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16. Abstract

The Texas Department of Transportation (TxDOT) directed this research project to include development of traffic operations recommendations for hurricane evacuation. This was accomplished largely through reviews of "lessons learned" reports and interviews with staff members of departments of transportation of other states that border the Gulf of Mexico or the Atlantic Ocean and have experience conducting hurricane evacuations. Reviews of state hurricane evacuation plans and associated literature point to many similarities among these states in their approach to evacuations; e.g., most states have some form of contraflow freeway operations. Conversely, few states convert shoulders for evacuation lanes. This document describes findings from among agencies involved in traffic operations practices for hurricane evacuations and offers recommendations for hurricane evacuations in Texas.

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RECOMMENDED PRACTICES FOR HURRICANE EVACUATION TRAFFIC OPERATIONS

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DISCLAIMER

The contents of this document reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge was Andrew J. Ballard, P.E. (Texas #59027).

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CHAPTER 1. INTRODUCTION

Texas has experienced numerous hurricanes which caused significant damage and loss of life. Even prior to the historic 2004 hurricane season in which four hurricanes struck Florida and surrounding states, the State of Texas had developed hurricane evacuation routes and various tools necessary for enhancing evacuation efforts from its coastal communities. Before the end of the 2004 hurricane season, Texas Governor Rick Perry directed that a review of this state's hurricane preparedness be accomplished. This review produced a report (*1*) that identified specific recommendations for improving evacuation and other preparedness aspects.

In addition, the Texas Department of Transportation (TxDOT) directed this research project to include development of traffic operations recommendations for hurricane evacuation. This was accomplished largely through reviews of "lessons learned" reports and interviews with staff members of departments of transportation of other states that border the Gulf of Mexico or the Atlantic Ocean and have experience conducting hurricane evacuations.

Reviews of state hurricane evacuation plans and associated literature point to many similarities among these states in their approach to evacuations; e.g., most states have some form of contraflow freeway operations. Conversely, few states convert shoulders for evacuation lanes.

This document describes findings from among agencies involved in traffic operations practices for hurricane evacuations and offers recommendations for hurricane evacuations in Texas.

CHAPTER 2. POLICY ISSUES

When a hurricane threatens a coastal population, residents and businesses must take actions that deviate from their normal day-to-day practices. Such actions may include employees leaving work early, children leaving schools in the middle of the day, industrial plants shutting down processes, etc. Clearly, emergency responders, including TxDOT, engage in similar responses; however, as an emergency responder, TxDOT does much more. In addition to deploying resources (e.g., staffing emergency operations centers and sending field personnel to take actions at freeway ramps, traffic signals, ferry operations, etc.), an agency like TxDOT needs to have various policies and regulations in place that, in an emergency, give it the flexibility necessary to accomplish the urgent tasks that are required. It is recommended that the following issues be reviewed by TxDOT to determine the best means of incorporating this type of flexibility into its policies so that emergency response can be facilitated.

Provisions for Employees in Emergency Operations

From the time at which TxDOT staff members begin preparing for an evacuation to the time at which the post-storm recovery phase is completed, many staff members will have worked many long shifts. Some staff members will have worked long hours over several days. Some may work in districts different from their home district, and some may engage in tasks that are outside their normal work duties. Emergencies can require that resources, including human resources, be deployed in unusual ways. Since the most important resource a public agency has is its people, it is recommended that TxDOT ensure that staff members who are required to work extended hours without opportunity to return home are supplied with the provisions they need to enable them to accomplish the extraordinary tasks required in an emergency. Such items may include food, beverages, sleeping accommodations, etc. In addition, a policy should be considered that will provide compensation to staff during such extraordinary circumstances.

According to the Texas Attorney General (Tex. Const. art. III, § 51; art. VIII, § 3; art. XVI, § 6(a); Op. Tex. Att'y Gen. No. C-557 [1965]), the Texas Constitution prohibits a state agency from purchasing food that would be consumed by state employees. In recent emergencies, this apparent hurdle to providing the necessary provisions to state employees has been handled by language in the governor's emergency proclamation which states, "*As provided in section 418.016, all rules and regulations that may inhibit or prevent prompt response to this threat are suspended for the duration of the incident.*" This practice is recommended to continue.

State-Issued Communications Equipment

During an evacuation, as seen with Hurricanes Katrina and Rita in 2005, the standard communications systems are overloaded with very high demands. This can be worsened during the hurricane recovery phase, as cellular telephone towers and radio towers may be damaged. To facilitate communications among TxDOT staff and between TxDOT and other critical agencies, it is critical to have redundancy in communications technologies. Land-line telephone systems and cellular telephone systems can become overwhelmed during an emergency evacuation.

The National Communications System (NCS) of the Department of Homeland Security (2) offers several communications features to emergency response agencies. Among these are two services that are designed to push emergency service providers' phone calls through when communication networks are congested: Government Emergency Telecommunications Service (GETS) for land-line phone calls and the Wireless Priority Service (WPS) for wireless calls. Eligible users include senior elected officials, emergency operations center (EOC) coordinators, transportation agency personnel, etc. With WPS, TxDOT would register its critical phones with the commercial telecom provider(s) within the WPS program. The NCS recommends satellite telephones as a backup. Satellite telephones are not dependent upon cellular phone towers; however, they are adversely affected by solar flares, and they require a clear line of sight and therefore are not reliable from indoors. The NCS also offers a Telecommunications Service Priority (TSP) program whereby agencies can register their telephone system and thereby receive priority by the telecommunications carrier when service needs to be restored in the aftermath of an emergency. It is recommended that TxDOT take advantage of GETS, WPS, and TSP. TxDOT should ensure that WPS is provided to all the wireless devices that will be used by critical personnel in the regions susceptible to overwhelmed phone usage.

When familiar communications networks (e.g., land lines and cell phones) can no longer handle the demand for voice calls, very often text messaging can still get through. Consequently, it is recommended that critical personnel be trained in the use of text messaging.

Another communication device that can be effective in this type of emergency is 800 MHz radio. In the Houston area, the Office of Emergency Management and the Sheriff's Office are among several local agencies that use this high-band type of radio. A greater number of these radios among TxDOT staff will facilitate improved communications during evacuation and especially during recovery when typical communications systems may be damaged from the storm.

It is recommended that TxDOT review its complement of cellular telephones, 800 MHz radios, and satellite telephones and evaluate its capabilities to communicate when conventional systems are limited. Such limitations may occur when the cellular telephone systems are overloaded when the evacuating public is consuming system capacity or when conventional systems are unavailable, e.g., during recovery from the hurricane when towers and antennae are destroyed. This review may require increasing the quantity of various communications devices among district personnel.

Currently, TxDOT policy allows districts to replace state-issued communications equipment such as cellular telephones; however, an increase in the quantity of these devices requires approval from TxDOT administration.

Emergency Contracts

Because implementing some elements of an evacuation plan (e.g., contraflow, emergency shoulder lane, etc.) is labor intensive, it may be beneficial to let contracts for tasks that contractors can perform, thereby allowing TxDOT to deploy its in-house staff to other tasks. For example, evacuation plans that require staff members and vehicles to supplement barricades and cones to physically block several entrance ramps necessitate a large number of personnel. The addition of contractors' employees, under an emergency contract, can provide the much-needed additional

human resources. Similarly, emergency repair contracts are needed for the recovery phase of a hurricane event.

It is recommended that annual contracts be let, prior to the hurricane season, to provide the additional personnel and equipment that may be necessary if an evacuation is called and for the repair of infrastructure during the recovery.

Courtesy Patrols

Courtesy patrols provide a department of transportation (DOT) with an excellent positive customer service image. When a courtesy patrol stops and assists a distressed motorist, the DOT is seen in perhaps its most favorable light. In addition to the value that courtesy patrols provide in facilitating traffic flow by getting a stalled vehicle off the road or shoulder, they also contribute greatly to the image of the department. Some states operate courtesy patrols with in-house staff and equipment, and others contract out this service. It is recommended that TxDOT provide for expansion of its courtesy patrol operation during major emergencies. This would add value to the department during major evacuation events as well as enhance routine traffic incident management.

The expansion of courtesy patrol operations may be accomplished either through outsourcing or the addition of in-house patrols. One means of temporarily expanding this service with in-house staff may be through cross-training existing maintenance staff and outfitting maintenance vehicles with necessary equipment and supplies such that they can function as courtesy patrols during an emergency.

511 Travel Information System

As discussed in more detail in a subsequent chapter of this document, the relatively new 511 Traffic and Travel Information telephone system is growing across the nation. It allows motorists to use their telephones to access motorist information on a route-by-route basis. It is recommended that TxDOT deploy its 511 system soon and that it be linked with the existing 211 Community Information and Referral Services telephone system.

Restrictions on Vehicle Types

An evacuation is a trying time for motorists. Where motorists are directed to use unfamiliar lanes (e.g., contraflow or shoulders), the experience introduces unusual features to drivers. In the case of contraflow, there are no or few traffic signs, entrance ramps may be used as exit ramps, motorists encounter “wrong way” messages from pavement markings, etc. To simplify the experience for motorists, it is recommended that vehicles towing trailers and trucks be directed to the normal lanes and be restricted from the contraflow or emergency shoulder lanes.

Such a restriction may require changes to the state law. Currently, the Texas Transportation Code, Sections 545.0651 and 545.0652, allow restriction of trucks from certain lanes; however, restricting passenger vehicles towing trailers will likely require additional legislation.

Budgeting and Staffing

The state's highway system is a complex business involving planning, designing, constructing, maintaining, and operating the infrastructure. In the past, after highways were constructed, they still needed maintenance; however, operating them was a simple matter relative to today's highways. Now, operating the highways is a growing component of this business, as traffic management activities expand. This has often been reflected in the expression that "we can't build our way out of congestion"; i.e., the transportation system must be actively managed. This includes managed lanes, intelligent transportation systems (ITS), incident management, etc.

Operating a transportation network during a hurricane evacuation requires a great deal of coordination, human resources, traffic monitoring, motorist information systems, demand management, and flexibility. With these complexities and the growth of transportation operations, it may be appropriate to separate budgeting for this function from that of maintenance.

During the preparation for a hurricane, TxDOT staff members follow a prescribed sequence of steps associated with Operational Conditions (OPCON) 1 through 5. These extend over several days. Then, following the arrival of the hurricane, there are many consecutive days in which staff members are on active duty. Such ongoing work requirements suggest that TxDOT review its policies for standby pay and overtime pay, as well as its overall staffing levels for critical positions during emergencies.

CHAPTER 3. CONTRAFLOW

Among the states subject to hurricane threats, the evacuation toolbox's major feature is some form of contraflow. Most of these plans call for operating the four-lane divided controlled-access highway such that traffic in all four lanes is traveling away from the coast toward inland destinations where the dangers posed by the approaching hurricane are significantly reduced. The terminology for this varies among the states, with the most common term being "contraflow." Other terms include "lane reversal" and "reverse laning." A variation on this concept exists where one of the two coast-bound lanes is reversed so that it carries inland-bound traffic while the remaining lane continues to carry traffic toward the coast (*3*). In South Carolina, this is termed "counter flow." South Carolina also employs "counter flow" on limited-access expressways including US 17, US 21, and US 501.

The only implementation of hurricane evacuation contraflow on a limited-access expressway is a 23-mile segment of US 501 in South Carolina. This operation began outside of Myrtle Beach, South Carolina, and carried evacuees through two very small towns and terminated near Marion, South Carolina. The State's US 501 contraflow plan calls for staffing 26 intersections with 180 persons per 24 hours, i.e., 60 persons per eight-hour shift. With regard to equipment, South Carolina uses flip-down signs at intersecting streets requiring cross-street approach traffic to turn onto US 501 in the direction of evacuating traffic. Additionally, "approximately 1000 cones and other safety equipment" are deployed.

One of the most critical features of a contraflow lane is its inland terminus. Clearly, it is important to ensure that the traffic on the highway, which now has twice the number of inland-bound lanes as it normally carries, is distributed in a way that does not create a bottleneck. The typically recommended design to accomplish this is by terminating the contraflow at a freeway interchange with direct connect ramps, as Figure 1 depicts the inland terminus of I-64 in Richmond, Virginia (*4*). In this example, the inland-bound (westbound) traffic is required to exit onto the intersecting I-295; downstream of this exit, Virginia DOT has constructed a crossover that allows the contraflow traffic to move onto the normal inland-bound lanes. Beyond (west of) this interchange, the freeway operates with normal eastbound and westbound traffic flows. An issue with this type of contraflow terminus is the likely unavailability of sufficient capacity in the interchange under typical daily conditions. The very nature of a destination city is that it is operating with "business as usual" unlike the communities that are evacuating. This means that its public is likely utilizing its roadway lanes in its usual manner. Virginia DOT is evaluating the impact that background traffic will have on this interchange during a contraflow operation. They are considering closing government offices and public schools early in order to reduce local trips at the interchange and within the community.

Mississippi DOT employs another type of inland terminus on its contraflow operation on I-59 between the Louisiana state line and Hattiesburg, Mississippi. As shown in Figure 2, the contraflow lanes merge into a single lane, and the normal inland-bound lanes also merge into a single lane. The contraflow traffic then uses the crossover to enter the left inland-bound lane (*5*). The merging of four lanes into two lanes, of course, produces congestion and is not recommended unless the traffic demand has been reduced by motorists' exiting at upstream interchanges.

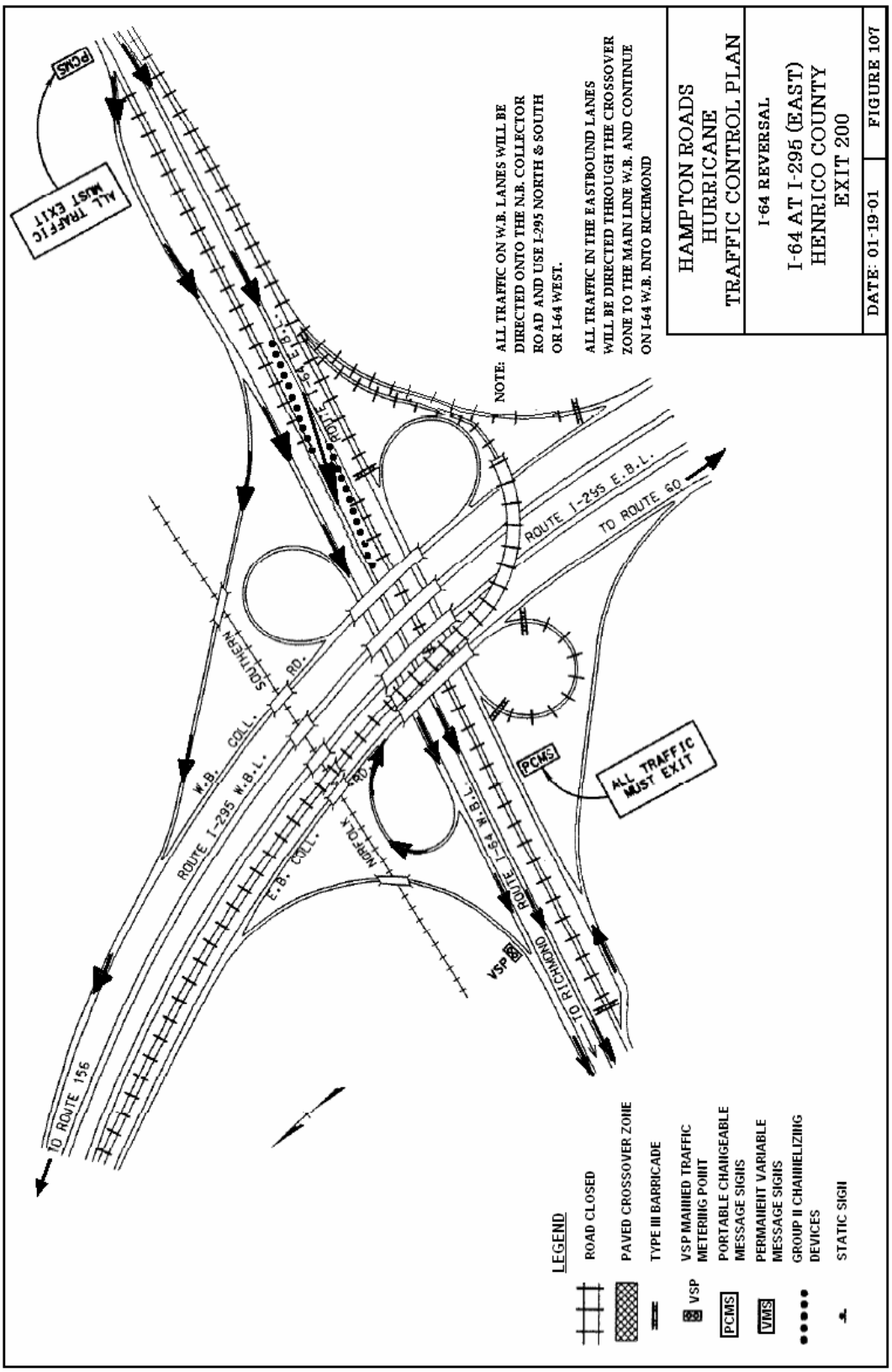

Figure 1. Inland Terminus via Crossover and Direct Connect Ramps (Adapted from *4*).

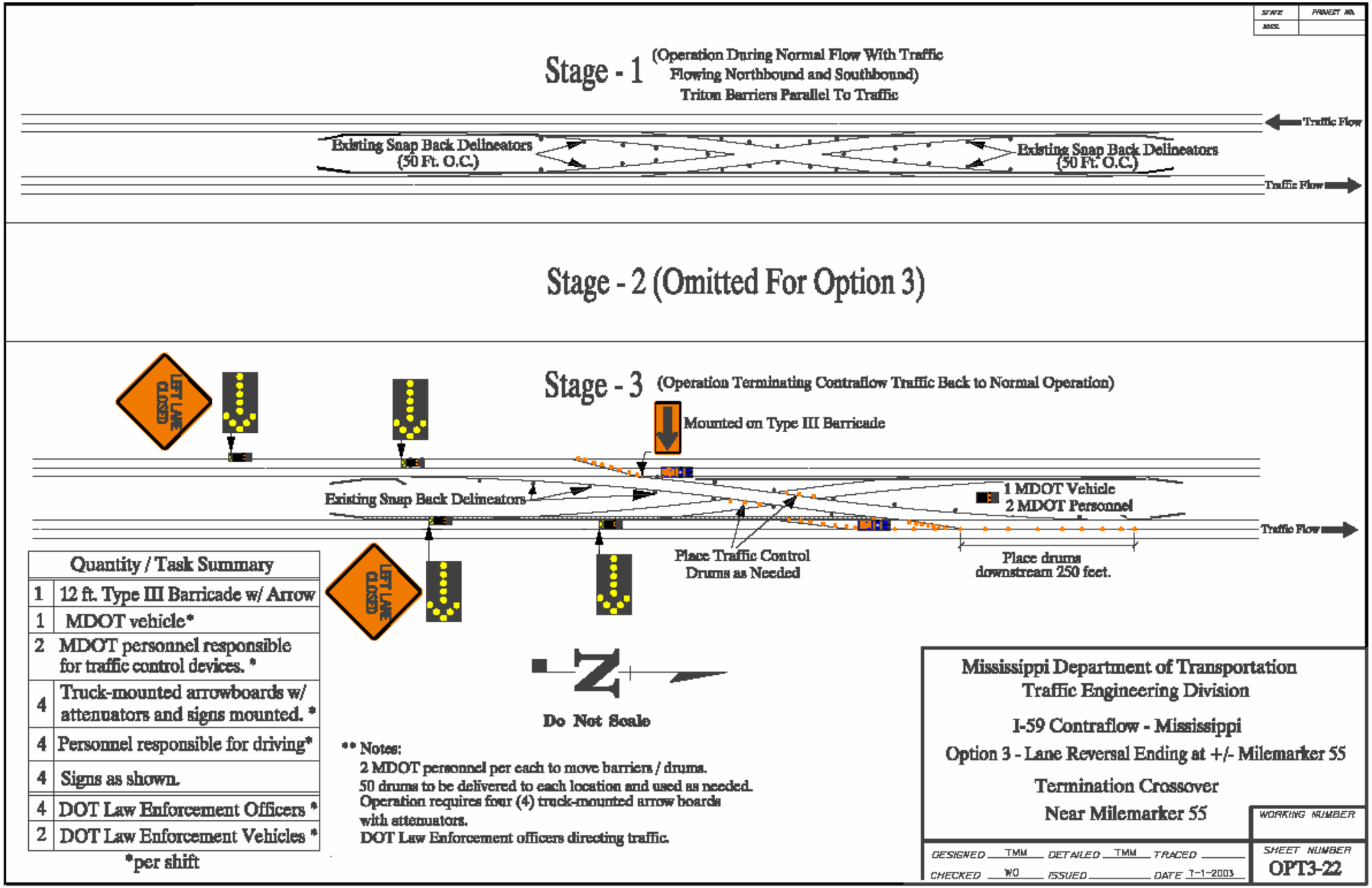

Figure 2. Inland Terminus via Crossover and Merge (Adapted from 5).

In 2004, Alabama deployed contraflow operations on I-65 for Hurricane Ivan. The intent was to commence operations when traffic flows reached a predetermined threshold. However, the public and elected officials were anxious to use it, and the Alabama DOT consequently began its contraflow operation in response. This led to a policy change in which the DOT now has a schedule-based contraflow plan in contrast to a traffic response-based contraflow plan. The schedule-based plan allows the DOT staff to better prepare and operate the plan in the safer daylight hours rather than risk nighttime operations. Alabama also made a change to its crossovers in the contraflow plan. Prior to its first operation in 2004, four crossovers were constructed throughout I-65 with the intent of allowing traffic to balance itself if one side of the highway became much more congested than the other. Although the DOT staffed each crossover in preparation to open them, they found that they did not need to do so. The new plan now eliminates the crossovers and allows the staff members to be used elsewhere (*6*, *7*).

Another lesson learned in Alabama relates to the public service message regarding contraflow. Because the implementation of contraflow operations is time consuming, Alabama DOT's plan called for closing the coast-bound lanes at 6 a.m. and allowing inland-bound traffic into those lanes at 8 a.m., thereby giving them two hours to clear the lanes of coast-bound traffic. Unfortunately, the message that went to the public was such that some motorists believed that 6 a.m. was the start time. Motorists began gathering at the entrance to the contraflow two hours earlier than the 8 a.m. start time. Although these motorists could evacuate via the normal inland-bound lanes, they were upset that they could not use the contraflow lanes (*6*).

Florida does not install static signs for contraflow traffic. They accomplish traffic control with highway patrol officers who are posted at the coast-bound ramps to prohibit inland-bound motorists from exiting the contraflow lanes along the route except at the contraflow terminus (*8*).

Virginia also does not install static signs along the contraflow route. They communicate with motorists using portable changeable message signs (PCMSs) and law enforcement personnel. The controlled-access highway from Hampton, Virginia, toward Richmond is an 80-mile contraflow operation. Because Virginia DOT considers this to be a lengthy trip at potentially low speeds, the trip may take a long time. Therefore, they designed two intermediate interchange opportunities along the way. PCMSs are used to inform contraflow motorists that they are approaching an exit and that services are available (*9*).

Contraflow operations require coast-bound entrance ramps to be closed. Georgia (*10*) uses permanently installed railroad-type gates on both sides of the ramp to assist in this task, as shown in Figure 3. The gates are located behind existing roadside barriers where possible, to minimize occurrences of motorists' driving around them. As illustrated in Figure 4, these gate pairs are located at each end of the ramp and supplement the law enforcement officer located at the ramp entrance (*11*). Upon completion of these ramp closures, state police must flush the lanes (i.e., drive the coast-bound lanes) to 1) ensure that all traffic has left the lanes, including stalled vehicles, and 2) visually ensure that all the ramps are indeed barricaded and staffed. Texas' plan for I-37 accomplishes this task by assigning separate officers to the northern and southern reaches of the highway and simultaneously flushing each, thereby decreasing the time required to prepare for contraflow traffic (*12*).

Figure 3. Drop Gate Barricade at Entrance Ramp in Georgia (*10*).

Because of the unusual nature of motorists operating in lanes that are temporarily contraflow, there is some concern relative to the minimal amount of traffic control devices available for these motorists, the limited, or non-existent, intermediate opportunities for motorists to exit the highway, etc. Therefore, North Carolina (*13*) and Alabama (*6*) plan to operate contraflow only during daylight hours. Conversely, South Carolina operated its contraflow operation during 2004's Hurricane Charley evacuation from 8 p.m. to 7 a.m. (*14*), and in Texas the I-37 contraflow plan does not rule out nighttime operation (*12*, *15*).

Associated with the issue of daytime versus nighttime operation is the timing of the call for evacuation. Conceptually, each community's unique characteristics (e.g., population, highway network, etc.) dictate the amount of evacuation time that is required. Consequently, the timing of the call for evacuation must occur no later than the specified number of hours before the onset of tropical storm force winds arrive. A call that occurs later than this threshold will result in some occupants of the community being unable to evacuate. The thresholds for each community have been pre-determined. If the evacuation plan includes contraflow and the policy is to operate contraflow only during the daylight hours, then the timing of the call for evacuation needs to

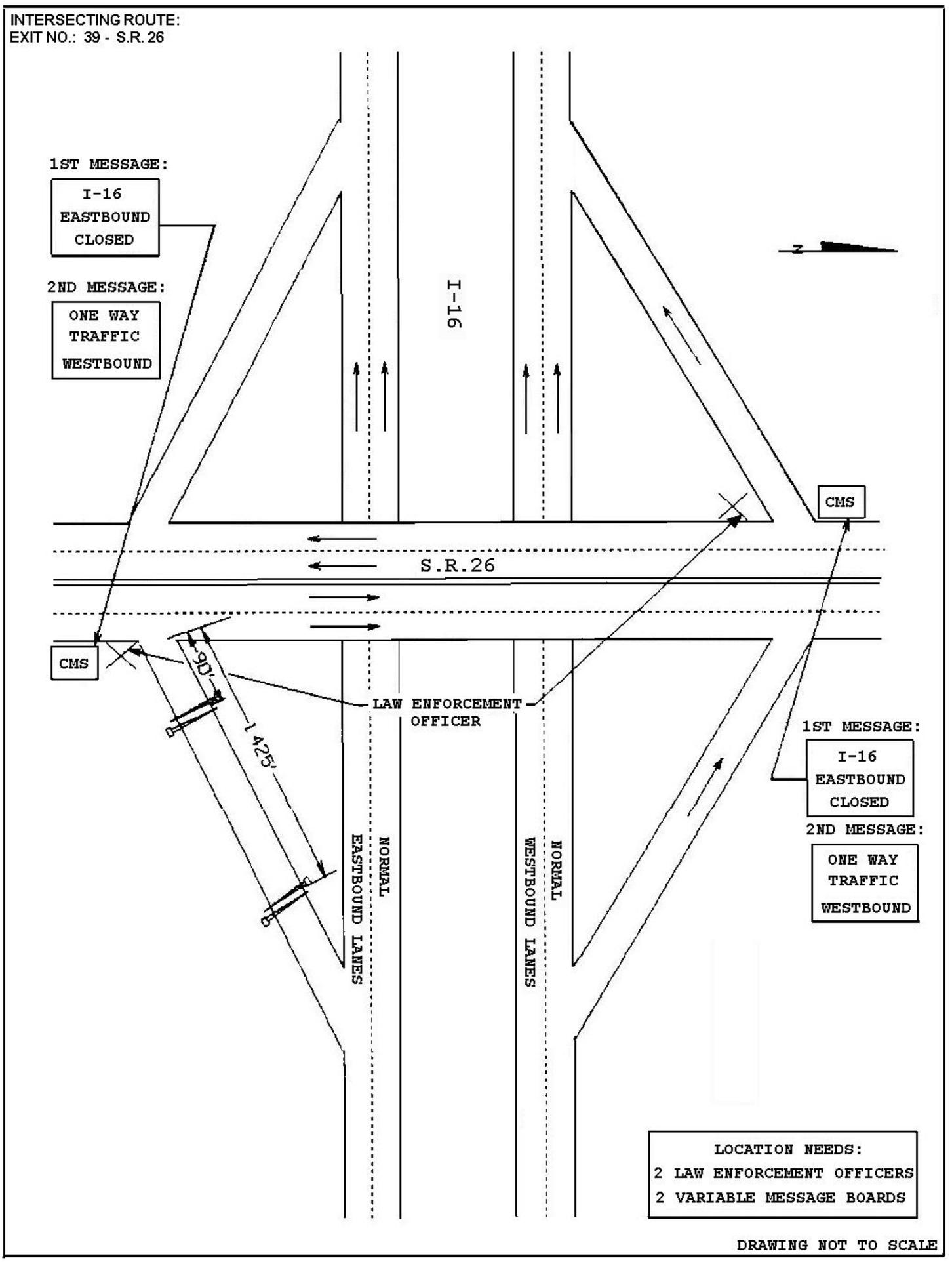

Figure 4. Gate and Officer Locations on Georgia's I-16 (11).

provide sufficient time to ensure that the contraflow operation occurs during the daylight hours. The effect of this may result in moving up the timing of the call for evacuation. Of course, the more hours there are between the call to evacuate and landfall, the greater the possibility that the hurricane can change its course and thereby affect the need to evacuate particular communities. In the case of a very large community (e.g., Houston), the benefits of operating contraflow only in the daylight may not be sufficient to justify scheduling the call for evacuation earlier.

Some states (*16*) allow contraflow traffic to enter and exit from the contraflow side of the highway at several interchanges; however, most states restrict this frequent type of access. Virginia DOT disallows re-entering into the contraflow lanes after exiting them; this policy is borne out of concerns with the introduction of unnecessary safety variables, e.g., left-hand merging, etc. (*17*).

Interstate highways have milepoint markers and numbered exit ramps. During evacuation operations on these routes, aerial surveillance may be assisted by the installation of horizontal signing on the ramps indicating to overhead observers the exit number associated with the ramp, as shown in Figure 5. This feature would not be applicable to non-interstate highways which do not have similar numbered reference markers that are identified in the field.

Figure 5. Temporary Mile Marker for Aerial Surveillance (*18*).

To provide contraflow motorists with information regarding their route, some states have installed flip-down signs on the contraflow side. Figure 6 illustrates South Carolina's use of a flip-down sign.

Figure 6. Flip-Down Sign on Contraflow Route in South Carolina (*18*).

During the Houston and Galveston evacuations for Hurricane Rita in 2005, a well-documented enormous traffic jam occurred on several routes, with traffic traveling at speeds as slow as one or two miles per hour for a dozen or more hours. As officials flushed the coast-bound lanes in preparation for initiation of contraflow on controlled-access highways, many motorists opted to cross the median to enter the contraflow lanes and travel in the inland-bound direction as contraflow vehicles. Unfortunately, others crossed the median to gain access to the coast-bound lanes in an effort to return home after hours of frustration in exceedingly slow-moving traffic. Clearly, this combination of vehicles traveling in both directions on the same lanes is extremely hazardous. This phenomenon was not reported in other states, presumably because the speeds during evacuations were not so low as to motivate frustrated motorists to engage in these types of maneuvers. Consequently, it may be necessary to add a positive barrier in medians on contraflow facilities to prevent head-on collisions related to unauthorized median crossings.

The following are recommendations concerning contraflow:

- When feasible, operate contraflow during daylight hours (*3*, *7*).
- Quantify the required lead time prior to initial operation of the contraflow and emergency shoulder lane plan so that the "go/no go" decision can be made early enough to allow setup time for these exceptional operations.
- Restrict trucks to non-contraflow lanes (*16*).
- Establish criteria for implementing the contraflow plan.
- Establish criteria for shutting down the contraflow operation.
- When contraflow is operating, ensure that DOT and local agencies, especially emergency services agencies, understand which alternate routes are available for accessing the coastal communities (*3*).
- Install horizontal signing with exit numbers on exit ramps on contraflow routes to facilitate communications between aerial observers and EOC personnel (*16*).
- Display mile markers on front and back on the contraflow route (*16*).
- Automated traffic recorders on coast-bound lanes must be configured to collect volume data for traffic flows in normal and contraflow directions.
- Use flip-down signs for detours necessary where contraflow is in operation.
- For contraflow operations, completely close coast-bound entrance ramps with barricades and on-site personnel. For lengthy contraflow operations (e.g., more than 50 miles), it is recommended that contraflow traffic be allowed to exit the highway to access public services, e.g., restrooms, fuel stations, etc., at a limited number of locations along the evacuation route. Motorists that exit the contraflow lanes may not re-enter but may enter the normal inland-bound lanes.
- An alternative to closing most intermediate exit points is to allow contraflow traffic to depart the freeway at most, or all, interchanges. This option requires law enforcement and DOT personnel at each interchange. Additionally, this type of operation is improved if the contraflow side has two-sided mile markers and flip-down signs with exit numbers and destination signs (*16*).
- If background traffic can be minimized, it is best to terminate contraflow operations at an interchange with another controlled-access highway where the two normal inland-bound lanes are forced onto the intersecting highway via normal ramps, and, downstream of this point, the contraflow traffic is crossed over to the normal inland-bound lanes (*16*, *19*).
- Install a positive barrier in the median on highways with contraflow to prevent unauthorized crossovers.

CHAPTER 4. EMERGENCY SHOULDER LANE

An emergency shoulder lane for hurricane evacuation is where, during an evacuation, traffic is allowed to travel inland on the shoulder as well as the adjacent travel lanes. Most states do not include shoulder lanes in their plans. Reasons for this include the following:

- Shoulders are needed for stalled vehicles.
- Law enforcement and courtesy patrol vehicles need to use shoulders for rapid access.
- Shoulders are discontinuous primarily because of older bridges that do not have shoulders.
- Pavements are not structurally adequate.
- Shoulder cross slopes are too dissimilar from the adjacent lane.

Texas and Florida each include an emergency shoulder lane on one evacuation route. In Florida, I-75 south of Sarasota has three northbound lanes. South of this area, there are only two northbound lanes for a 21-mile distance beginning in Port Charlotte. Florida DOT operates a hurricane evacuation emergency shoulder lane on this 21-mile segment, thereby temporarily extending the three-lane section between Port Charlotte and Sarasota (*20*).

Texas includes an emergency shoulder lane on I-37 from Corpus Christi toward San Antonio (*12*). The emergency shoulder lane is to be opened in two stages. The plan calls for the left shoulder to be opened to traffic in the urban portion of the plan, which is generally within the city limits of Corpus Christi, during the window that is 36 to 48 hours prior to the onset of tropical storm force winds. In the subsequent 12 hours, the right shoulder lane may be opened in the rural portion, which extends from the US 77 interchange (north) toward San Antonio and terminates at the SH 72 exit. The interface between the urban and rural sections requires DOT personnel to apply temporary lane transition markings since the shoulder employed in the plan shifts from the left shoulder (urban) to the right shoulder (rural). At the inland terminus, the shoulder traffic is forced off I-37 via the exit ramp, which leads to a stop-controlled intersection. Traffic bound for San Antonio turns left, and traffic bound for Austin turns right. Figures 7 and 8 illustrate the associated signs and pavement markings. The signs are placed at wide intervals along the highway. To initiate traffic use on the shoulder, the panel on the right side of the sign, which reads, “X Shoulder for Emergency Use Only” is removed, revealing a “through” arrow and a legend that reads, “Shoulder Open to Traffic,” indicating that the shoulder is available.

One of the advantages that emergency shoulder lanes have over contraflow lanes is time. Unlike contraflow, there is no need for law enforcement personnel to flush lanes, a task that can take hours depending on the length of the highway with contraflow. Once the emergency shoulder lane begins operation, it can continue until traffic demands are exhausted instead of being subject to a time limit, as some states have with their contraflow operations. Additionally, emergency shoulder lanes require much less staff resources from the DOT and the Department of Public Safety (DPS) during the evacuation.

Figure 7. I-37 Emergency Shoulder Lane Sign.

In Corpus Christi, Texas, the hurricane evacuation plan calls for the use of emergency shoulder lane operation on I-37 until the EOC terminates it or until the contraflow plan is implemented (*12*). The DPS captain in the Corpus Christi District will make the call to switch from the emergency shoulder plan to the contraflow plan, based on traffic and storm conditions. The intent is to not operate the emergency shoulder lane concurrently with contraflow; however, it is reasonable to assume that as long as the traffic demand remains for the emergency shoulder lane, it may be impractical to terminate it (*15*).

The following are recommendations concerning emergency shoulder lanes:

- Quantify the required lead time prior to initial operation of the emergency shoulder lane plan so that the "go/no go" decision can be made early enough to allow setup time.
- Restrict trucks and trailers to non-shoulder lanes.
- Establish criteria for implementing the emergency shoulder plan.

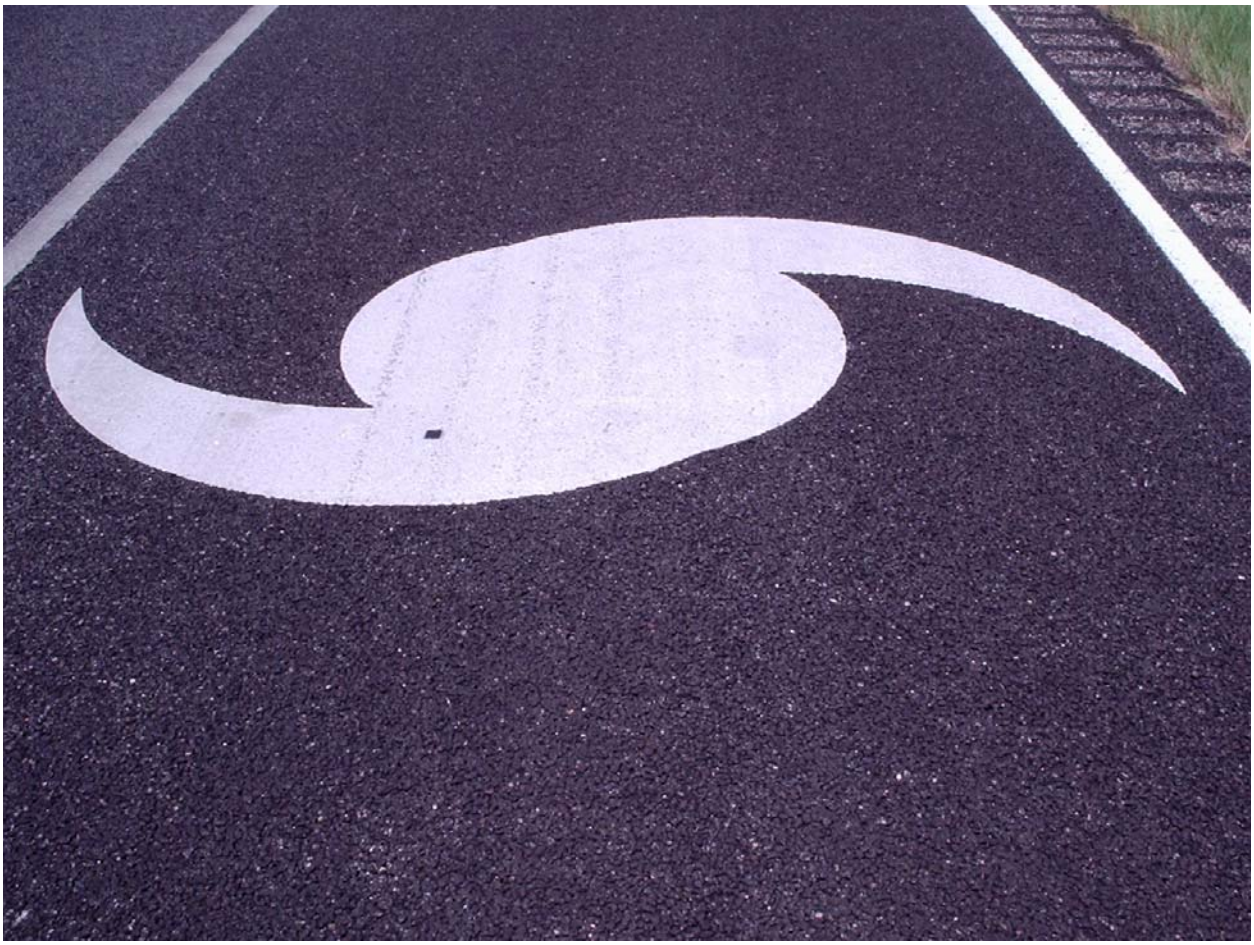

Figure 8. I-37 Emergency Shoulder Lane Pavement Marking.

CHAPTER 5. TRAFFIC SIGNALS

Florida is considering permanently installed generators located at major signalized intersections (*21*). Permanently located generators provide the benefit of not having to consume time and labor required to deploy a portable generator. Additionally, because such a generator is more securely situated than a generator chained to a pole, there is less likelihood of it being stolen in the storm's aftermath when the public's demand for generators is extremely high. The drawback to permanent generators that are rarely needed is the maintenance commitment required to ensure that they will function when they are needed. Florida's 2004 experience notwithstanding, the nature of hurricanes has been that any given community rarely experiences multiple hurricane-induced power outages within a small number of years. Consequently, it is unlikely that any given signalized intersection on the Texas coast will lose power for a period of days very often.

One state reported a theft problem with portable generators at traffic signals where a thief plugged his electric saw into the generator and then cut the chain that was used to secure the generator to the site; he then stole the generator. One remedy for this problem might include developing a lockable cage that is larger than the generator so that a thief could not reach the electrical outlet with the cord of his electric saw. Alternatively, it may be possible for a generator to be designed such that it is not susceptible to this type of theft.

The use of generators for operating traffic signals in the aftermath of a hurricane can introduce issues of refueling at a time when fuel is likely to be in scarce supply. Ideally, a power supply (e.g., solar panels) that does not require continual refueling is desirable; however, the solar power technology that is currently available is not adequate to operate a signalized intersection in a cost-effective fashion.

When a traffic signal's power goes out, motorists are required by law to treat the intersection as if it were an all-way stop-controlled intersection. However, experience shows that many motorists are not sure how to behave in this situation. Some agencies install portable stop signs to supplement the message to approaching motorists. In the hectic aftermath of a hurricane, this can be a burden on limited human resources available. Unfortunately, the alternative of not providing portable stop signs, particularly for nighttime operations, can lead to traffic control devices with insufficient target value. When the portable signs are put into place, the traffic signal controller should be set to ensure that when power is restored the signal operates in the flash mode that displays red to the approaches with the portable stop signs and yellow to those that do not have these signs. Because technicians from other districts, who are not familiar with the site-specific signal equipment, may be dispatched to the region after the hurricane, it is important that accurate flash mode documentation is kept in the controller cabinet, particularly for intersections of two major routes where it may not be apparent which route is the one that is to receive the yellow indications.

Florida (*21*), in the aftermath of the 2004 hurricane season, allows districts to remove signal heads if they meet the following criteria:

1. sufficient resources are available to accomplish task and
2. their absence does not impact evacuation efforts or public safety.

The benefits of signal removal include the following:

1. signal heads that could have been destroyed are saved,
2. the removal made heads available for immediate reinstallation,
3. absent heads saved empty disconnects from damage,
4. the removed weight of heads in conjunction with span tightening saved the intersection, and
5. the removal allowed the signal to be returned to operation sooner.

The disadvantages of their removal include the following:

1. liability with respect to crashes;
2. unnecessary if the hurricane changes track; and
3. in cleanup, removed heads may be assumed to have been damaged and subsequently replaced by contractors.

To facilitate evacuation on non-controlled access highways, some states (*14*, *22*) provide law enforcement personnel with the capacity to operate traffic signals manually. Mississippi installed "stop-time" switches along its evacuation routes to facilitate movement on the heavy approaches. Reportedly, stop-time switches are applicable for 2070 controllers at split diamond interchanges.

It may be beneficial to develop evacuation traffic signal timing plans, as Virginia DOT has done (*9*) and the City of Norfolk, Virginia, is currently doing (*23*). This may reduce the demand for law enforcement personnel at signalized intersections (*21*). Perhaps stop-time switches and law enforcement personnel can be deployed to the more critical routes, and evacuation signal timing plans can be applied on other evacuation routes.

Although much of the signalized infrastructure in Florida was wind-load rated, that state found that its signal head hangers were a weak link in 2004 hurricanes. They are therefore revising their design standard (*16*).

In the aftermath of a storm, relief efforts often include calls to other state and local agencies from outside the affected areas. This can be supplemented by establishing emergency response contracts with traffic signal construction and maintenance contractors. Since contractors are typically under contract with multiple agencies, it is also necessary to arrange with other public agencies such that signal contractors can be temporarily released from routine work elsewhere in favor of emergency response work in the hurricane damaged area. This may be accomplished by encouraging other agencies to include "time suspension" clauses in their contracts or other mechanisms to relieve contractors from liquidated damages so they can assist in emergency response.

If signal heads are removed, it is important to document the intersections where this is done so that after the storm, as damage assessment teams are observing missing equipment, there is no mistake regarding what happened to the heads.

Because hurricane damage may result in long-term road closures, as in the notable case of the I-10 causeway in Pensacola, Florida, in 2004, there can be significant detours. The DOT should be prepared to develop signal timing plans based on extraordinary traffic patterns (*21*).

The following are recommendations concerning traffic signals:

- Review design standards for transportation infrastructure, including freeway signing, traffic signal spanwire and mast arm designs, video imaging vehicle detection systems, intelligent transportation systems cameras, lane control signals, etc., to ensure sign and signal infrastructure in coastal communities can survive hurricane-force winds (*21*).
- Prioritize key intersections for repair after the storm (*24*).
- Deploy generators to the most critical signalized intersections (*21*).
- Develop a cage for the generator that must be unlocked to plug an electrical device into the generator, thereby thwarting thieves who would use its power to cut the generator free.
- Ensure that existing controller cabinets on major routes are equipped with an accessible power panel for the generator. Ensure that specifications for new cabinets accommodate this feature.
- Develop a plan for refueling generators and develop options for occasions when fuel is unavailable for extended periods of time and/or sufficient numbers of refueling personnel are unavailable.
- Require light-emitting diode (LED) signal heads to minimize power consumption. Assign higher priority to high-volume highways nearer the coastal communities (*21*).
- Consider instituting stop control when needed until power resumes and signals are operational (*21*).
- Retime signals in aftermath where damage closes a major road, thereby significantly altering traffic patterns (*21*).
- Prior to the emergency, develop emergency response contracts with traffic signal construction/maintenance contractors (*21*).
- Consider a policy regarding temporary signal head removal prior to the storm.
- Consider replacing spanwire signals with mast arm signals on major routes so that storm damage potential is reduced.
- Install stop-time switches at all major interchange traffic signals that are capable of operating with them; stop-time switches are toggle switches that allow law enforcement officers to manually control signals.
- Ensure signals on evacuation routes have switches that allow operators to give priority to the evacuation traffic approach with flashing yellow displays while all conflicting movements receive flashing red.
- Train staff in signal damage assessment and documentation procedures required by the Federal Highway Administration (FHWA) and the Federal Emergency Management Administration (FEMA).

CHAPTER 6. MOTORIST INFORMATION

Typically, evacuation routes extend into rural areas where ITS devices (e.g., dynamic message signs [DMS]), cameras, etc.) are usually not located. A notable exception is the recent installation of DMSs on I-10 between Houston and San Antonio. There are several means of providing information to motorists at critical points in such areas. Flip-down signs can be used to direct motorists to alternative hurricane evacuation routes where this may be desirable. Of course, flip-down signs have the advantages over PCMSs of being low-cost items, and they are already in place and therefore do not require programming during the busy pre-evacuation preparation time. Conversely, PCMSs have the advantages over flip-down signs of increased target value and customizable messages, and they can be used for various special events unrelated to the hurricane evacuation over the service life of the PCMS.

North Carolina opted for widespread use of PCMSs over flip-down signs because of the advantages listed above. In addition, they are not concerned about wind damage to the PCMSs because their policy is to cease evacuation support two hours prior to the onset of tropical storm force winds. This allows field crews the time required to secure the PCMSs out of harm's way (*13*).

Other means of communicating with evacuating, and re-entering, motorists include highway advisory radio (HAR), Wizard CB, and 511. HAR is well documented as a tool for communicating to motorists who tune in to the designated radio frequency. HAR has a limited range of 3 to 5 miles. Motorists are advised of the existence of the HAR and the specific radio frequency by the use of static highway signs. Wizard CB (*13*, *25*) has been used to deliver HAR-type messages over a citizens band radio channel which is commonly monitored by commercial vehicle operators. North Carolina plans to use Wizard CB at the Port of Wilmington to advise truckers of hurricane evacuation route availability and also to tell them that trucks are prohibited from choosing the contraflow lanes on I-40 but can use the normal lanes.

An increasing number of states have begun implementing the 511 Traffic and Travel Information telephone system. The system is advertised via roadside signs as shown in Figure 9. Motorists can dial 511 to listen to recorded messages providing current information for specific routes and roadway segments, including anticipated travel delays, traffic accidents, roadway blockages, and lane closures. In a hurricane evacuation or re-entry, this is particularly useful in providing current information. In the immediate aftermath of Hurricane Katrina's striking Florida, the following messages were disseminated audibly to 511 callers who requested information for U.S. Highway A1A in Miami-Dade County and Florida's Turnpike in Broward County, respectively:

> *"Debris, not only tree limbs but sand and flooding, is going to be your biggest concern on Collins Avenue, A1A. You are advised not to travel on this roadway. You'll also find traffic signals down and malfunctioning. Should you encounter an intersection with no traffic signal, treat it as a four-way stop."*

> *"Florida's Turnpike in Broward County. . . . Keep an eye out for debris as we have plenty of debris on the turnpike . . . The turnpike has lifted all tolls in Broward County. Actually tolls have been lifted through mile marker 263 in the vicinity of Orlando."*

Figure 9. Motorist Information Sign for 511 System.

Florida DOT's Orlando District (*8*) reported that the 511 system was an asset in the 2004 season. Because the system is designed to be very flexible, the DOT inserted a "floodgate" message at the front end of the branching menu that normally is presented to callers. The floodgate message can provide some overriding message regarding evacuation or re-entry that all motorists should hear. If they want to receive additional information on this subject, they are then directed to select a particular numeric code; otherwise, they are presented with the normal 511 menu (*17*).

A telephone number that was useful during Hurricane Rita in Texas was 211, which provides community information and referral services. As of 2005, approximately half of the U.S. population, including all of Texas, had 211 service coverage. This service typically brings the caller into one-on-one contact with an information and referral specialist, who helps the caller find services related to such things as housing, clothing, immigration, job search, support groups, vaccinations, etc. Transportation topics account for less than 10 percent of 211 calls. During Hurricane Rita, TxDOT provided information useful to evacuees to the 211 operators. This produced positive feedback to both TxDOT and the 211 system. Because many of the evacuees can be expected to need both traffic information (511) and human services information (211), it is recommended that the 511 system being developed in Texas provide an option to link callers to the 211 system.

DMSs are used by most states that have hurricane evacuation plans. The messages vary among communities. In Orlando, the DMSs display a phone number that motorists can use to find lodging (*8*). The DPS in Corpus Christi, Texas, promotes using DMS and PCMS messages to direct motorists to tune in to appropriate radio frequencies for evacuation-related messages, in contrast to displays of specific shelter information (*15*).

Evacuees can benefit from motorist information on websites. Initially, this is beneficial to the public before they begin their trip. After they have begun their evacuation trip, website information is helpful for motorists with computers equipped with wireless fidelity (Wi-Fi) technology. TxDOT is currently installing this technology at all its rest areas and welcome centers. This installation also includes kiosks for those travelers who do not have their own laptop computers or similar devices (*26*).

Persons who search the Internet for hurricane evacuation information may opt for various websites. Consequently, it is important to link the DOT evacuation information to likely alternative websites, e.g., Department of Public Safety, Governor's Division of Emergency Management, local municipalities and counties, police and sheriff's offices, and local broadcast media websites. It can be expected that during an emergency such as an evacuation, websites will be in very high demand. This can overload the website's capacity and effectively shut down the website. Consequently, steps should be taken to minimize the bandwidth requirements for such times.

Houston's TranStar website (*27*) includes a real-time traffic map for Houston, as shown in Figure 10, which provides meaningful information to the public to assist them with decisions related to their evacuation trip. Figure 10 illustrates conditions at one point during the Hurricane Rita evacuation. In addition, users of the TranStar website can access a page where they can select the name of the route, the direction of travel, and the limits of the segment of interest, and the site will display current and historical speeds in graphical form as shown in Figure 11. Users can assess the degree to which evacuation traffic is building or receding. The site also provided specific hurricane links for users seeking transportation information relative to Hurricanes Katrina and Rita. These data are available to everyone via the Internet.

South Carolina (*28*) and Florida (*29*) operate permanent data collection stations that feed speed and volume data to their traffic management centers (TMCs) and/or EOCs and to the general public. Each website displays a statewide map, as shown in Figures 12 and 13, that graphically shows which data collection stations are updated on an hourly basis. When the user selects one of the hourly updated sites, a table is displayed showing the recent data and the historical average for that hour. Even more meaningful to the evacuating motorist is the display of the average speed. Both states' websites also display these data graphically (Figures 14 and 15). Figure 14 displays conditions during Hurricane Ophelia in 2005. Figure 15 was captured during Hurricane Katrina's earlier visit to Florida prior to its devastating strike against Louisiana and Mississippi.

Louisiana's evacuation plan includes contraflow operations on three interstate highway routes: I-10E, I-10W, and I-55. For Hurricane Katrina in 2005, the Louisiana Department of Transportation and Development operated its plan which directed thousands of evacuees from New Orleans to Baton Rouge and beyond into Texas. TxDOT displayed shelter information on

DMSs as Hurricane Katrina evacuees traveled on I-10 from Beaumont to Houston and in the metropolitan Houston area. In addition, TranStar staff provided Houston-area shelter information to the TxDOT Travel Information Center in Orange, Texas, near the Louisiana state line, to give to westbound evacuees entering Texas.

The following are recommendations concerning motorist information:

- Disseminate motorist information via HAR. Install static signs informing motorists of the HAR frequency.
- Create a 511 Motorist Information Services telephone system whereby callers can receive dynamic traveler information. Link this service with the existing 211 Community Information and Referral Services telephone system. Install static 511 signs along evacuation, and other, routes advertising the existence of the service (*16*, *21*).
- Deploy DMSs at critical decision points along evacuation routes, preferably where this technology will have multiple traffic uses beyond only hurricane evacuation.
- Where DMS is not feasible, install flip-down signs and/or PCMSs for hurricane evacuation messages.
- Develop statewide guidelines for the use of DMSs during hurricanes (*21*).
- Provide motorist information via press releases, brochures, posters, commercial traffic services, and websites (*16*).
- Provide a hurricane season guide annually as an insert through all daily newspapers in coastal communities to include hurricane preparation tips, evacuation routes, surge zone maps, shelter sites, web addresses, phone numbers, weather radio stations, etc. (*14*).
- Link the DOT road closure webpage to websites of various partners, including the Department of Public Safety, Division of Emergency Management, local municipality and county, traffic management center, local law enforcement, and local broadcast media.
- Disseminate motorist information at welcome centers, rest areas, and temporary comfort stations (*16*, *30*).
- Provide DOT staff members at welcome centers to assist with motorist information (*30*).
- Establish a website that shows current and historical hourly traffic volumes and speeds at various locations on evacuation routes, thereby allowing officials and the public to gauge traffic congestion on an hourly basis.

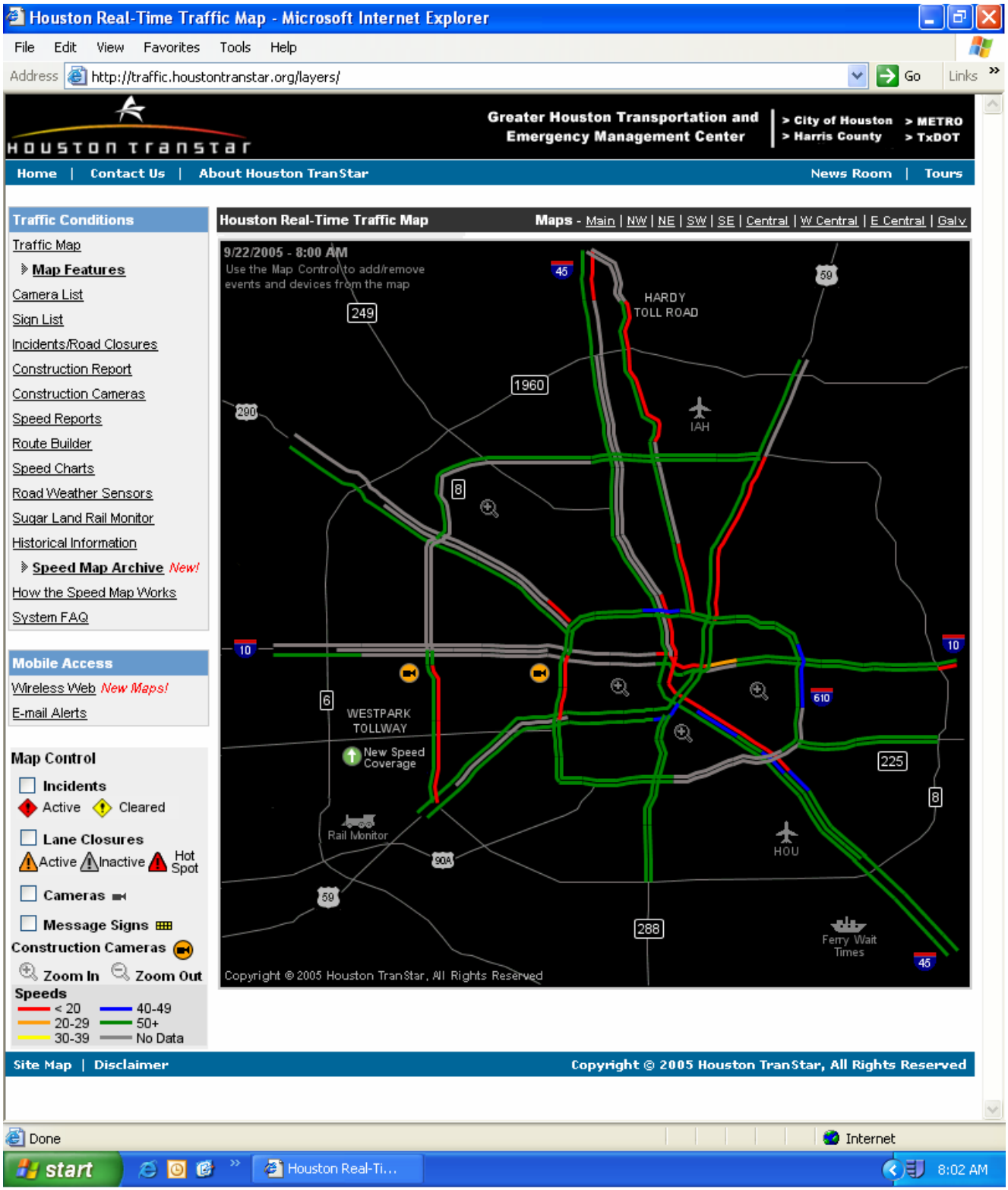

Figure 10. Houston's TranStar Real-Time Speed Map (27).

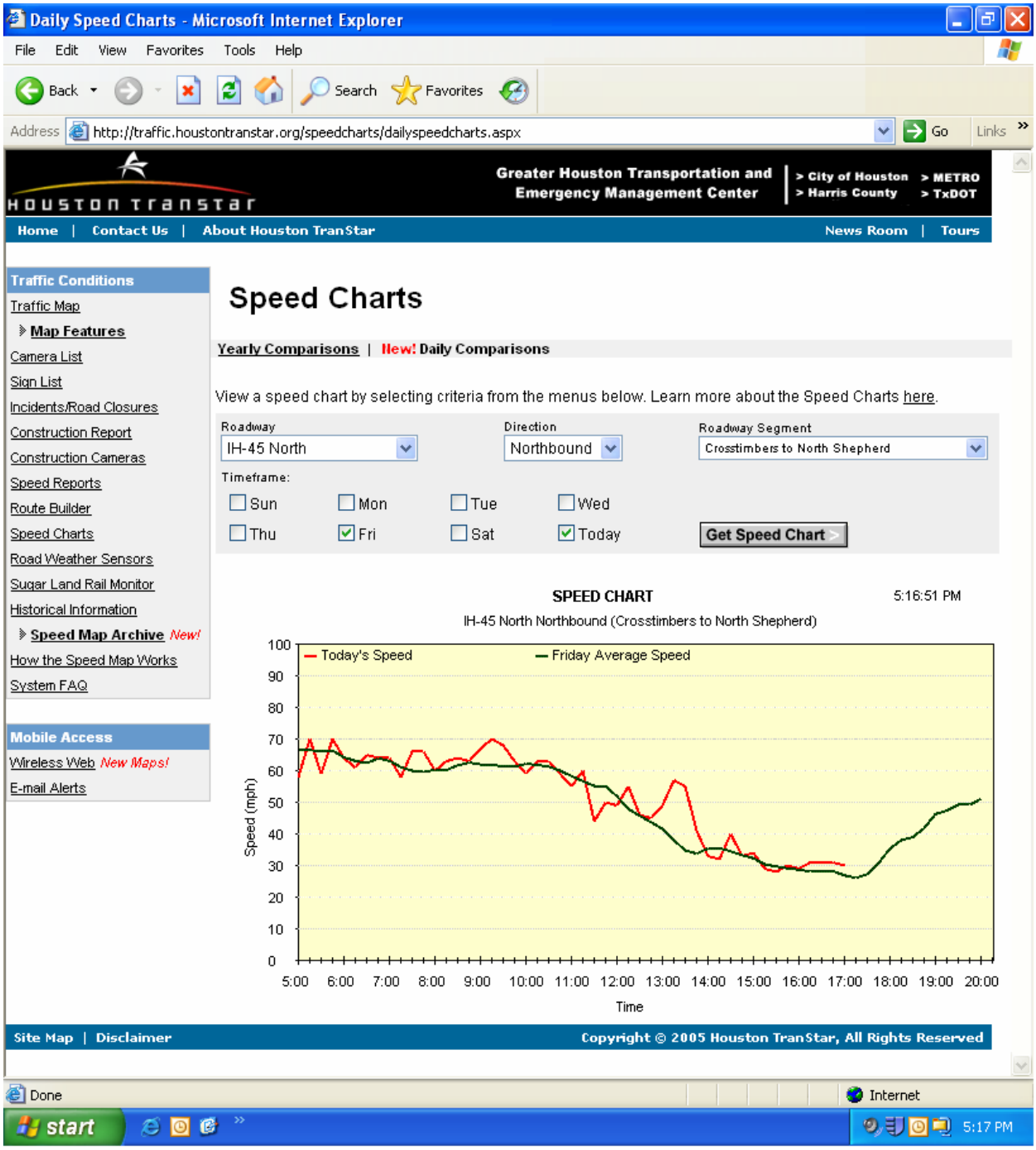

Figure 11. Houston's TranStar Speed Report (27).

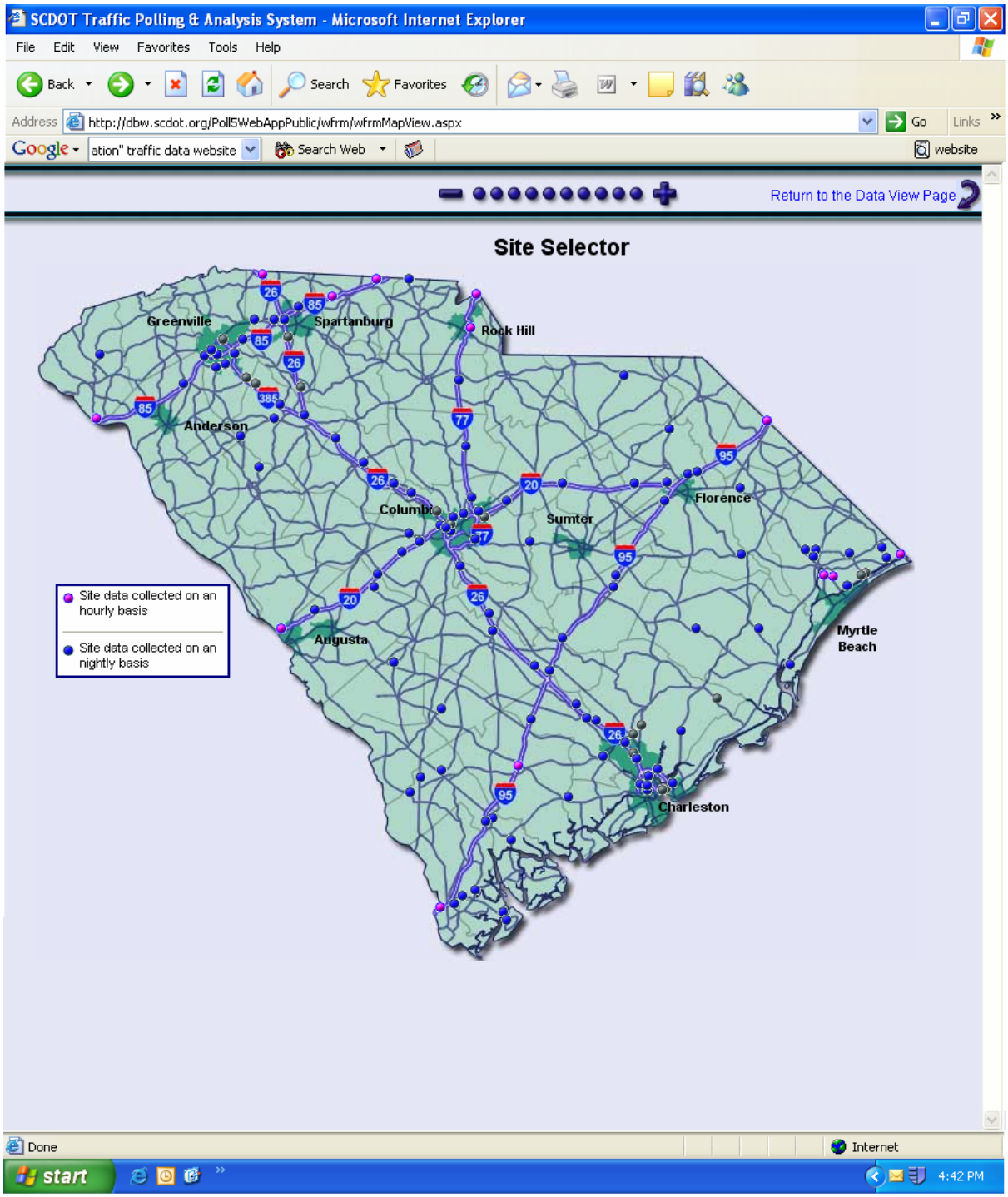

Figure 12. South Carolina's Online Traffic Map (*28*).

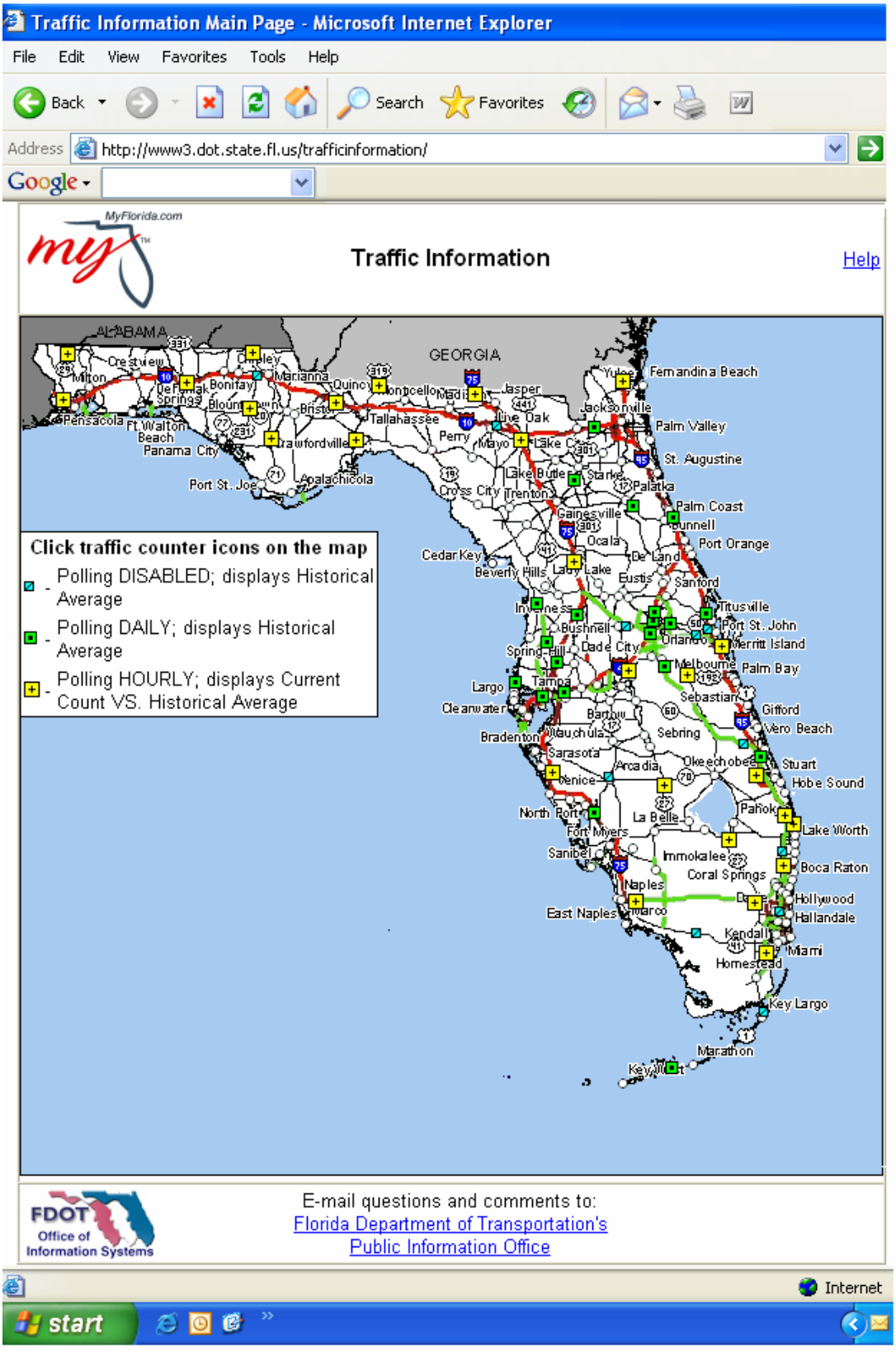

Figure 13. Florida's Online Traffic Map (29).

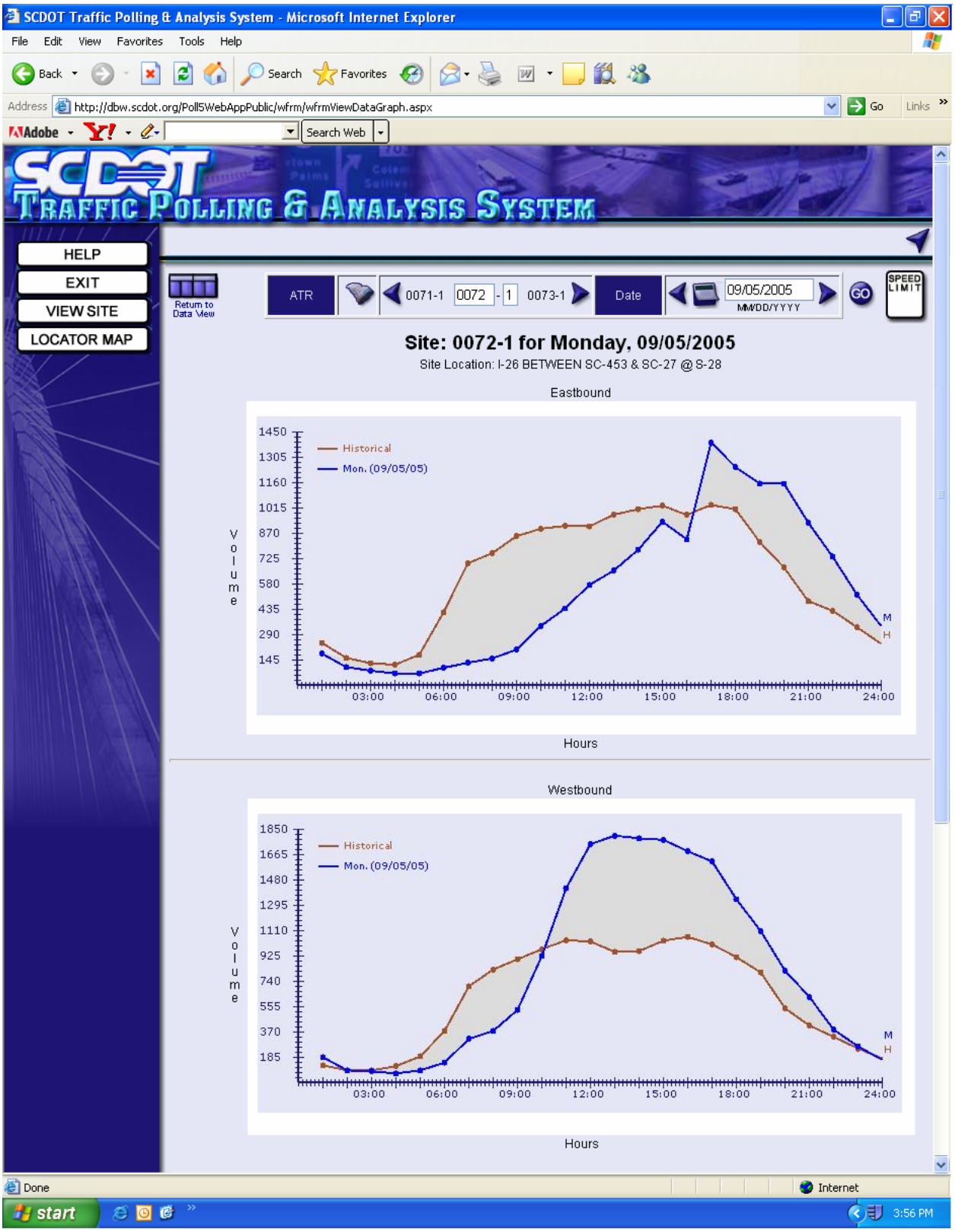

Figure 14. South Carolina's Online Traffic Volume Trend (*28*).

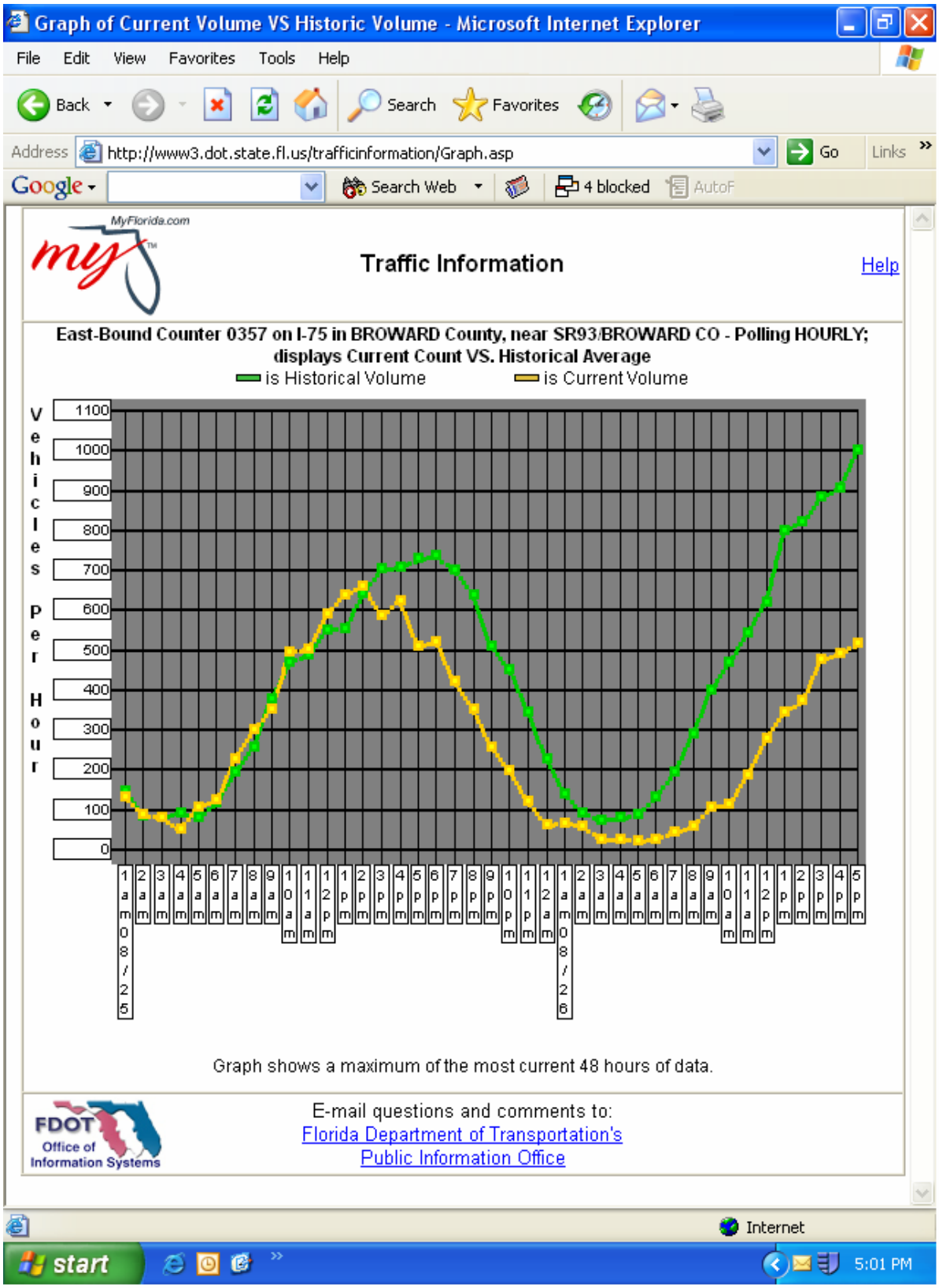

Figure 15. Florida's Online Traffic Volume Trend (29).

CHAPTER 7. PREPAREDNESS

Alabama (*16*) and South Carolina (*31*) advocate the use of 800 MHz radio systems for communications in hurricane emergencies. This type of system is also used in the Houston region (13 counties), where virtually all fire departments and law enforcement agencies can communicate with each other on 800 MHz radios (*32*).

Several states (*16*, *33*) engage in an annual hurricane readiness tabletop exercise. The objective of such an exercise is to discern the abilities of participating agencies to understand the roles of each agency in deploying resources to respond to the various phases of the hurricane emergency. These include evacuation, re-entry, and cleanup. South Carolina (*14*) annually conducts a tabletop exercise in December and a field exercise in June in which the state DOT and the state Department of Public Safety deploy their resources to the field locations where they would be needed in a hurricane emergency. The traffic control devices are not actually put into place, but the DOT trucks do actually bring them to the site. This level of readiness exercise instills confidence in all the participants to 1) see and know that all the materials and manpower will be delivered to the proper locations, 2) identify which yard/field office the equipment will be coming from, 3) observe the time required to deliver and unload, and 4) meet the participants from other agencies. The exercise also reveals gaps that can be remedied in a non-emergency environment.

Construction work zones can introduce a problem for hurricane evacuation. Where construction can be easily terminated and all lanes reopened, contracts should require this when an evacuation order is issued. This type of quick reopening of lanes is not possible with some construction projects, e.g., bridge replacements. A solution is illustrated on I-37 between Corpus Christi and San Antonio, where there are two lanes in each direction separated by a grass median. Here, twin bridge structures cross a river in Atascosa County. Construction completely closes the northbound (inland-bound) bridge. The southbound side has been temporarily widened to accommodate three lanes with space for a temporary concrete barrier. Crossovers have been constructed north and south of the work zone, thereby shifting two lanes from the northbound side to the southbound lanes. Southbound traffic is reduced to one lane. The result is continuity of two lanes in the direction of evacuating traffic. This work zone is not within the limits of the emergency shoulder lane plan; consequently, there are only two northbound lanes in use. Where a similar long-term road closure such as this bridge replacement project may be within the limits of the emergency shoulder lane operation, the Texas Department of Public Safety will request crossovers of sufficient width to carry three lanes of evacuating traffic (*15*).

Most toll operators have a policy of suspending tolls during hurricane evacuation for general purpose traffic. Florida additionally recommends that tolls not be charged to relief workers during the recovery phase after the event (*21*).

The following are recommendations concerning preparedness:

- Consider 800 MHz radio and satellite phone communications (*16*).
- Consider licensing selected DOT staff in amateur (ham) radio so the department can communicate with local ham operators which typically mobilize during emergencies and are often associated with the American Red Cross.

- Suspend construction and maintenance contract work (*3*). Suspensions should be overseen at a statewide level to ensure work sites on evacuation routes in various districts are coordinated.
- Organize damage assessment and repair teams in advance of the event (*24*).
- Announce to all DOT staff members their duties and responsibilities for pre- and post-storm assignments.
- Prepare agreements with local governments and other states to suspend time or waive liquidated damages for their contractors to assist in emergency response activities (*24*).
- Prepare emergency repair contracts in advance (*24*).
- Construction contracts need to require contractors to cease all activities, clear all equipment, and open to traffic all lanes including those under construction when an evacuation order is issued (*33*).
- Establish vehicle towing contracts to deploy tow trucks along evacuation routes to move stalled vehicles off the roadway.
- Suspend toll collection during evacuation and re-entry (*21*).
- Suspend tolls for relief workers during cleanup (*21*).
- Keep current regarding the FEMA/Emergency Response Manual's policies and requirements for reimbursement of costs associated with hurricane emergencies (*30*, *34*).
- Ensure that traffic operations personnel are present in the State Operations Center (SOC) (*34*).
- Schedule regular briefings and conference calls among traffic operations personnel (*30*).
- Cross-train personnel on operation of critical equipment (*21*, *30*).
- Deploy digital cameras and downloading equipment among field personnel (*30*).
- Assess DOT mobile communications capabilities with particular attention to desired redundancy (*30*).
- Maintain current contact information for each employee. Information should include state-issued and personal cellular phone number, home phone number and address, family member contact information, etc. (*21*). The use of personal cellular phones may require a modification to the "TxDOT Cell Phone Guidelines" which discourages use of personal cell phones for state business.
- Create an employee call-down procedure whereby immediately after the storm supervisors contact their immediate subordinates to discern the status of their safety and availability to report to duty. Each supervisor then reports their findings to their superior (*35*).
- It may be helpful to require affected employees and critical contractors call into an out-of-area phone number, e.g., a DOT office in a destination city, where their status can be documented.
- Install generators at communications towers (*21*).
- Conduct an annual mobilization exercise involving DOT, DPS, and other partner agencies (*14*, *16*).
- Develop positive relationships and improve communications between partner agencies.
- Develop a routine maintenance plan for generators and all other equipment regardless of the infrequency of use (*21*).
- Develop an alternative communications plan for implementation when primary communications mechanisms become dysfunctional. Primary and alternative

communications plans should serve staff, contractors, utilities, local agencies, shelter operators, and other relevant partners (*21*).

- Label equipment with the DOT facility to which it will ultimately be returned (*30*).

CHAPTER 8. RESOURCE DEPLOYMENT

South Carolina Department of Transportation (SCDOT) (3) operates a contraflow operation on I-26 between Charleston and Columbia. SCDOT supplements its existing rest areas with eight temporary "comfort stations," four per direction. Each is equipped with 20 portable toilets and 18,000 bottles of water (20 oz). Through an annual contract, SCDOT uses a contractor to supply the water to the DOT. Upon notification of a mandatory evacuation order, SCDOT simultaneously deploys its trucks to carry the water bottles to each comfort station.

The demand for critical commodities increases beyond its normal level before, during, and after a hurricane. As was evident with the evacuation in the Houston and Galveston areas during Hurricane Rita, motorists found that the availability of fuel was a major concern. Even if future evacuation efforts result in operating speeds that are reasonable, in contrast to the very slow speeds during Hurricane Rita, a fuel availability policy is needed for evacuating motorists. Such a policy needs to be developed with private sector suppliers. All options should be considered. Because some Texas coastal communities have refineries, there may be opportunities for them to take some types of extraordinary steps prior to shutting down the refineries to increase fuel availability and distribution to evacuees. Critical refinery employees and fuel delivery trucks must be allowed to travel in and out of fuel sites, even during mandatory evacuations. Consideration should be given to the designation of selected fuel stations as primary distribution points during and immediately prior to a hurricane evacuation. Discussions with this industry are recommended.

Additionally, the DOT needs to establish a policy for managing its fuel. This includes a plan to "top off" the tanks of all equipment prior to the storm. It also includes ensuring that its fuel trucks are distributed appropriately before the storm. It should be anticipated that other agencies (e.g., FEMA, utilities, National Guard, and local agencies) may experience fuel shortages and extend a request to the DOT (34). Finally, when the DOT's critical employees are unable to travel between home and work because of the unavailability of fuel from commercial retailers during a hurricane evacuation or recovery, the DOT should adopt a policy that allows them the use of DOT fuel.

States respond to emergencies such as hurricane evacuations in accordance to sequential operating conditions known as OPCONs. Normal conditions are referred to as OPCON 5. As the hurricane enters the Gulf of Mexico and ultimately triggers a full-scale evacuation, DOT personnel progress through the various stages until reaching OPCON 1. Each OPCON is associated with a window of time in advance of the onset of tropical storm force winds. With each OPCON, several specific tasks must be accomplished as per checklists prepared prior to the hurricane season. These typically include very detailed responsibilities, e.g., ensuring that DMSs, HAR, and other field equipment are in working order.

About a week before landfall, Florida DOT maintenance yards inventory their critical items, e.g., PCMSs, sand bags, barrels, barricades, fuel, etc. They do not pre-deploy them in anticipation of the storm at that time because of the uncertainty of a hurricane's route (8). However, because Texas' geography and size differ significantly from Florida's, in Texas it can be helpful to pre-position equipment, materials, and personnel out of the hurricane's path so they are ready to move in after the storm.

The following are recommendations concerning resource deployment:

- Contract with suppliers to deploy critical supplies (e.g., bottled water, food, diapers, and portable toilets) at temporary "comfort stations" to augment existing rest areas on evacuation routes (*3*).
- Develop a fuel availability policy with private sector suppliers. Investigate all options for ensuring adequacy of fuel supply for evacuating motorists, emergency responders, and critical DOT staff members.
- Be prepared for requests from other agencies that will need fuel (*34*).
- Adopt a policy that allows DOT staff to access DOT fuel for work/home commutes in personal vehicles during evacuation and recovery, when retail fuel supplies are not available.
- Pre-position personnel, equipment, and supplies, including fuel, maintenance equipment, etc., out of the hurricane's path so they are ready to move in after the storm (*12*, *34*).
- Review sufficiency of fuel procurement and distribution processes (*30*).
- Sweep shoulders on evacuation routes prior to landfall to facilitate safety in the event of vehicle breakdowns (*10*).
- Ensure that sufficient stockpiles of repair parts and materials are deployed at multiple locations so they can be readily available (*3*).
- Develop and distribute detailed checklists for all personnel for each OPCON level.

CHAPTER 9. INTELLIGENT TRANSPORTATION SYSTEMS

South Carolina (*16*) supplements its permanent ITS network with four mobile units which combine DMSs and traffic cameras. During an emergency, these can be used to monitor traffic operations at sites where no permanent field devices are located. Due to insufficient recurring congestion issues, some sites may not warrant permanent installations, yet during an emergency, DMSs and traffic cameras may be highly desirable.

Florida recommends developing and maintaining an inventory of an adequate quantity of spare parts for ITS field devices. However, this concept should be expanded in recognition of the dynamic nature of the ITS industry. As with most high-technology industries, it is not uncommon for equipment acquired only a few years ago to no longer be supported due to technology providers merging or going out of business. This can mean that replacement parts are not available. Consequently, it is recommended that TxDOT make a practice of upgrading its devices that are no longer supported and maintain a reasonable stockpile of devices for which supplier support can continue to be expected.

The following are recommendations concerning intelligent transportation systems:

- Install cameras at critical points, e.g., beginning of contraflow or emergency shoulder lanes and any major decision points along the route (*16*).
- Develop and deploy mobile stations equipped with highway advisory radio, a traffic camera, and a DMS.
- Identify redundant communication systems for controlling ITS field devices (e.g., voice-over Internet protocol) for critical elements.
- Prioritize critical field devices for allocation of backup power and communications systems (*21*).
- Make a practice of upgrading ITS devices that are no longer supported, and maintain a reasonable stockpile of devices for which supplier support can continue to be expected.
- Consider a requirement for maintenance contractors to maintain specified quantities of generators to maintain power to essential ITS field devices.
- Develop center-to-center communications between the evacuating community(ies) and refuge community(ies), as well as the rural areas and pass-through communities along evacuation routes.

CHAPTER 10. COURTESY PATROL

Several states use contractors to operate their highway courtesy patrols (*10*, *21*). Because there already exist contractors in these states that operate courtesy patrols, it is relatively easy to modify the contract to require additional patrols be called into service for an emergency event; however, in a community where all the courtesy patrol operations are performed by in-house forces, it may be more difficult to find qualified contractors. Regardless whether patrols are in-house or contracted, it is imperative that they all are equipped with proper communications equipment. As with all communications issues in hurricane evacuation and re-entry operations, it is critical that alternative communications plans be established in the event that the primary plan fails due to hurricane damage, e.g., power outages, communications tower damage, etc.

To improve the capability to respond to motorists' needs, most states redeploy courtesy patrols from other districts to the district(s) where an evacuation is soon to begin.

Georgia's Highway Emergency Response Operator (HERO) program is very popular among that state's motorists. The DOT receives a "HUGE public relations boost" from the HERO program (*10*).

The following are recommendations concerning courtesy patrols:

- Assign courtesy patrols to each evacuation route, with the most critical routes receiving highest priority (*3*, *10*, *16*).
- Consider supplementing existing courtesy patrols with contract courtesy patrols (*34*).
- Ensure all courtesy patrols, in-house and contractor, are equipped with communications equipment (*21*).
- In addition to courtesy patrols, tow trucks need to patrol the evacuation routes primarily to move stalled vehicles out of the flow of traffic (*1*).

CHAPTER 11. TRAFFIC OPERATIONS AND EOC/TMC

As with any major emergency, the EOC and the TMC will open for operations in the event of a hurricane. The EOC is staffed with operations staff from several relevant agencies, including the DOT. Several of these agencies may also staff the TMC.

The EOC and TMC are the key communications and operations centers which the DOT uses for command and control. Among their many duties, it is essential that TMC staff have robust communications with field personnel including those that are traveling on evacuation routes that are not equipped with ITS infrastructure. The TMC must also remain in contact with the TxDOT maintenance engineer, who is in communication with the SOC.

Because a hurricane emergency is a rare event for any given community, the potential for familiarity with preparedness and response procedures may not be as high as for events that occur every year. Therefore, it is particularly critical that the TMC has a documented plan for this specific type of emergency. According to Florida's post-2004 hurricane season assessment (*21*), the plan should be updated annually and should include the following:

1. list of all staff with their contact information;
2. roles and responsibilities of the staff;
3. expected staffing criteria and schedules;
4. criteria for starting up and shutting down the TMC for a hurricane emergency, including an indication of remote operations capability;
5. identification of provisions necessary to be provided to the staff, how to obtain the provisions, and what the staff will be responsible for supplying;
6. maintenance plan including year-round maintenance, immediately prior to hurricane emergency TMC activation, during activation, and immediately after the emergency event;
7. test plan for all equipment including generators and an alternative communications system;
8. alternative communications plan for communicating with staff, contractors, utilities, local agencies, shelter operators, and other partners if power and cellular communications services are down; and
9. procedures for post-storm damage assessment teams.

Florida is beginning to test a plan to use unmanned aerial vehicles for traffic surveillance. The initial phase of the study indicates this technology may have promise. Further testing is needed (*19*). South Carolina calls on state and local aircraft to monitor traffic operations and provide an hourly report to the EOC (*3*).

The following are recommendations concerning traffic operations and the EOC/TMC:

- Equip DOT personnel on evacuation routes with robust communications equipment (*7*, *16*).
- Schedule regular briefings and conference calls among traffic operations personnel (*30*).
- Establish a single focal point for DOT information to be released to the media.
- Provide meals and snacks for DOT staff such that the need for cash on hand is minimized (30), and make meals and snacks accessible to the media at the TMC/EOC while the centers are activated.

- Keep state and local officials informed regarding transportation issues during evacuation (*30*).
- Document steps for setting up and shutting down the TMC for hurricane emergency operations (*21*).
- Identify materials and supplies necessary to be provided to TMC staff and materials and supplies which the staff is expected to provide (*21*).
- Develop a communications plan to connect the TMC with the SOC (*21*).
- Use aerial surveillance of evacuation routes with aircraft equipped with communications to the SOC (*16*).
- Before and after the hurricane, allow traffic services aircraft to provide traffic information where field equipment is not available.
- Assign a traffic management liaison to the Office of Emergency Management's command center.

CHAPTER 12. RECOVERY PHASE

After the storm has passed, the massive cleanup phase begins. Florida DOT's District 1 (Bartow, Florida) produced a map indicating locations of all employees' homes to facilitate post-storm efforts to locate all employees. These were used to locate those employees who could not be located via the telephone call-down procedure. After the hurricane, the district employees established a donation account at their credit union. Funds were used to purchase items such as generators, chain saws, etc., for the temporary personal use of individual employees. A committee was created to prioritize employee needs and oversee the funds. The purchased equipment was then passed around among employees. The highest priorities were those persons with medical needs and/or infants. The policy acknowledged that every employee had three levels of duty: their DOT job, their neighbors/community, and their own family. The family came first (*35*).

Mandatory evacuations are new to Texas, beginning in 2005. When the evacuation order is mandatory, some DOT personnel and their families will leave their homes and evacuate to safer locations. The DOT needs to clearly state its policy regarding the work-related obligations of staff members during a hurricane emergency. Nevertheless, it is prudent for the DOT to recognize that all personnel may not be able to return to their duty stations immediately. Delays, which may be measured in days, could result from unavailability of fuel, serious personal property damage, or personal injury. The DOT's recognition of these realities needs to be reflected in its policies so that unnecessary repercussions are not attached to employees during extraordinary circumstances such as a hurricane emergency.

The following are recommendations concerning the recovery phase:

- Prepare temporary housing for DOT staff members during the recovery phase (*30*).
- Provide procedures for food and lodging expenses for DOT personnel involved in response and recovery, especially for those from other districts (*30*).
- Provide critical incident stress management training for employees (*30*).
- Where practical, use PCMSs in support of the residential decal re-entry effort.

CHAPTER 13. ADDITIONAL RECOMMENDATIONS

As with more routine aspects of incident management, hurricane evacuation succeeds where the agency personnel have developed relationships of mutual respect. This can be facilitated through annual hurricane evacuation tabletop and field exercises. Because some of these same parties work together for other types of incident management issues, some of the relationships already exist (*14*).

Plans should be developed to utilize existing freeway high occupancy vehicle (HOV) lanes. HOV lanes may best be used by evacuating buses and vans carrying special-needs populations, or it may be preferable to reserve HOV lanes for emergency vehicles that require access toward the coastal communities. In either scenario, a capacity analysis for the community should be done to assess the impact of including or excluding HOV lanes from use by general purpose evacuation traffic.

Depending on the time of day, it is possible that evacuation traffic may be flowing in the direction opposite the normal flow scheduled for specific hours.

A new research project funded by the Southwest Region University Transportation Center will develop specifications and an action plan of steps needed to integrate Texas coastal region traffic data into the HURREVAC model to better manage evacuation route roadways and assist in routing decisions.

During the Hurricane Rita evacuation in the Houston District, DMSs as far away as El Paso, San Antonio, Dallas, and Shreveport were used to advise motorists of the congestion and significant delays in the Houston area. These assisted in redirecting some cross-country traffic at decision points hundreds of miles from the scene. Similarly, during the Hurricane Katrina evacuation in Louisiana, DMSs in Houston and San Antonio performed the same function regarding traffic in Baton Rouge and New Orleans.

The following are additional recommendations:

- In the aftermath, where highway infrastructure is severely damaged, sign and mark detours for large vehicles and/or through traffic.
- Ensure that chains of command within TxDOT, at all levels, are clear and are followed (*30*).
- Conduct post-event evaluations of TxDOT emergency response and recovery (*30*).
- Agencies should work closely with the Metropolitan Transit Authority of Harris County to develop an action plan for using HOV facilities for hurricane evacuation.
- Work to utilize the Transportation Information System in the HURREVAC model to better manage evacuation route roadways and assist in routing decisions.
- Keep adjacent districts and destination districts advised of impacts on traffic before, during, and after the hurricane emergency.

CHAPTER 14. TEXAS COASTAL REGIONS

The five TxDOT districts along the coast of the Gulf of Mexico each present different issues relative to hurricane evacuation. While the purpose of this document is not to specify evacuation routes, it is worthwhile to address some of the unique characteristics found in each district.

A key element of hurricane evacuation operations in Texas, as well as other states, is to coordinate between districts. In the case of the 2005 hurricane season, DMS messages related to the events were displayed in Houston, San Antonio, and Dallas. The response and recovery phase included TxDOT staff traveling from many other districts to the region to bring equipment, materials, and labor.

With Hurricane Rita, the initial landfall predictions prompted the Corpus Christi area to begin evacuation. As Rita came closer to landfall, the predicted path moved up the Texas coast, causing evacuations from the Corpus Christi area eastward into Louisiana, including population centers in Galveston, Houston, and Beaumont, as well as numerous smaller communities. Because evacuation plans are developed independently for each of the five Texas coastal study areas (Rio Grande Valley, Coastal Bend, Matagorda, Houston/Galveston, and Lake Sabine), some evacuees from one study area found routes occupied with evacuees from other study areas.

One of the lessons learned is that no district can plan or operate for hurricane evacuation in isolation.

Another lesson relates to evacuation traffic demand management. Evacuation plans were based on evacuating specific zones based on predicted storm surge and flooding; however, many persons from other areas joined in the evacuation. The result was that perhaps three times as many persons joined the exodus and the transportation network was stressed beyond expectations. Consequently, it is recommended that post-Rita analyses address the demand side of the supply-and-demand aspect of this evacuation task.

Beaumont District

One of the features unique among TxDOT districts found in the Beaumont District is the role it plays as a route through which motorists travel from or through Louisiana to Texas seeking safety. The "ITS Architectures and Deployment Plans" for the Beaumont Region (*36*) placed a high priority on hurricane evacuation management. This included the following:

- hurricane evacuation signal coordination,
- hurricane evacuation website with evacuation routes and road closure information, and
- improved hurricane evacuation planning (including coordination with Louisiana).

The need for coordination with Louisiana became evident with the evacuation traffic during Hurricane Katrina in 2005, as lodging in Beaumont filled and motorists needed information about where to find services. In the immediate aftermath, TxDOT used its DMSs in the Beaumont District to advise eastbound motorists that I-10 was closed in Baton Rouge. Similarly, Houston's TranStar displayed the DMS messages on I-10 east of Houston and on its webpage, as shown in

Figures 16 and 17. The phone number displayed in Figure 16 is operated by the American Red Cross.

Figure 16. DMS Advising Evacuees with Critical Information (27).

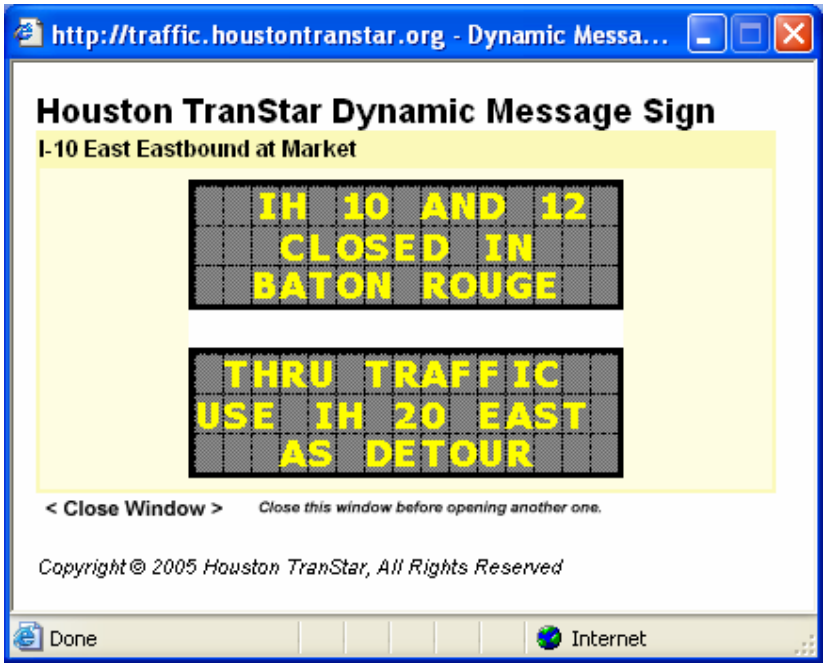

Figure 17. DMS Message Displayed to Motorists Traveling toward Storm-Damaged Area (27).

Houston District

The Houston-Galveston study area includes the counties of Brazoria, Galveston, and Harris; this represents over 3500 square miles and 4.1 million residents according to 2003 population estimates and is the largest metropolitan area in Texas that is subject to hurricane threats. Prior to the remarkable 2005 hurricane season, DPS and emergency management officials from each of the three counties developed an updated evacuation plan (*37*) which featured "channeled" evacuation corridors to expedite the movement of traffic away from the coastal region and the storm tidal surge zone. It is expected that these evacuation corridors will have limited access further inland, allowing evacuation traffic to proceed northward with very little interference from local traffic. Traffic signals will be set to flashing yellow along the corridors to favor the evacuating traffic. After an evacuation order is given, the citizens departing a community will be required to use the designated route for their community. The designated evacuation corridors are as follows:

- Brazoria County
  1. SH 36 to Brenham
  2. SH 288 to College Station (via Beltway 8, US 290, and SH 6)

- Galveston County
  1. SH 146 to Lufkin
  2. I-45 to Huntsville
  3. SH 6 to College Station

- Harris County (southeast)
  1. SH 146 to Lufkin
  2. I-45 to Huntsville

The goal of the evacuation plan is that all citizens are allowed to evacuate inland before the winds reach 39 mph (tropical storm force). For a Category 3, 4, or 5 (based upon the Saffir-Simpson scale) hurricane, the decision to recommend/require evacuation will have to be made 30 to 36 hours prior to the expected arrival of the 40 mph winds. All of the evacuation scenarios are based upon the expected storm surge tidal levels. Additional water due to rain and/or driven rain is not generally considered.

Evacuating the Houston-Galveston area is unique in many respects. A major one is that evacuating the coastal region involves traveling through a major urban area. This complicates the movement of evacuees in that the roadways chosen as evacuation routes generally operate near capacity, and traffic demands often exceed capacity during peak commuter periods. In addition, some Houston area residents own property in the coastal region and may choose to drive to that area to secure and/or remove their belongings, returning to their Houston area homes using the evacuation routes. Another concern is that with many roadways in the Houston region under construction, the flow of evacuees may be hindered by the reduced roadway capacities. Along the major evacuation routes from Galveston, TxDOT works to schedule the construction activities to minimize impacts for the directional evacuation traffic, i.e., any major capacity restrictions for I-45 Gulf Freeway northbound are typically scheduled during the December to May time period.

A common question from the general public is whether I-45 (Gulf Freeway) could be turned into a contraflow operation to facilitate northbound evacuation traffic demands. A 1998 Texas Transportation Institute study (*38*) looked at the feasibility of converting a single lane of the southbound direction into an additional northbound travel lane. The evaluated contraflow scenarios used the existing emergency barrier openings in the freeway median for traffic to cross over to the southbound inside lane for use as the contraflow lane. The study reported that based upon the results of several simulation scenarios, the benefits of contraflow operation would be marginal considering the difficulty in staffing and deploying the contraflow lane in a short time frame and under anticipated adverse weather conditions. While the study indicated that a contraflow lane concept may benefit those departing Galveston Island, the overall traffic impacts when combined with traffic evacuating mainland coastal regions may not be positive. The study's conclusion stated, "it is questionable if a contraflow lane would significantly increase movement across the Galveston Causeway during a hurricane evacuation."

Yoakum District

The Yoakum District has limited populations along its coastal communities; consequently, the issues involved in hurricane evacuation are typically those of traffic signal operations and motorist information. I-10 is the only controlled-access highway in the district. It extends east and west through the northern counties in the district. There are no shelters within the district. All evacuation routes carry motorists to destinations north of I-10, primarily via U.S. and state highways.

Corpus Christi District

As described in a previous chapter, the emergency shoulder lane on I-37 is the unique hurricane evacuation tool in this district. It currently extends inland to SH 72 and should be extended farther north toward San Antonio.

Pharr District

Hurricane evacuation in the Rio Grande Valley generally directs evacuees to US 281 and then north to San Antonio and beyond. Laredo can also provide refuge. Issues in this district include concerns with stalled vehicles stopped on freeway lanes, particularly in construction work zones where there are temporarily no shoulders available. This concern is not unique to any particular district and should be addressed through incident management policies that include the immediate moving of stalled vehicles out of the path of evacuating traffic.

Among all these coastal districts, plans for hurricane evacuation are being reviewed in light of the impact the 2005 hurricane season had on Texas.

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