Technical Report Documentation Page

1. Report No. FHWA/TX-13/9-1001-3	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF TRAFFIC CONTROL DEVICES, YEAR 4		5. Report Date Published: August 2013
		6. Performing Organization Code
7. Author(s) Adam M. Pike, Paul J. Carlson, and Darrell W. Borchardt		8. Performing Organization Report No. Report 9-1001-3
9. Performing Organization Name and Address Texas A&M Transportation Institute College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Project 9-1001
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Technical Report: September 2011–August 2012
		14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Traffic Control Device Evaluation and Development Program
URL: http://tti.tamu.edu/documents/9-1001-3.pdf

16. Abstract

This project was established to provide a means of conducting small scale research activities on an as-needed basis so that the results could be available within months of starting the specific research. This report summarizes the research activities that were conducted between September 2011 and August 2012.

The research included two primary activities and two secondary activities. The two primary activities were: (1) Rural Intersection Sign Reduction Evaluation, and (2) Update on Sequential Dynamic Curve Warning System Research. The two secondary activities were: (1) Development of Hurricane Evacuation Animation Maps for CRP, and (2) Mobile Pavement Marking Retroreflectivity Data Training.

17. Key Words Traffic Control Devices, Retroreflective Sign Sheeting, LED Signs, Hurricane Evacuation, Mobile Pavement Marking Retroreflectivity	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 40	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

EVALUATION OF TRAFFIC CONTROL DEVICES, YEAR 4

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Report 9-1001-3
Project 9-1001
Project Title: Traffic Control Device Evaluation and Development Program

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: August 2013

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was Paul J. Carlson, P.E. #85402.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because these are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors thank the project director, Michael Chacon of the TxDOT Traffic Operations Division, for providing guidance and expertise on this project. Wade Odell of the TxDOT Research and Technology Implementation Office was the research engineer. The other members of the project monitoring committee included the following project advisors:

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CHAPTER 1: OVERVIEW

This research project was established as a mechanism for obtaining quick research results on high-priority traffic control device topics that cannot be programmed in the traditional research program because of the need for a smaller scope and quicker turnaround time. This project originally began as TxDOT Project 0-4701, which was active for five years (*1-5*). Upon the completion of Project 0-4701, a new TxDOT project was started with a similar objective, Project 0-6384, later renumbered Project 9-1001 (*6-8*). This report presents the year four activities of the project.

CHAPTER 2: RURAL INTERSECTION SIGN REDUCTION EVALUATION

A West TX district proposed to the research team the topic of reducing the number of signs at rural intersections. Specifically, the district wanted to know if they could reduce the number of signs they need to install and maintain at low volume rural intersections. The intersection of State Highway 6 (SH 6) and Farm to Market 2003 (FM 2003) was of particular interest to the district. The district provided the research team with the current and proposed signage layouts for the intersection. The research team evaluated the proposed signage reduction by investigating the sign requirements from the *2009 Manual on Uniform Traffic Control Devices* (MUTCD) (*9*) and the *2011 Texas MUTCD* (*10*). Recommendations based on the site conditions and the investigation of the MUTCDs are provided.

SITE CONDITIONS

The intersection of SH 6 and FM 2003 is a rural intersection approximately 3 miles south of Crowell, TX. FM 2003 has good visibility of the intersection with SH 6. County Road 127 intersects SH 6 opposite of FM 2003. The SH 6 and FM 2003 intersection was of particular interest because of the very low traffic volume and the change in traffic volume over time. Traffic counts in 1979 indicated 120 vehicles per day whereas counts in 2009 indicated 30 vehicles per day. It can be assumed that with such low traffic volumes and a decreasing traffic volume that the majority of the traffic is local traffic familiar with the road and area destinations. Therefore, there may be no need for the numerous route, junction, and destination signs surrounding this low-volume rural intersection.

A physical visit to the site to perform a site investigation was not conducted as part of this task. Google street view images were used to get an understanding of the site conditions and sign inventory at the time these images were taken. The signs visible in the street view images were compared to those that TxDOT provided on the site layouts. Figure 1 represents the current TxDOT signage layout at the intersection. Figure 2 represents the proposed signage layout for the intersection.

Figure 1 indicates there are 23 TxDOT maintained signs associated with this intersection. In reviewing the street view images of the site, the researchers found that there was no W1-7, two-direction large arrow sign, opposite the FM 2003 intersection with SH 6. There were an additional two signs found on the northbound leg of SH 6 that were the reassuring assembly for north traffic on SH 6. In total, the research team found 24 TxDOT maintained signs associated with the intersection. This number is far greater than the proposed seven signs in Figure 2. Of the proposed signs in the reduced plan, the two-direction large arrow sign could also be removed because it was not present in the current setup, resulting in only six signs in the reduced plan. Table 1 provides a list of the current and proposed signage at the SH 6 and FM 2003 intersection.

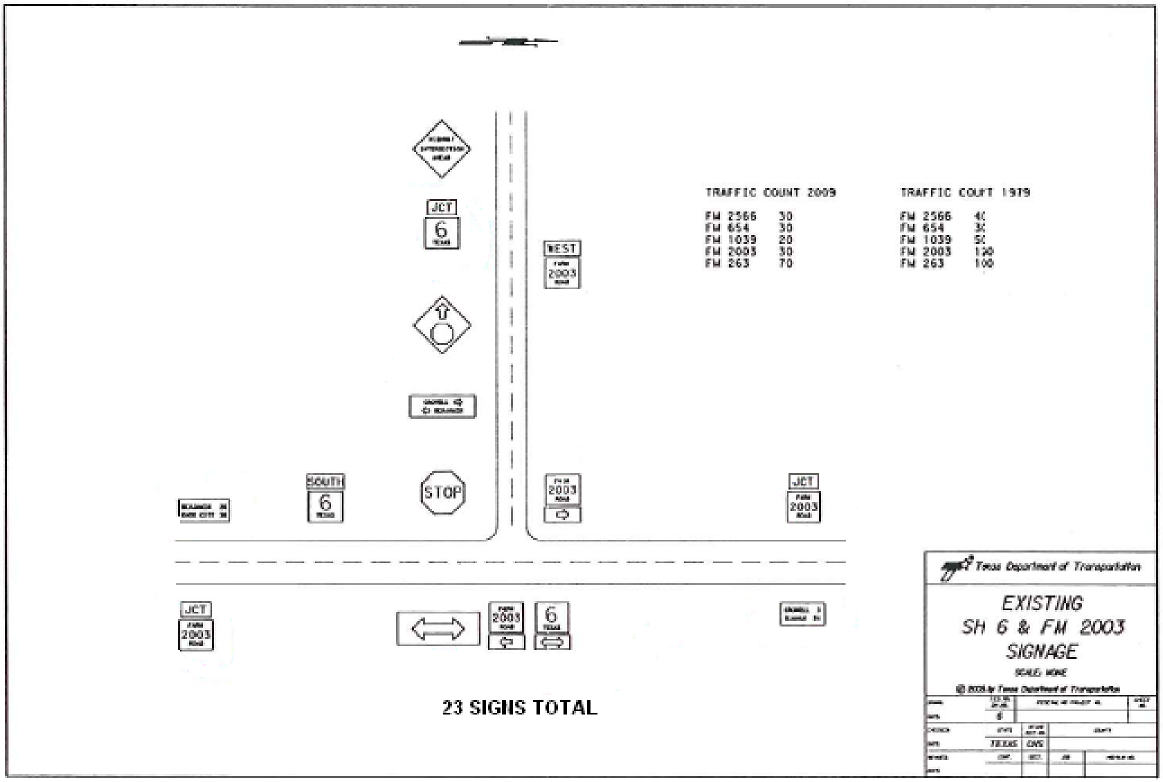

Figure 1. SH 6 and FM 2003 Existing Signage.

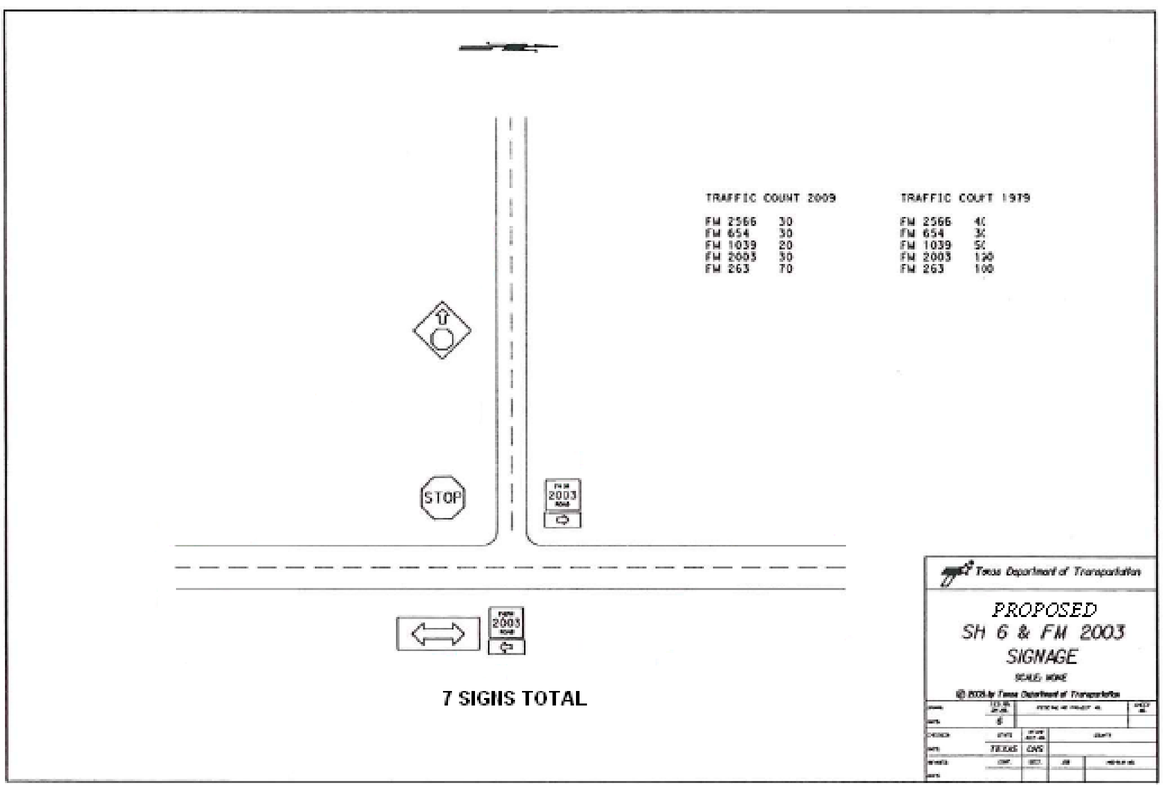

Figure 2. SH 6 and FM 2003 Proposed Signage.

Table 1. SH 6 and FM 2003 Sign Inventory.

Sign Type	Number of Signs Currently Installed	Proposed Number of Signs Installed
STOP R1-1	1	1
Stop Ahead W3-1	1	1
Highway Intersection Ahead W2-1aT	1	0
Destination (2 lines) D1-2	1	0
Distance (2 lines) D2-2	2	0
Texas State Highway Route Marker M1-6T	4	0
Texas Farm Road Route Marker M1-6F	5	2
Junction M2-1	3	0
Cardinal Direction NORTH M3-1	1	0
Cardinal Direction SOUTH M3-3	1	0
Cardinal Direction WEST M3-4	1	0
Directional Arrow (single head) M6-1	2	2
Directional Arrow (double head) M6-4	1	0
Two-Direction Large Arrow W1-7	0	1
Total Number of Signs	24	7

MUTCD INVESTIGATION

The MUTCD (*1*) governs the use of traffic control devices on streets and highways. Texas maintains its own version of the MUTCD, which governs the traffic control devices under its authority (*10*). The Texas MUTCD will be used as the primary source of information during this investigation since there are specific signs used in Texas that are not included in the national MUTCD. For the most part, the documents are similar when looking at signage that is not specific to Texas. The investigation will evaluate the TMUTCD requirements for the regulatory, warning, route, and guide signs located at the SH 6 and FM 2003 intersection. Direct quotes and selections of material from the TMUTCD pertaining to this investigation will be used throughout this section. Please refer to the TMUTCD for the full text of each section described. The use of italic and bold text shows emphasis on particular information.

Signs in General

Section 2A.04 of the TMUTCD provides guidance on the excessive use of signs. The following excerpt indicates that regulatory and warning signs should be used infrequently so that these remain effective when displayed. The guidance also indicates that route and guide signs should be used frequently to promote efficient operations. There are no specific numbers associated with the terms “frequently” or “conservatively.”

Section 2A.04 Excessive Use of Signs
Guidance:
Regulatory and warning signs should be used conservatively *because these signs, if used to excess, tend to lose their effectiveness.* ***If used, route signs and directional guide signs should be used frequently*** *because their use promotes efficient operations by keeping road users informed of their location.*

Regulatory Signs

The SH 6 and FM 2003 intersection is currently a stop sign controlled intersection on the FM 2003 approach. The stop sign was included in the reduced signage plan and is required by TMUTCD Section 2B.05.

Section 2B.05 STOP Sign
Standard:
When it is determined that a full stop is always required on an approach to an intersection, a STOP (R1-1) sign ***shall*** *be used.*

Warning Signs

The SH 6 and FM 2003 intersection currently has two warning signs that are both on the FM 2003 approach to SH 6. The first warns of the Highway Intersection Ahead, and the second warns of the Stop Ahead. Section 2C.01 of the TMUTCD covers the function of warning signs, and Section 2C.02 covers their application. The usage of warning signs is on a case-by-case basis depending on onsite conditions, and an engineering study or engineering judgment.

Section 2C.01 Function of Warning Signs
Support:
Warning signs call attention to unexpected conditions on or adjacent to a highway, street, or private roads open to public travel and to situations that might not be readily apparent to road users. Warning signs alert road users to conditions that might call for a reduction of speed or an action in the interest of safety and efficient traffic operations.

Section 2C.02 Application of Warning Signs
Standard:
The use of warning signs shall be based on an engineering study or on engineering judgment.
Guidance:
The use of warning signs ***should be kept to a minimum*** as the unnecessary use of warning signs tends to breed disrespect for all signs.

The usage of the Stop Ahead sign is covered in TMUTCD Section 2C.36. The Stop Ahead sign shall be used when the stop sign is not visible for a sufficient distance. Given the site conditions, the stop sign is visible for a very long distance because the roadway is straight and flat, so the Stop Ahead sign is not required. It is common practice for TxDOT to provide a Stop Ahead sign in this type of situation. The TMUTCD states it as an option that the Stop Ahead sign may be used even when there is adequate viewing distance. The research team recommends using the Stop Ahead sign for this intersection.

> Section 2C.36 Advance Traffic Control Signs
> Standard:
> The Advance Traffic Control symbol signs include the Stop Ahead (W3-1)…signs. *These signs **shall be installed** on an approach to a primary traffic control device that is not visible for a sufficient distance to permit the road user to respond to the device*.
> Option:
> An Advance Traffic Control sign **may be used** for additional emphasis of the primary traffic control device, even when the visibility distance to the device is satisfactory.

The usage of the Highway Intersection Ahead sign is covered in TMUTCD Section 2C.46A. The Highway Intersection Ahead sign may be used on the approaches to an intersection of important highways, roads, or streets. The TMUTCD provides guidance that the sign should be limited to locations involving high approach speeds, restricted sight distance, or a high number of crashes. The research team would support excluding this sign in a reduced signage situation based on TxDOT not including the Highway Intersection Ahead sign in their reduced signage plan (assuming a limited crash history on the FM 2003 approach), the good visibility of the intersection, and the inclusion of the Stop Ahead sign providing additional warning.

> Section 2C.46A Highway Intersection Ahead Sign
> Option:
> *The HIGHWAY INTERSECTION AHEAD (W2-1aT) sign **may be used** on the approaches to an intersection of important highways, roads, or streets.*
> Guidance:
> *The use of this sign should be limited to locations involving high approach speeds, restricted sight distances or a high number of crashes indicating a need for the sign.*

The signage layout that the district has provided indicated the use of a two-direction large arrow sign. This sign was not seen in the street view images of the site. CR 127 is on the opposite side of the intersection from FM 2003. Given the site conditions, it does not appear that this sign would be necessary based on TMUTCD Section 2C.47.

Section 2C.47 Two-Direction Large Arrow Sign
Standard:
The Two-Direction Large Arrow (W1-7, W1-7T) signs shall be a horizontal rectangle.
If used, it shall be installed on the far side of a T-intersection *in line with, and at approximately a right angle to, traffic approaching from the stem of the T-intersection.*

Guide Signs

The SH 6 and FM 2003 intersection currently has 21 guide signs. Section 2D.02 of the TMUTCD covers the application of guide signs. Guide signs are essential, but in low volume situations such as the SH 6 and FM 2003 intersection, some of the repetitiveness of the signs may be unnecessary. The research team evaluated which guide signs at the intersection are required and which ones are optional.

Section 2D.02 Application
Support:
Guide signs are essential to direct road users along streets and highways, to inform them of intersecting routes, to direct them to cities, towns, villages, or other important destinations, to identify nearby rivers and streams, parks, forests, and historical sites, and generally to give such information as will help them along their way in the most simple, direct manner possible.

SH 6 and FM 2003 are both numbered routes and thus require route and auxiliary signage as stated in Section 2D.10. Subsequent sections in the TMUTCD describe what specific signage is required and what is optional at the intersection of numbered routes.

Section 2D.10 Route Signs and Auxiliary Signs
Standard:
All numbered highway routes shall be identified *by route signs and auxiliary signs.*
The signs for each system of numbered highways, which are distinctive in shape and color, shall be used only on that system and the approaches thereto.
Support:
Route signs are typically mounted in assemblies with auxiliary signs.

Route sign assemblies are described in Section 2D.29. Assemblies consisting of a route sign and auxiliary signs to indicate the direction are required at the intersection of numbered routes. Therefore all three approaches of the SH 6 and FM 2003 intersection are required to have a route sign and auxiliary signs on a single assembly indicating the route.

Section 2D.29 Route Sign Assemblies
Standard:
A Route Sign assembly ***shall consist of a route sign and auxiliary signs that further identify the route and indicate the direction.*** *Route Sign assemblies* ***shall be installed on all approaches to numbered routes that intersect with other numbered routes.***

Cardinal direction and directional arrow auxiliary signs are described in Sections 2D.15 and Section 2D.28. These auxiliary signs are used in conjunction with route signs to form directional assemblies as described in Section 2D.31. The SH 6 and FM 2003 intersection has a configuration that would use Item B on both SH 6 approaches and Item C on the FM 2003 approach. In all cases the required directional assemblies would consist of a route sign and a directional arrow. As noted in the guidance, straight through movements should be indicated with directional assemblies but it is not required.

Section 2D.15 Cardinal Direction Auxiliary Signs
Guidance:
Cardinal Direction auxiliary signs carrying the legend NORTH, EAST, SOUTH, or WEST ***should be used*** *to indicate the general direction of the entire route.*

Section 2D.28 Directional Arrow Auxiliary Signs
Standard:
If used, the Directional Arrow auxiliary sign shall be mounted below the route sign and any other auxiliary signs in Directional assemblies, and displays a single- or double-headed arrow ***pointing in the general direction that the route follows.***

Section 2D.32 Directional Assembly
Standard:
A Directional assembly ***shall consist of a Cardinal Direction auxiliary sign, if needed; a route sign; and a Directional Arrow auxiliary sign.*** *The various uses of Directional assemblies* ***shall be as provided in Items A through D****:*

B. ***The beginning of a route*** *(indicated in advance by a Junction assembly)* ***shall be marked by a Directional assembly with a route sign displaying the number of that route and a single-headed arrow*** *pointing in the direction of the route.*

C. *An intersected route (indicated in advance by a Junction assembly) on a crossroad where the route is* ***designated on both legs shall be designated by:***

1. Two Directional assemblies, each with a route sign displaying the number of the intersected route, a Cardinal Direction auxiliary sign, and a single-headed arrow pointing in the direction of movement on that route; or
2. ***A Directional assembly with a route sign displaying the number of the intersected route and a double-headed arrow, pointing at appropriate angles to the left, right, or ahead.***

Guidance:

Straight-through movements **should** *be indicated by a Directional assembly with a route sign displaying the number of the continuing route and a vertical arrow.* A Directional assembly should not be used for a straight-through movement in the absence of other assemblies indicating right or left turns, as the Confirming assembly sign beyond the intersection normally provides adequate guidance.

Junction signage is covered in Sections 2D.13 and 2D.30. A junction assembly consisting of a junction sign and a route sign is required in advance of every intersection of two numbered routes. Therefore all three approaches of the SH 6 and FM 2003 intersection are required to have a junction assembly.

Section 2D.13 Junction Auxiliary Sign

Standard:

The Junction (M2-1) auxiliary sign **shall** carry the abbreviated legend JCT and **shall** be mounted at the top of an assembly directly above the route sign, the sign for an alternative route that is part of the route designation, or the Cardinal Direction auxiliary sign where access is available only to one direction of the intersected route.

Section 2D.30 Junction Assembly

Standard:

A Junction assembly ***shall consist of a Junction auxiliary sign and a route sign.*** The route sign shall carry the number of the intersected or joined route.

The Junction assembly ***shall be installed in advance of every intersection where a numbered route is intersected or joined by another numbered route.***

Confirming and reassurance assemblies are described in Section 2D.34. If used the assemblies are required to consist of a route sign and a cardinal direction auxiliary sign. These assemblies are not required and can be considered for removal if a reduced number of signs at the intersection is desired. The low traffic volumes at this intersection and the proximity of other intersections on SH 6 that have signage indicating the route lessen the need for this type of signage.

Section 2D.34 Confirming or Reassurance Assemblies
Standard:
If used, *Confirming or Reassurance assemblies shall consist of a Cardinal Direction auxiliary sign and a route sign.*
Guidance:
A Confirming assembly should be installed just beyond intersections of numbered routes. It should be placed 200 to 300 feet beyond the far shoulder or curb line of the intersected highway.
Route signs for either confirming or reassurance purposes should be spaced at such intervals as necessary to keep road users informed of their routes.

Sections 2D.36, 2D.37, and 2D.41 describe the usage of destination and distance signs. In addition to guidance by route numbers it is desirable to provide additional information about destinations with destination and distance signs. Destination and distance signs are not required and can be considered for removal if a reduced number of signs at the intersection is desired. The low traffic volumes at this intersection and the proximity of other intersections on SH 6 that have signage indicating the destinations and distances lessen the need for this type of signage.

Section 2D.36 Destination and Distance Signs
Support:
In addition to guidance by route numbers, ***it is desirable to supply the road user information concerning the destinations*** *that can be reached by way of numbered or unnumbered routes.* This is done by means of Destination signs and Distance signs.

Section 2D.37 Destination Signs
Standard:
Except on approaches to interchanges, the Destination (D1-1 through D1-3) sign, if used, shall be a horizontal rectangle displaying the name of a city, town, village, or other traffic generator, and a directional arrow.
Standard:
Except as otherwise provided in this Manual, an arrow pointing to the right shall be at the extreme right of the sign, and an arrow pointing left or up shall be at the extreme left. The distance numerals, if used, shall be placed to the right of the destination names.

*Destination signs **should be used**:*

A. *At the intersections of U.S. or State numbered routes with Interstate, U.S., or State numbered routes*; and

B. At points where they serve to direct traffic from U.S. or State numbered routes to the business section of towns, or to other destinations reached by unnumbered routes.

Section 2D.41 Distance Signs
Standard:
If used, the Distance (D2-1 through D2-3) sign shall be a horizontal rectangle of a size appropriate for the required legend, carrying the names of no more than three cities, towns, junctions, or other traffic generators, and the distance (to the nearest mile) to those places.
The distance numerals shall be placed to the right of the destination names.
Guidance:
*The **distance and destination displayed should be selected on a case-by-case basis** by the jurisdiction that owns the road or by statewide policy.* A well-defined central area or central business district should be used where one exists. In other cases, the layout of the community should be considered in relation to the highway being signed and the decision based on where it appears that most drivers would feel that they are in the center of the community in question.

RECOMMENDATIONS

Fewer signs to install and maintain saves money, but a balance with safety and efficient vehicle operation also needs to be maintained. Each individual intersection and its local conditions may require a slightly different set of signs to provide drivers with the necessary information to find their destinations and operate a vehicle safely. Based on this individual site and the requirements of the MUTCD and the TMUTCD, the researchers have recommended the reduced signage for the intersection in Table 2. This recommendation is based on a desire to implement a reduced number of signs at this individual intersection. The current signage at the intersection is acceptable and does not need to change unless a reduction in signs is desired.

The recommended number of signs, if reducing signs at the intersection was desired, is 14 compared to the 24 currently installed. The reduction in signs comes from removing the following:

- Reassuring assemblies consisting of the route marker and cardinal direction signs (six signs total).
- Destination and distance signs (three signs total).
- Highway intersection ahead sign (one sign).

Table 2. Reduced Signage Recommended for the SH 6 and FM 2003 Intersection.

Sign Type	Number of Signs Currently Installed	Minimum Signage Required	Reduced Signage Recommended
STOP R1-1	1	1	1
Stop Ahead W3-1	1	0	1
Highway Intersection Ahead W2-1aT	1	0	0
Destination (2 lines) D1-2	1	0	0
Distance (2 lines) D2-2	2	0	0
Texas State Highway Route Marker M1-6T	4	2	2
Texas Farm Road Route Marker M1-6F	5	4	4
Junction M2-1	3	3	3
Cardinal Direction NORTH M3-1	1	0	0
Cardinal Direction SOUTH M3-3	1	0	0
Cardinal Direction WEST M3-4	1	0	0
Directional Arrow (single head) M6-1	2	2	2
Directional Arrow (double head) M6-4	1	1	1
Two-Direction Large Arrow W1-7	0	0	0
Total Number of Signs	24	13	14

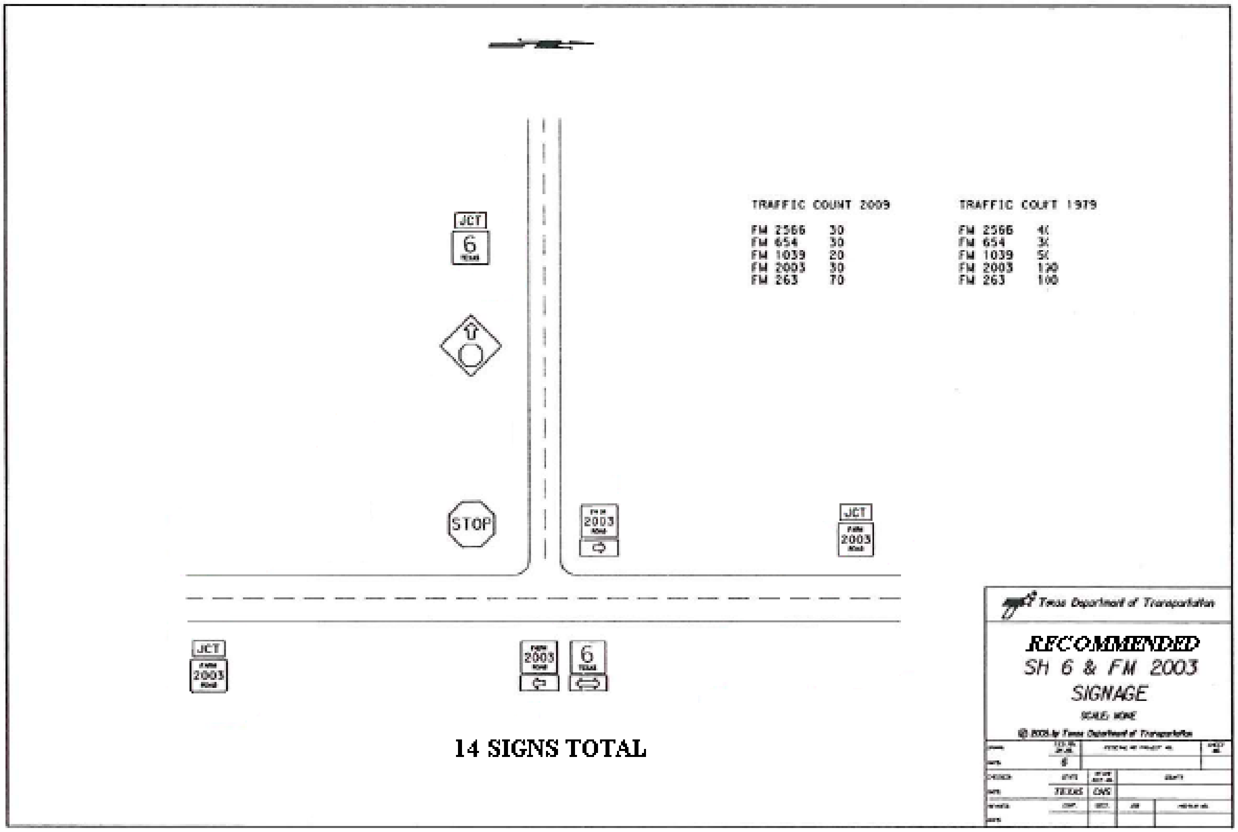

Figure 3. SH 6 and FM 2003 Reduced Signage Recommended.

CHAPTER 3: UPDATE ON SEQUENTIAL DYNAMIC CURVE WARNING SYSTEM RESEARCH

The TTI research team is part of a group working on a FHWA Highways for Life project evaluating the sequential dynamic curve warning system. The following web address is the FHWA page for the project, http://www.fhwa.dot.gov/hfl/partnerships/safety_eval/tapco.cfm . This section of the report will provide TxDOT an update on the portion of the project that is taking place on TxDOT roadways.

PROJECT BACKGROUND

The basis for the project is that horizontal curves are an area that experiences a high rate of crashes compared to tangent sections and thus can provide the best bang for the buck as far as investment to reduce crashes. The majority of crashes on curves are single vehicle run off the road crashes. The sequential dynamic curve warning system replaces the standard curve warning signs and chevrons in a curve with solar-powered LED-imbedded signs. The system detects cars approaching the curve above a predetermined speed and activates flashing LEDs in the curve warning sign and sequentially in the chevrons to alert the driver of the upcoming curve. The goal of the system is to alert the drivers of the curve in hopes of reducing the speeds of the upper percentiles of drivers. Drivers traveling the curves closer to the advisory speed should result in greater safety. In addition to monitoring speeds, the research team will also monitor crashes in the curves. Researchers will use a Before and After study to evaluate the systems impact on crashes.

TTI is working with the Center for Transportation Research and Education at Iowa State University on this national project. Iowa State is managing eight new sites in three different states on state roads and evaluating several other previously installed systems. TTI is managing four new sites in Texas on TxDOT roads and evaluating four other curves (non-DOT roads) in Texas that have already had the system installed. TAPCO, the manufacturer of the system, is providing the systems free of charge to the host states. At the end of the project, the DOT has the option to keep or return the signs.

The system was of interest to several people within TxDOT and it was agreed that Texas would serve as a host state. To help TTI provide better support to TxDOT and to lessen any burdens on TxDOT, it was agreed to use funding from the 9-1001 project to support TTI's efforts in evaluating the sequential dynamic curve warning system.

SITE SELECTION

The goal for Texas was to have four installation sites for the sequential dynamic curve warning system and eight comparison sites. The research team used two methods to identify possible locations: 1) recommendations from TxDOT and 2) exploration of a curve crash database. Both methods of identifying sites and the process of selecting the final sites are described in the following sections.

Site Identification

The TTI team started the process of identifying potential curve locations by contacting each of the 25 TxDOT districts via e-mail. The districts were asked if they were interested in participating in the study and, if so, if they had any sites that met the following criteria:

- Two-lane rural paved roads.
- Posted speed limit of 50 mph or above.
- Existing chevrons.
- No unusual conditions within the curve (RR crossing or major access).
- High crash location (10 or more in the last five years, not including animal collisions): speed related would be preferred.
- No major rehab/changes in alignment/operations in the last 3 years.
- No major rehab/changes in alignment/operations planned for the next 2 years.

Six districts responded with 15 suggested curves. These curves were then reviewed for geometric and site characteristics, using Google Earth. The crash histories at the curves were also evaluated. Several of the curves were found to not adequately meet the criteria the research team was looking for. The researchers wanted to have at least 20 curves to visit, hoping that at least 12 would be suitable for the study. Because of this need for additional sites, they explored a second method to identify curves.

The TTI team decided to use a database that was developed in another research project to help identify potential curves. The database contains single-vehicle, run-off-the-road crashes for every horizontal curve in the state. The crash database was filtered to exclude curves with few crashes. The remaining curves were then viewed in Google Earth to determine if their geometric and site characteristics matched the criteria for the study.

In total, the research team found 27 potential curve locations in TX that met or came close to meeting all of the criteria established for the study. They used TxDOT's Crash Records Information System (CRIS) to verify the crashes in the curves. The researchers extracted traffic and geometric data such as AADT, heavy-vehicle percentage, surface width and type, and shoulder width and type from TxDOT's Road-Highway Inventory Network (RHiNo) database. The horizontal curve information was extracted from the Texas Reference Marker System (TRM) Geometrics (GEO-HINI) database. The GEO-HINI database contains geometrics for all curves on all highways in the state. Each curve is given a unique curve identifier number, and the beginning and end mile points of each curve are located through a given reference marker and curve length from that marker. Based on the information gathered, the team then proceeded to conduct site visits at all 27 of the potential curve locations. Figure 4 provides the locations of all of the suggested and visited curves in Texas. The green markers represent the preexisting flashing chevron locations in Texas. The yellow markers represent tentative comparison sites and the blue markers represent tentative installation sites. The red markers represent locations that were suggested or considered based on crashes but were the lowest priority sites before the site visits.

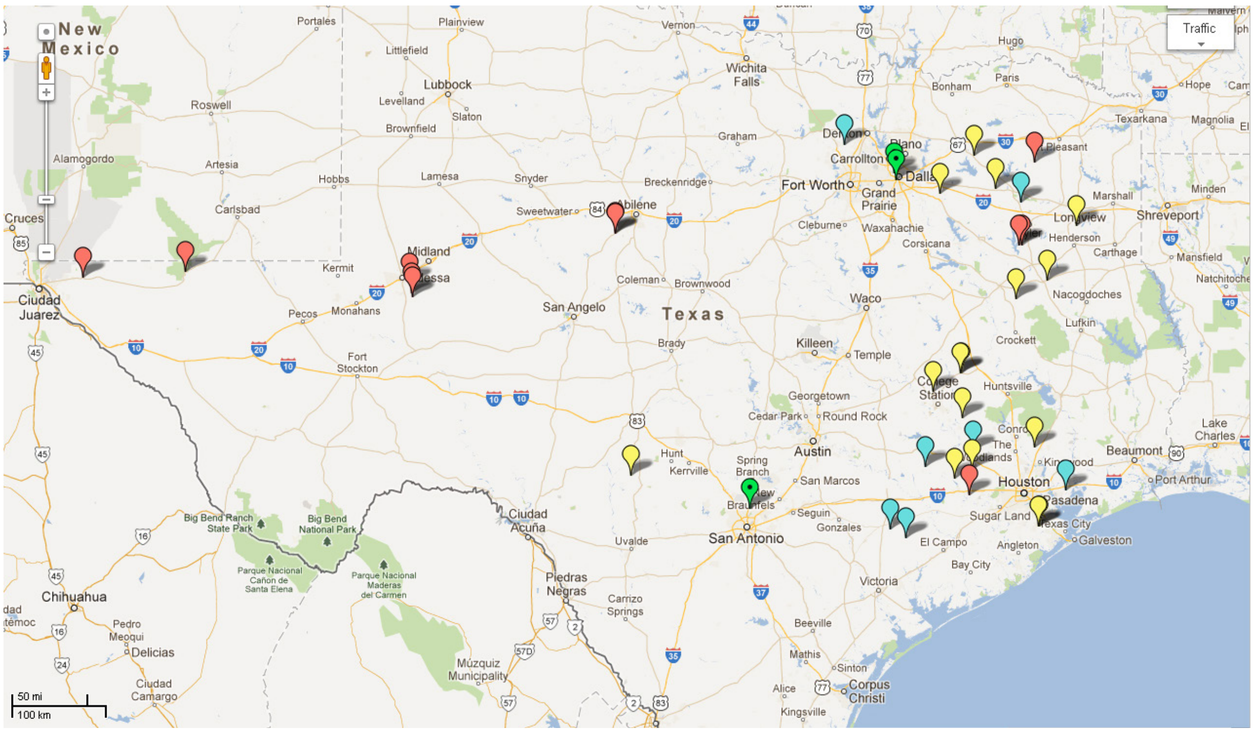

Figure 4. All Suggested and Visited Sites in TX.

Site Visits

The TTI team traveled to all of the initial sites except those in West Texas. They visited 27 potential curve locations to document site conditions, and took or recorded pictures and video prior to and throughout the curves. The number and size of the chevrons were also recorded. The researchers also documented the site characteristics such as lane and shoulder width, tangent and curve advisory speeds, road surface conditions, pavement markings and road side conditions such as driveways and guardrails.

A ball bank indicator (BBI) was used to determine if the posted advisory speeds are appropriate and consistent between the different curves. The researchers initially drove through the curves at the posted advisory speed and monitored the BBI reading. The research team was looking for a sustained maximum reading of around 10. If the reading was higher than 10, the researchers would drive through the curve 5 mph slower than the curve advisory speed while monitoring the BBI. The curve was driven at 5 mph slower increments until the BBI was at approximately 10. If the initial BBI reading was less than 10, the researchers drove through the curve at 5 mph increments faster than the advisory speed while monitoring the BBI until the reading was approximately 10. In general, the research team was looking for the advisory speed to be within 5 mph of the speed that resulted in a BBI reading of approximately 10.

In addition to the BBI readings, the research team also collected spot speeds at many of the visited sites. Some sites were not collected due to the following reasons:

- Adjacent utilities work that would influence speeds.
- Lack of an area to safely be in a position to record speeds.
- The curves were viewed as not being useable for the study.

Where speeds were collected, the researchers collected the speeds on any approach that may be considered for installation of the flashing chevrons. Some curves such as S curves or curves that had another curve nearby were limited in the directions of travel that can be considered due to the influence of the adjacent curves. Speeds were typically collected for approximately an hour at each location. Some of the lower volume locations had few readings, but enough to get a grasp on the speeds at which the drivers were approaching the curves. Speeds were recorded just prior to the PC. The spot speeds were collected to evaluate the speeds while entering the curve, and if they were higher than the posted advisory speed. At all sites the average speeds collected were above the posted advisory speeds.

Selected Sites

Using the information gathered during the site visit allowed the research team to compare the physical features of the curves to those listed in the TxDOT databases to ensure accuracy. The field visits also yielded speed information and additional visual information about the curve location. By using the field visit information with the crash history of the curves and the predetermined criteria for site selection, the researchers selected the 12 best curves for Texas. Of these 12 curves, four were selected for the installation of the sequential dynamic curve warning system. Figure 2 shows the location of the selected sites. The yellow markers represent comparison sites, the blue markers represent the installation sites, and the green markers represent preexisting flashing chevron locations in Texas. Table 3 has a summary of the site characteristics and notes. The rows shaded gray are the four installation sites.

One factor that influenced the selection of the sites was a recent change in law that removed nighttime and truck speed limits from TxDOT roadways. Prior to the new law, all roads in Texas that had a speed limit of 70 mph or above during the day were limited to 65 mph during the night. By January 2012, the majority of roads were resigned to remove the truck and night speed limits. For this reason, the research team did not want to select any roads with a

70 mph speed limit or above, or roads with truck speed limits due to a possible influence on speeds and crashes that the new law may have.

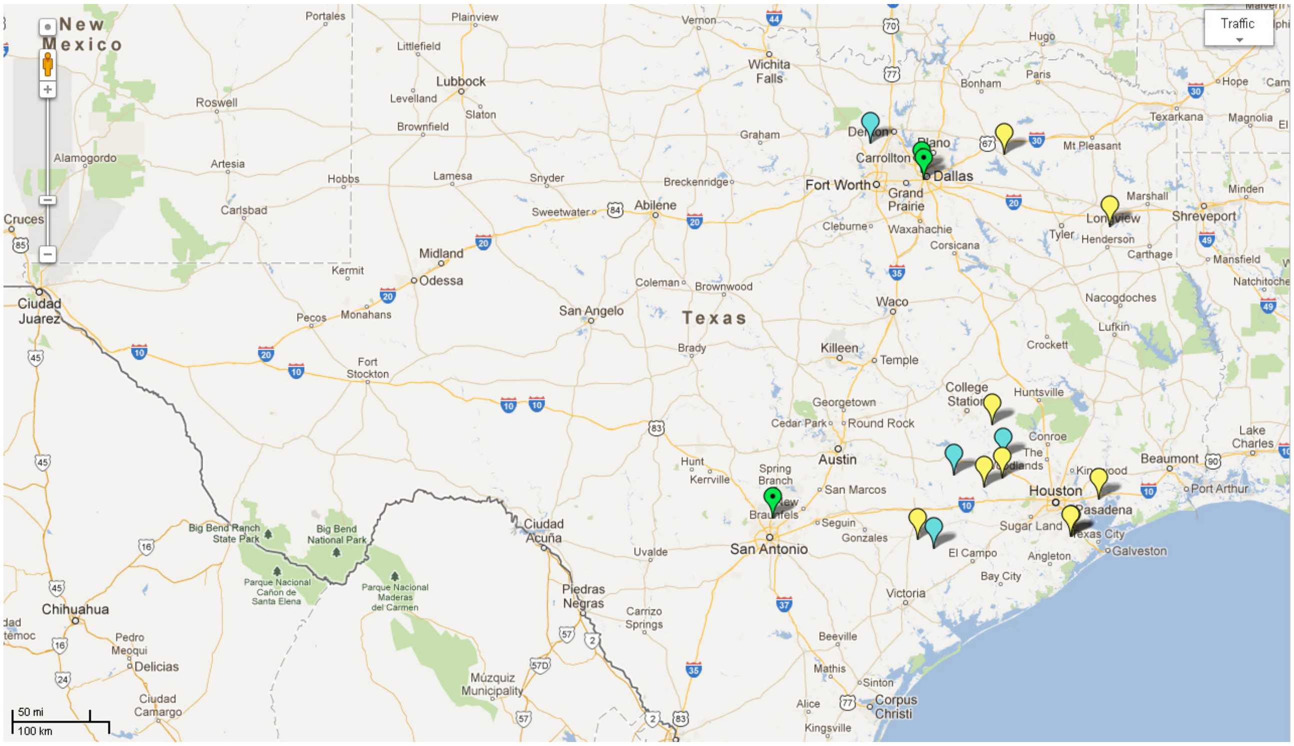

Figure 5. Final Install and Comparison Sites in Texas.

Table 3. Site Characteristics.

Site I.D.	Route	ADT	% trucks	Posted Speed of Tangent Sections	Curve Advisory Speed	Number of Chevrons	Chevron Size (in.)
BEA565	FM 565	9300	6.5	50	40	5	18x24
BRY3090	FM 3090	360	14.1	60-65	30	7	18x24
DAL407	FM 407	5000	11	55	40	6	18x24
HOU1488	FM 1488 (FM362)	4400	10.6	55	40	13	18x24
HOU362	FM 362	2600	13.7	55	40	13	18x24
HOU517	FM 517	10400	4.2	60	50	9	18x24
PAR1567	FM 1567	1550	3.9	55	40	5	24x30
TYL1249	FM 1249	710	5	55	50	5	18x24
YOA109	FM 109	2500	9.1	60	35	6	18x24
YOA331	FM 331	940	5.6	60	50	5	18x24
YOA530A	FM 530	1200	11.7	60	40	7	18x24
YOA530B	FM 530	560	9.8	60	35	6+arrow	18x24 chevron, 36x18 arrow

SIGN INSTALLATION

The research team worked with the equipment manufacturer to build the correctly sized signs to replace the current ones at each site with the sequential dynamic curve warning system. The research team and the equipment manufacturer installed the signs at all four sites in three days. The FM 530 site took extra time to get the speed radar adjusted adequately due to a slight curve in the road where the radar was detecting the vehicles. Varying sign mounting hardware at the different sites and even within an individual site added time to the installation but did not pose a problem. All of the signs were installed from a truck or from a ladder, depending on the site characteristics and the mounting height of the signs.

Figure 6 shows the flashing LED curve warning sign. The new sign also has a solar charging system and speed activation radar. The box above the sign contains the speed activation radar and the controller for the flashing system that communicates with the chevrons. The radar is able to shoot through the plastic shell of the box. Each site in Texas had the speed activation set at 10 mph above the curve warning speed. This means that any vehicle approaching the curve warning sign and going 10 mph or greater above the curve warning speed would activate the system. Each chevron also has a controller so they can communicate with each other for the sequential flashing. Each site had a slightly different flash rate, based on the number of chevrons, the posted speed, and the chevron spacing. Each chevron has its own individual solar panel charging system. All of the solar panels were aimed toward the south to maximize charging time.

Figure 6. New Flashing Curve Warning Sign with Speed Activation and Solar Charging System.

The Texas installations were the first set of installations for TAPCO where the standard round sign poles had chevrons mounted for both directions. It was expected that with two chevrons on the same pole, there may be clearance issues with the additional hardware of the flashing chevron signs. There was also a concern that it may be difficult to properly align both signs for their directions of travel. TAPCO designed a bracket system to be used with the standard sign mounting hardware that allows the flashing chevron sign to be moved slightly away from the pole, thus allowing enough clearance to not be affected by the sign on the other side. This bracket also allowed the flashing chevron sign to be turned independent of the standard mounting hardware, which allows for much easier alignment of the directional LEDs that are integrated into the sign face. After the sign was tightened to the brackets, the signs were rotated until they were positioned for optimal visibility of the flashing LEDs to the drivers. The LEDs have a narrow cone so they need to be facing toward the road. The additional brackets allowed the signs to be easily rotated and then tightened into place.

Figure 7 is a picture of one of the installed chevrons in front of a fence that vehicles have hit numerous times. The homeowner came out and talked to the installation crew to see what was going on and was happy to hear about the system. He indicated his property has been hit at least five times in the last eight years since he has owned it.

Figure 7. Installed Flashing Chevron near Where Vehicles Have Driven through Fence.

DATA COLLECTION

Two types of data will be collected during this project. The first type of data is crash records; the second is operational data at the sites. Crash records will be collected for a period before the installation of the signs and throughout the study period. This will allow the researchers to conduct a before and after study with a control group on the impact of the signs with regards to number and severity of crashes. Operational data collection will consist of collecting speed data at various points at each site. Free flow speed will be collected upstream of the curve where the system will not influence the speed. Speeds will also be collected at the point of curvature and midpoint of the curve. Operational data will be collected using road tubes and will be collected for at least 24 hours at each site. Crash data will be collected at all 12 sites, while operational data will only be collected at the four installation sites.

The signs will be installed and studied for 18 months. Operational data were collected prior to the installation of the signs. Operational data will be collected three additional times at 1 to 2, 11 to 12, and 17 to 18 months after installation at each of the four installation sites. The signs were installed in July 2012.

FUTURE WORK

The next steps for the research are to continue to monitor the sites to ensure proper operation of the sequential dynamic curve warning system, and to collect and analyze the crash and operational data. Data collection is expected to end in January 2014. At the conclusion of the data collection the research team will work with TxDOT to either replace the signs with the original signage that was removed or will leave the sequential dynamic curve warning system in place. The research team will report the Texas results of the study to TxDOT after the final set of data has been collected and analyzed.

CHAPTER 4: ADDITIONAL RESEARCH ACTIVITIES

DEVELOPMENT OF HURRICANE EVACUATION ANIMATION MAPS FOR CRP

This task concentrated on the development of animated evacuation maps for the Corpus Christi District to facilitate the dissemination of evacuation related information by the local print and broadcast media. The overall goal of this effort was to provide information to the media to facilitate improved communication of the importance of using alternate routes to I-37 in the event of a hurricane evacuation from the region. The diversion of traffic from I-37 to alternate routes during either an evacuation under normal traffic control, EvacuLane operation, or full Contraflow operations will result in an overall improvement in region wide evacuation traffic flows and reduced motorist delays.

In the previous two years' activity, TTI staff developed maps that highlighted the alternate routes to using I-37 during an evacuation event and delivered each of the maps into animation files. The work effort this year utilized enhanced mapping software to provide for increased clarity and information to users. Additionally, the motion maps were also developed in high-resolution versions that could be made available to the media as well as for inclusion in web pages for direct distribution to the general public. A PowerPoint™ presentation file for each evacuation route was also prepared. The animation maps were developed for each of the five recommended alternate routes as well as for I-37 (see Figure 8) and all were delivered to the District prior to the June 1 start of the 2012 Atlantic hurricane season.

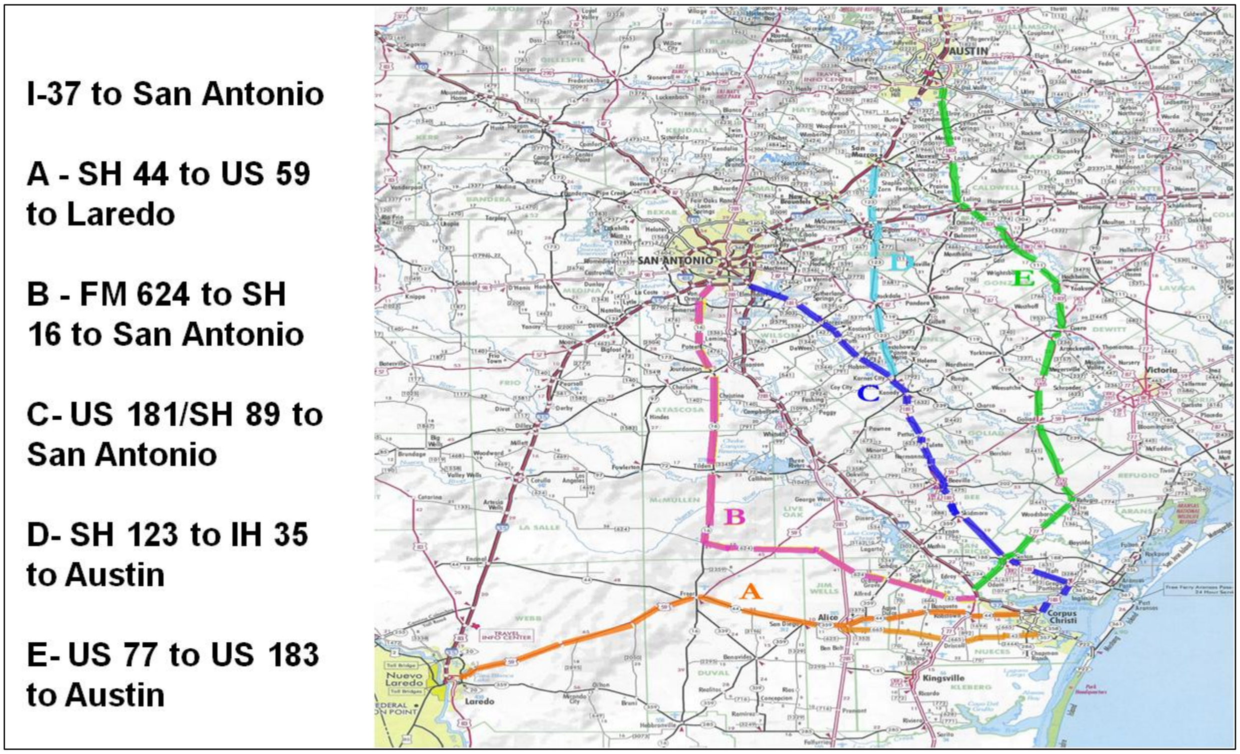

Figure 8. Evacuation Routes from Corpus Christi District.

MOBILE PAVEMENT MARKING RETROREFLECTIVITY DATA TRAINING

In recent years, the use of mobile retroreflectometers to collect retroreflectivity readings on pavement markings in Texas has increased. The mobile retroreflectometer is a powerful tool that can collect large amounts of pavement marking retroreflectivity data. This often results in large amounts of data that can be overwhelming and difficult to interpret.

TxDOT approached the research team late in the fiscal year and requested that work be started on developing training to help interpret mobile retroreflectivity data. There are many questions that arise as far as validating the quality of the data, interpreting the data received, and how to best use the various forms of data that can be requested from the contractor. The goals of this training will be to help TxDOT:

- Understand the data collection process.
- Verify data accuracy.
- Understand and use the data received.

Currently, Special Specification 8094: Mobile Retroreflectivity Data Collection for Pavement Markings governs the collection of mobile retroreflectivity data. This specification is used for verifying that new markings are meeting required initial retroreflectivity levels, as well as for measuring the retroreflectivity of pavement markings for maintenance purposes.

In the next fiscal year of this project the research team will continue and complete the work on this topic if the research panel approves the additional work. The researchers will conduct a series of surveys and interviews of districts that have had recent experience with mobile pavement marking retroreflectivity data collection. They will use the experiences of these districts to help develop the training so that other districts can implement the positive aspects and improve on the negatives of past data collection.

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