
I am comfortable taking alternate routes recommended by policemen on the scene, even in unfamiliar areas	54.8%	36.9%	4.8%	1.2%
I am an aggressive driver	3.6%	22.6%	14.3%	21.4%
I always have a map of the area in my car	47.6%	26.2%	9.5%	7.1%
I usually stay on main roads to avoid getting lost	16.7%	31.0%	20.2%	8.3%
I am more comfortable waiting out a delay to ensure I reach my destination	7.1%	29.8%	31.0%	9.5%
I become impatient quickly when stuck in traffic	10.7%	42.9%	8.3%	14.3%
Radio reports should provide estimated delay lengths	42.9%	36.9%	10.7%	3.6%
Radio reports should report estimated delay times	35.7%	45.2%	8.3%	1.2%
I watch for information on overhead message signs	57.1%	29.8%	6.0%	2.4%
I watch for information on overhead message signs	51.2%	33.3%	1.2%	0.0%
I'm willing to take risks on new routes to avoid delays	42.9%	41.7%	4.8%	6.0%
I'm willing to take risks on new routes to avoid delays	40.5%	41.7%	4.8%	3.6%
I'm willing to take risks on new routes to avoid delays	44.0%	42.9%	4.8%	0.0%
I am suspicious of estimated delays reported on overhead traffic signs	19.0%	38.1%	26.2%	9.5%
I am suspicious of estimated delays reported on overhead traffic signs	19.0%	42.9%	15.5%	3.6%
I am reluctant to leave main roads for other routes	7.1%	27.4%	25.0%	31.0%
I am reluctant to leave main highways for other routes	7.1%	19.0%	33.3%	13.1%
I am uneasy about leaving main roads without knowing the availability of services	19.0%	35.7%	23.8%	19.0%
I am uneasy about leaving main roads without knowing the availability of services	11.9%	34.5%	17.9%	8.3%
I enjoy finding new routes to my destination	21.4%	35.7%	22.6%	14.3%
I enjoy finding new routes to my destination	28.6%	34.5%	8.3%	7.1%
I am comfortable reading, following highway maps	69.0%	17.9%	7.1%	2.4%
I am comfortable reading, following highway maps	70.2%	17.9%	4.8%	0.0%

TABLE 36 Confidence Intervals for Selected Characteristics by Age Group*

	Overall	18-24**	25-35	36-45	46-55	56-65	Over 65
Annual Income <$20,000	1.1 +/- 1.5	20.0 +/18.0					
Annual income $20,000-$50,000	14.1 +/- 2.6	50 +/- 17.1					
Annual income $50,000-$75,000	19.1 +/- 2.7						
Annual income $75,000-$100,000	22.2 +/- 2.8						
Annual income > $100,000	37.9 +/- 2.8	5 +/- 13.0	15.6 +/-7.7			53.3 +/-5.1	
High School Graduate	5.1 +/- 2.0						
Some college	19.6 +/- 2.7	40 +/- 18.4	7.3+/- 6.4				
College graduate	37.4 +/- 2.9		60.4 +/-6.7				
Advanced College degree	37.0 +/- 2.8					46.2 +/-5.5	
More comfortable waiting out a delay to not get lost	30.5 +/- 2.9	60 +/- 15.0	3.1 +/- 5.2				
Suspicious of time delays reported by VMS	62.5 +/- 2.2	35 +/- 18.7					
Plan to evacuate with group	84.1 +/ 2.5						70.2 +/-9.8
Have planned evacuation	57.7 +/- 3.3		37.5 +/-9.7				72.6 +/-9.6
Comfortable driving all night	78.0 +/- 2.8						
Will detour to avoid congestion (no svc info)	61.1 +/- 3.3						
Member of group requires special lodging	19.7 +/- 2.7						
Member of group requires special assistance	5.6 +/- 1.6						
Member of group requires special medical assistance	6.8 +/- 1.7						
Head of household	66.5 +/- 3.2						
Past evacuation as adult	25.0 +/- 2.9						
Aggressive Driver	29.6 +/- 3.1						
Become impatient quickly when stuck in traffic	46.7 +/- 3.4						
Will try alt routes to avoid traffic delays	84.3 +/- 2.5						
Like stay main roads avoid getting lost	49.3 +/- 3.4						
Reluctant to leave main roads w/o svc info	48.6 +/- 3.4						
Enjoy finding new routes to my destination	58.3 +/- 3.3						
Comfortable reading/following maps	85.4 +/- 2.4						

*Only group characteristics without confidence overlap to the overall sample population.

**Only 20 survey participants were in the 18-24 year old group.

TABLE 37 Selected Characteristics' Student t-Test and Chi-squared Test Significance Values for the 18-24 Year Old Age Group Compared to the Sample Population (Significance Is Indicated by p-values ≤ 0.05, Marked with an Asterisk)

	All Ages	18-24	t-Test	Chi-Squared
I plan to evacuate with a group	678	17	0.877	0.887
I have planned my evacuation	469	6	0.013	0.055
I would be comfortable driving all night	632	17	0.456	0.481
Will detour to avoid congestion (no services information)*	499	6	0.004	0.038
A member of my group will require special lodging	160	3	0.597	0.617
A member of my group will require special assistance	46	0	0.273	0.091
A member of my group require special medical assistance	53	0	0.237	0.084
Head of Household?	558	10	0.073	0.193
I have completed a past evacuation as an adult*	210	0	0.008	0.000
I am an aggressive driver	264	4	0.234	0.260
I become impatient quickly when stuck in traffic	391	8	0.465	0.497
More comfortable waiting out delay to ensure destination reached	280	12	0.019	0.105
I usually stay on main roads to avoid getting lost	411	13	0.208	0.258
I check traffic information on radio before beginning trips	452	11	0.943	0.947
Willing to take risks on new routes to avoid delays	707	15	0.107	0.335
Willing to take risks on new routes to avoid delays	667	14	0.155	0.355
Willing to take risks on new routes to avoid delays	650	14	0.258	0.426
Suspicious about the delays reported on HMS	506	7	0.012*	0.064
Suspicious about the delays reported on HMS	517	13	0.914	0.920
Uneasy about leaving main roads for other routes	401	13	0.171	0.225
Uneasy about leaving main roads for other routes	359	9	0.952	0.955
Enjoy finding new routes to my destination	485	11	0.660	0.687
Enjoy finding new routes to my destination	464	8	0.123	0.194
Comfortable reading, following highway maps	718	16	0.233	0.513
Comfortable reading, following highway maps	714	16	0.269	0.532
Annual Income				
<$20K*	9	4	0.000*	
$20K - $50K	41	10	0.000*	0.086
$50K - $75K	159	2	0.303	0.314
$75K - $100K	303	2	0.192	0.173
>$100K*	300	1	0.003	0.001
Education Level				
High School Graduate	41	0	0.302	
Some College	159	8	0.025	0.206
College Graduate	303	7	0.826	0.838
Advanced College Degree	300	5	0.270	0.288

TABLE 38 Selected Characteristics' Student t-Test and Chi-Squared Test Significance Values for the 25-35 Year Old Age Group Compared to the Sample Population (Significance Is Indicated by p-values ≦ 0.05, Marked with an Asterisk)

	All Ages	25-35	t-Test	Chi-Squared
I plan to evacuate with a group	678	80	0.926	0.930
I have planned my evacuation*	469	36	0.000	0.005
I would be comfortable driving all night	632	74	0.833	0.842
I will detour to avoid congestion (no services information)	499	64	0.334	0.351
A member of my group will require special lodging	160	25	0.148	0.229
A member of my group will require special assistance	46	3	0.296	0.416
A member of my group require special medical assistance	53	4	0.365	0.396
Head of Household?	558	59	0.140	0.193
I have completed a past evacuation as an adult	210	20	0.278	0.293
I am an aggressive driver	264	38	0.169	0.220
I become impatient quickly when stuck in traffic	391	50	0.480	0.498
More comfortable waiting out delay to ensure destination reached	280	36	0.569	0.589
I usually stay on main roads to avoid getting lost	411	49	0.956	0.957
I check traffic information on radio before beginning trips	452	55	0.781	0.787
Willing to take risks on new routes to avoid delays	707	80	0.279	0.377
Willing to take risks on new routes to avoid delays	667	74	0.207	0.294
Willing to take risks on new routes to avoid delays	650	72	0.227	0.309
Suspicious about the delays reported on HMS	506	61	0.837	0.842
Suspicious about the delays reported on HMS	517	66	0.341	0.356
Uneasy about leaving main roads for other routes	401	48	0.927	0.929
Uneasy about leaving main roads for other routes	359	41	0.764	0.770
Enjoy finding new routes to my destination	485	62	0.373	0.390
Enjoy finding new routes to my destination	464	57	0.695	0.703
Comfortable reading, following highway maps	718	81	0.221	0.351
Comfortable reading, following highway maps	714	78	0.054	0.171
Annual Income				
<$20K	9	3	0.103	
$20K - $50K	41	22	0.022*	0.118
$50K - $75K	159	27	0.038	0.120
$75K - $100K	303	27	0.193	0.266
>$100K*	300	15	0.000	0.001
Education Level				
High School Graduate	41	3	0.404	0.500
Some College*	159	7	0.003	0.009
College Graduate*	303	58	0.000	0.002
Advanced College Degree	300	27	0.086	0.106

TABLE 39 Selected Characteristics' Student t-Test and Chi-Squared Test Significance Values for the 35-45 Year Old Age Group Compared to the Sample Population (Significance Is Indicated by p-values ≦ 0.05, Marked with an Asterisk)

	All Ages	36-45	t-Test	Chi-Squared
I plan to evacuate with a group	678	146	0.038*	0.062
I have planned my evacuation	469	90	0.581	0.594
I would be comfortable driving all night	632	122	0.449	0.482
I will detour to avoid congestion (no services information)	499	106	0.359	0.374
A member of my group will require special lodging	160	36	0.475	0.510
A member of my group will require special assistance	46	12	0.397	0.516
A member of my group require special medical assistance	53	12	0.688	0.736
Head of Household?	558	118	0.319	0.332
I have completed a past evacuation as an adult	210	45	0.625	0.643
I am an aggressive driver	264	56	0.625	0.639
I become impatient quickly when stuck in traffic	391	87	0.207	0.232
More comfortable waiting out delay to ensure destination reached	280	48	0.225	0.241
I usually stay on main roads to avoid getting lost	411	73	0.187	0.212
I check traffic information on radio before beginning trips	452	87	0.624	0.634
Willing to take risks on new routes to avoid delays	707	141	0.931	0.935
Willing to take risks on new routes to avoid delays	667	135	0.763	0.769
Willing to take risks on new routes to avoid delays	650	129	0.857	0.863
Suspicious about the delays reported on HMS	506	107	0.389	0.402
Suspicious about the delays reported on HMS	517	106	0.697	0.704
Uneasy about leaving main roads for other routes	401	69	0.108	0.133
Uneasy about leaving main roads for other routes	359	62	0.156	0.178
Enjoy finding new routes to my destination	485	104	0.304	0.319
Enjoy finding new routes to my destination	464	97	0.542	0.552
Comfortable reading, following highway maps	718	146	0.584	0.599
Comfortable reading, following highway maps	714	143	0.965	0.967
Annual Income				
<$20K	9	1	0.570	
$20K - $50K	114	25	0.652	0.679
$50K - $75K	155	36	0.367	0.413
$75K - $100K	180	44	0.173	0.229
>$100K	307	48	0.046*	0.064
Education Level				
High School Graduate	41	5	0.280	0.333
Some College	159	32	0.971	0.972
College Graduate	303	68	0.275	0.306
Advanced College Degree	300	56	0.552	0.561

TABLE 40 Selected Characteristics' Student t-Test and Chi-Squared Test Significance Values for the 45-55 Year Old Age Group Compared to the Sample Population (Significance Is Indicated by p-values ≦ 0.05, Marked with an Asterisk)

	All Ages	46-55	t-Test	Chi-Squared
I plan to evacuate with a group	678	210	0.989	0.989
I have planned my evacuation	469	150	0.602	0.609
I would be comfortable driving all night	632	198	0.367	0.400
I will detour to avoid congestion (no services information)	499	156	0.876	0.879
A member of my group will require special lodging	160	51	0.844	0.850
A member of my group will require special assistance	46	16	0.681	0.717
A member of my group require special medical assistance	53	17	0.898	0.907
Head of Household?	558	171	0.820	0.825
I have completed a past evacuation as an adult	210	66	0.907	0.910
I am an aggressive driver	264	70	0.161	0.179
I become impatient quickly when stuck in traffic	391	107	0.118	0.139
More comfortable waiting out delay to ensure destination reached	280	90	0.959	0.960
I usually stay on main roads to avoid getting lost	411	128	0.944	0.945
I check traffic information on radio before beginning trips	452	140	0.944	0.994
Willing to take risks on new routes to avoid delays	707	216	0.613	0.638
Willing to take risks on new routes to avoid delays	667	209	0.737	0.744
Willing to take risks on new routes to avoid delays	650	202	0.936	0.938
Suspicious about the delays reported on HMS	506	162	0.552	0.561
Suspicious about the delays reported on HMS	517	163	0.748	0.753
Uneasy about leaving main roads for other routes	401	130	0.527	0.537
Uneasy about leaving main roads for other routes	359	123	0.193	0.217
Enjoy finding new routes to my destination	485	146	0.630	0.639
Enjoy finding new routes to my destination	464	144	0.981	0.981
Comfortable reading, following highway maps	718	228	0.328	0.351
Comfortable reading, following highway maps	714	226	0.410	0.430
Annual Income				
<$20K	9	1	0.307	
$20K - $50K	114	27	0.176	0.200
$50K - $75K	155	42	0.392	0.405
$75K - $100K	180	57	0.871	0.876
>$100K	307	112	0.057	0.082
Education Level				
High School Graduate	41	19	0.133	0.306
Some College	159	54	0.515	0.540
College Graduate	303	88	0.501	0.510
Advanced College Degree	300	89	0.650	0.657

TABLE 41 Selected Characteristics' Student t-Test and Chi-Squared Test Significance Values for the 55-65 Year Old Age Group Compared to the Sample Population (Significance Is Indicated by p-values ≦ 0.05, Marked with an Asterisk)

	All Ages	56-65	t-Test	Chi-Squared
I plan to evacuate with a group	678	166	0.848	0.853
I have planned my evacuation	469	126	0.121	0.140
I would be comfortable driving all night	632	157	0.610	0.617
I will detour to avoid congestion (no services information)	499	118	0.659	0.669
A member of my group will require special lodging	160	35	0.527	0.537
A member of my group will require special assistance	46	12	0.824	0.847
A member of my group require special medical assistance	53	13	0.977	0.979
Head of Household?	558	136	0.968	0.969
I have completed a past evacuation as an adult	210	53	0.779	0.787
I am an aggressive driver	264	58	0.395	0.407
I become impatient quickly when stuck in traffic	391	94	0.889	0.891
More comfortable waiting out delay to ensure destination reached	280	63	0.492	0.501
I usually stay on main roads to avoid getting lost	411	108	0.304	0.323
I check traffic information on radio before beginning trips	452	113	0.693	0.699
Willing to take risks on new routes to avoid delays	707	182	0.046*	0.070
Willing to take risks on new routes to avoid delays	667	164	0.765	0.771
Willing to take risks on new routes to avoid delays	650	164	0.337	0.351
Suspicious about the delays reported on HMS	506	117	0.425	0.446
Suspicious about the delays reported on HMS	517	121	0.530	0.546
Uneasy about leaving main roads for other routes	401	95	0.747	0.752
Uneasy about leaving main roads for other routes	359	85	0.766	0.771
Enjoy finding new routes to my destination	485	114	0.607	0.617
Enjoy finding new routes to my destination	464	105	0.312	0.334
Comfortable reading, following highway maps	718	174	0.900	0.906
Comfortable reading, following highway maps	714	177	0.503	0.516
Annual Income				
<$20K	9	0	0.137	
$20K - $50K	114	17	0.042*	0.068
$50K - $75K	155	31	0.270	0.285
$75K - $100K	180	31	0.045	0.061
>$100K*	307	105	0.000	0.002
Education Level				
High School Graduate	41	9	0.775	0.796
Some College	159	37	0.787	0.793
College Graduate*	303	57	0.026	0.041
Advanced College Degree*	300	91	0.018	0.040

TABLE 42 Selected Characteristics' Student t-Test and Chi-Squared Test Significance Values for the >65 Year Old Age Group Compared to the Sample Population (Significance Is Indicated by p-values ≦ 0.05, Marked with an Asterisk)

	All Ages	>65	t-Test	Chi-Squared
I plan to evacuate with a group*	678	59	0.002	0.048
I have planned my evacuation*	469	61	0.009	0.022
I would be comfortable driving all night	632	64	0.700	0.722
I will detour to avoid congestion (no services information)	499	49	0.558	0.578
A member of my group will require special lodging	160	10	0.081	0.094
A member of my group will require special assistance	46	3	0.419	0.511
A member of my group require special medical assistance	53	7	0.533	0.626
Head of Household?	558	64	0.166	0.182
I have completed a past evacuation as an adult	210	26	0.320	0.377
I am an aggressive driver	264	38	0.020*	0.061
I become impatient quickly when stuck in traffic	391	45	0.355	0.381
More comfortable waiting out delay to ensure destination reached	280	31	0.669	0.685
I usually stay on main roads to avoid getting lost	411	40	0.586	0.600
I check traffic information on radio before beginning trips	452	46	0.855	0.860
Willing to take risks on new routes to avoid delays	707	73	0.921	0.928
Willing to take risks on new routes to avoid delays	667	71	0.617	0.624
Willing to take risks on new routes to avoid delays	650	69	0.677	0.685
Suspicious about the delays reported on HMS	506	52	0.919	0.922
Suspicious about the delays reported on HMS	517	48	0.277	0.271
Uneasy about leaving main roads for other routes	401	46	0.359	0.384
Uneasy about leaving main roads for other routes	359	39	0.711	0.722
Enjoy finding new routes to my destination	485	48	0.627	0.642
Enjoy finding new routes to my destination	464	53	0.305	0.325
Comfortable reading, following highway maps	718	73	0.635	0.682
Comfortable reading, following highway maps	714	74	0.989	0.990
Annual Income				
<$20K	9	0	0.332	
$20K - $50K	114	13	0.726	0.751
$50K - $75K	155	17	0.807	0.820
$75K - $100K	180	19	0.934	0.937
>$100K	307	26	0.210	0.228
Education Level				
High School Graduate	41	5	0.725	0.797
Some College	159	21	0.243	0.325
College Graduate	303	25	0.166	0.185
Advanced College Degree	300	32	0.848	0.854

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Robert Michael Robinson is a Senior Project Scientist at the Virginia Modeling, Analysis, and Simulation Center and leads the Center's applied research in transportation. Mr. Robinson joined VMASC in January 2004 as a researcher for the Homeland Defense Modeling and Simulation project funded through U. S. Joint Forces Command (JFCOM). He served as VMASC's Director of Program Advancement/Business Development from October 2005 to October 2007.

Mr. Robinson became VMASC's lead transportation researcher for transportation and evacuation studies in October 2007. Since that time, he has served as the principal investigator or co-principal investigator on six funded projects with total funding of almost $1 million.

He was named to the Commonwealth of Virginia Joint Commission on Technology and Science Transportation Technologies Committee for 2008-2009 and served on the Virginia Elizabeth River Crossing Independent Review Panel in 2009.

Mr. Robinson served for 23 years as a nuclear submarine officer in the U.S. Navy with two tours in command.

EDUCATION

Master of Science	Physics Naval Postgraduate School	Thesis: *Emission Angles for Soft X-Ray Coherent Transition Radiation*
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