Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-09/0-4701-5		

4. Title and Subtitle	5. Report Date
EVALUATION OF TRAFFIC CONTROL DEVICES: FIFTH-YEAR ACTIVITIES	October 2008 Published: February 2009
	6. Performing Organization Code
7. Author(s) H. Gene Hawkins, Jr., Adam Pike, and Mehdi Azimi	8. Performing Organization Report No. Report 0-4701-5
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-4701
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 2007–August 2008 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/0-4701-5.pdf

16. Abstract

This project was established to provide a means of conducting limited scope evaluations of numerous traffic control device issues. During the fifth, and final, year of the project, researchers conducted four activities: improving the interface for the automated process for identifying the start and end of no-passing zones developed during the fourth year, continuing the evaluation of the performance of lead-free yellow thermoplastic pavement markings started at the end of the fourth year, continuing development of the *Work Zone Implementation Handbook*, and creating an updated edition of the *Sign Crew Field Book*. The last two of these activities produced stand-alone documents for Texas Department of Transportation (TxDOT) use. The evaluation of lead-free thermoplastic found that the material performs well in most, but not all, areas. The improved interface for the automated no-passing zone was tested in the field at two sites, and the results indicate that the results are consistent with existing no-passing zone markings when considered for vertical alignment only.

17. Key Words	18. Distribution Statement
Traffic Control Devices, No-Passing Zones, Pedestrian Countdown Timers, Thermoplastic Pavement Markings	No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	60	

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

EVALUATION OF TRAFFIC CONTROL DEVICES: FIFTH-YEAR ACTIVITIES

by

H. Gene Hawkins, Jr., Ph.D., P.E.
Research Engineer
Texas Transportation Institute

Adam Pike
Associate Transportation Researcher
Texas Transportation Institute

and

Mehdi Azimi
Graduate Research Assistant
Texas Transportation Institute

Report 0-4701-5
Project 0-4701
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Federal Highway Administration

October 2008
Published: February 2009

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

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 Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names may appear herein solely because they are considered essential to the object of this report. This report does not constitute a standard, specification, or regulation. The engineer in charge was H. Gene Hawkins, Jr., P.E. #61509.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and the FHWA. The authors would like to thank the project director, Michael Chacon, and the program coordinator, Meg Moore, both 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 members of the Project Monitoring Committee included:

- Stuart Corder, TxDOT Houston District;
- Paul Frerich, TxDOT Yoakum District;
- Carlos Ibarra, TxDOT Atlanta District;
- Doug Skowronek, TxDOT Traffic Operations Division;
- Ismael Soto, TxDOT Corpus Christi District;
- Brian Stanford, TxDOT Traffic Operations Division;
- Henry Wickes, TxDOT Traffic Operations Division;
- Roy Wright, TxDOT Abilene District; and
- Jerral Wyer, TxDOT Occupational Safety Division.

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CHAPTER 1: INTRODUCTION

INTRODUCTION

Traffic control devices provide one of the primary means of communicating vital information to road users. Traffic control devices notify road users of regulations and provide warning and guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream. There are three basic types of traffic control devices: signs, markings, and signals. These devices promote highway safety and efficiency by providing for orderly movement on streets and highways.

Traffic control devices have been a part of the roadway system since almost the beginning of automobile travel. Throughout that time, research has evaluated various aspects of the design, operation, placement, and maintenance of traffic control devices. Although there have been many different studies over the decades, recent improvements in materials, increases in demands and conflicts for drivers, higher operating speeds, and advances in technologies have created continuing needs for the evaluation of traffic control devices. Some of these research needs are significant and are addressed through stand-alone research studies at state and national levels. Other needs are smaller in scope (funding- or duration-wise) but not smaller in significance.

Unlike many other elements of the surface transportation system (like construction activities, structures, geometric alignment, and pavement structures), the service life of traffic control devices is relatively short (typically anywhere from 2 to 12 years). This shorter life increases the relative turnover of devices and presents increased opportunity for implementing research findings. The shorter life also creates the opportunity for incorporating material and technology improvements at more frequent intervals. Also, the capital cost of traffic control devices is usually less than that of these other elements. Research on traffic control devices can also be (but is not always) less expensive than research on other infrastructure elements of the system because of the lower capital costs of the devices.

The traditional Texas Department of Transportation (TxDOT) research program planning cycle requires about a year to plan a research project and at least a year to conduct and report the results (often two or more years). With respect to traffic control devices, this type of program is best suited to addressing longer-range traffic control device issues where an implementation decision can wait two or more years for the research results.

In recent years, elected officials have also become more involved in passing ordinances and legislation that directly relate to traffic control devices. Examples include: creating the logo signing program, establishing signing guidelines for traffic generators (such as shopping malls), and revising the *Manual on Uniform Traffic Control Devices* (MUTCD) to include specific signs. When these initiatives are initially proposed, TxDOT has a very limited time to respond to the concept. While the advantages and disadvantages of a specific initiative may be apparent, there may not be specific data upon which to base the response. Due to the limited amount of available time, such data cannot be developed within the traditional research program planning cycle.

As a result of these factors (smaller scope, shorter service life, lower capital costs, and the typical research program planning cycle), some traffic control device research needs are not addressed in a traditional research program because they do not justify being addressed in a stand-alone project that addresses only one issue. This research project addresses these types of traffic control device research needs. This project is important because it provides TxDOT with the ability to:

- address important traffic control device issues that are not sufficiently large (either funding- or duration-wise) to justify research funding as a stand-alone project,
- respond to traffic control device research needs in a timely manner by modifying the research work plan at any time to add or delete activities (subject to standard contract modification procedures),
- effectively respond to legislative initiatives associated with traffic control devices,
- conduct traffic control device evaluations associated with a request for permission to experiment submitted to the Federal Highway Administration (FHWA) (see MUTCD Section 1A.10),
- address numerous issues within the scope of a single project,
- address many research needs within each year of the project, and
- conduct preliminary evaluations of traffic control device performance issues to determine the need for a full-scale (or stand-alone) research effort.

FIRST-YEAR RESEARCH ACTIVITIES

During the first year of this research project, the research team undertook the research activities listed in Table 1-1. The first-year report describes the research efforts, results, and recommendations associated with these activities (*1*). Table 1-1 also presents brief descriptions of the results of the first-year efforts, along with the current implementation status.

Table 1-1. First-Year Activities.

Activity	Result	Status
Evaluated the effectiveness of dual logos.	Indicated that there is no evidence that the limited use of dual logos would be a problem.	TxDOT implemented dual logos with the logo signing contract that went into effect January 1, 2007. Dual logos were incorporated into the 2006 Texas MUTCD.
Assessed the impacts of rear-facing school speed limit beacons.	Found that rear-facing beacons improve compliance.	TxDOT incorporated rear-facing beacons in the 2006 Texas MUTCD.
Evaluated the impacts of improving Speed Limit sign conspicuity.	Found some indication that the red border improves compliance, but the data were not conclusive.	The effort was continued into the second and third years, and the results are described in each of those reports.
Crash-tested a sign support structure.	The support structure failed the test.	The support structure was redesigned, and additional crash tests were conducted outside of this project. These crash tests were successful. FHWA has approved the redesign support, and it is being used in Texas.
Evaluated the benefits of retroreflective signal backplates.	Found that there was no apparent benefit to using the retroreflective backplate at the study location.	FHWA issued an interim rule that allows the use of backplates under specific circumstances. Retroreflective backplates have been included in the 2006 Texas MUTCD.
Developed improved methods for locating no-passing zones.	Provided descriptions of multiple methods for determining the start and end of no-passing zones, but provided no testing of the accuracy of the methods.	A fourth- and fifth-year activity developed a method of using Global Positioning System (GPS) data to establish no-passing zones based on vertical alignment, and the results are described in each of those reports.

SECOND-YEAR RESEARCH ACTIVITIES

During the second year of this research project, the research team undertook the research activities listed in Table 1-2. The second-year report describes the research efforts, results, and recommendations associated with these activities (*2*). Table 1-2 also presents brief descriptions of the results of the second-year efforts, along with the current implementation status.

Table 1-2. Second-Year Activities.

Activity	Result	Status
Evaluated the effectiveness of an extinguishable message Left Turn Yield sign.	Found the sign significantly reduced crashes and conflicts at the one location studied.	TxDOT plans to identify the benefits of the treatment in a letter to districts.
Evaluated the impacts of improving Speed Limit sign conspicuity.	Found significant long-term benefits to using the supplemental red border evaluated in the first year.	Long-term benefits of the revised sign design were evaluated in the third year.
Evaluated the benefits of dew-resistant retroreflective sheeting.	Discovered that dew-resistant sheeting reduces the formation of dew on the sign face and improves nighttime visibility of the sign.	TxDOT should conduct field testing of the prototype material to evaluate long-term performance. The prototype material evaluated has not become a commercially available product.

THIRD-YEAR RESEARCH ACTIVITIES

During the third year of this research project, the research team undertook the research activities listed in Table 1-3. The third-year report describes the research efforts, results, and recommendations associated with these activities (*3*). Table 1-3 also presents brief descriptions of the results of the third-year efforts, along with the current implementation status.

Table 1-3. Third-Year Activities.

Activity	Result	Status
Evaluated the impacts of improving Speed Limit sign conspicuity.	Found that use of red border reduces vehicles' speeds when used where the speed limit decreases.	TxDOT is evaluating potential implementation as a change in the MUTCD. The red border treatment was included in the 2008 proposed changes to the 2003 national MUTCD.
Developed recommendations for sign and marking design for super high-speed roadways.	Recommended using a 22 inch minimum legend for freeway signs and a 6 inch wide pavement marking.	To be determined.
Compared marking retroreflectivity measurements using portable and handheld instruments.	Found that portable and mobile measurements are consistent with one another if both retroreflectometers are properly calibrated and operated correctly.	TTI established a mobile retroreflectivity certification program to promote accurate measurement of marking retroreflectivity using mobile units.
Updated the TxDOT *Traffic Signal Warrant Guidelines*.	Developed an updated warrant guide.	To be distributed by TxDOT.
Evaluated lateral placement of rumble strips on two-lane highways.	Found that there was insufficient information available to address the issue.	The issue will be addressed in detail in Project 0-5577.
Began development of the *Work Zone Implementation Handbook*.	Initiated handbook development.	Work on handbook continued in fourth and fifth years.

FOURTH-YEAR RESEARCH ACTIVITIES

During the fourth year of this research project, the research team undertook the research activities listed in Table 1-4. The fourth-year report describes the research efforts, results, and recommendations associated with these activities (*4*). Table 1-4 also presents brief descriptions of the results of the fourth-year efforts, along with the current implementation status.

Table 1-4. Fourth-Year Activities.

Activity	Result	Status
Developed an automated process for identifying the start and end of no-passing zones.	Developed a graphic interface to simplify use of the automated system and conducted additional field evaluations of its effectiveness.	The proof-of-concept has been confirmed but could use additional implementation refinement.
Developed guidelines for the use of pedestrian countdown signals.	Developed guidelines for when and where pedestrian countdown signals should be retrofitted for existing installations.	Pedestrian countdown signals are included in the 2008 proposed changes to the 2003 national MUTCD. The proposed changes would require countdown timers for all new installations and would require all existing intersections to convert within 10 years.
Evaluated the performance of lead-free yellow thermoplastic pavement markings.	Because this activity started late in the year, researchers were not able to analyze performance over a long enough period to draw conclusions.	The evaluation continued into the fifth year.
Developed improved guidelines for accessibility issues associated with traffic signalization.	Prepared a manual chapter on signalized intersection accessibility.	The chapter can be added to the appropriate TxDOT manual.
Continued development of the *Work Zone Implementation Handbook*.	Continued handbook development during the year.	Work on handbook continued in the fifth year.

FIFTH-YEAR RESEARCH ACTIVITIES

During the fifth year of this research project, the research team undertook the following research activities:

- refined the automated process for identifying the start and end of no-passing zones developed in the fourth year (Chapter 2),
- evaluated the performance of lead-free yellow thermoplastic pavement markings (Chapter 3),
- created an updated edition of the *Sign Crew Field Book* (Chapter 4), and
- continued development of the *Work Zone Implementation Handbook* (Chapter 4).

This report describes these activities in the chapters indicated in parentheses. Each of the chapters in this report has been prepared so that it can be distributed as a stand-alone document if desired.

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4. Hawkins Jr., H.G., C.L. Williams, and S. Sunkari. *Evaluation of Traffic Control Devices: Fourth-Year Activities*. FHWA/TX-08/0-4701-4, Texas Transportation Institute, The Texas A&M University System, College Station, Texas, October 2007.

CHAPTER 2:
AUTOMATED LOCATION OF NO-PASSING ZONES USING GPS

INTRODUCTION

Identifying and marking no-passing zones provides a challenge to transportation agencies. Many agencies currently use some form of method that involves physically evaluating sight distance in the field. The use of Global Positioning System (GPS) coordinates provides an alternative means of evaluating no-passing zone sight distance and creates the potential for an automated system. In the fourth year, researchers developed a computerized process that determines the start and end points of no-passing zones for the vertical profile based on GPS data. However, the steps for processing the GPS raw data and creating the input file were complicated and were not user friendly. In addition, the complexity created a potential for mistakes during those steps. To solve these problems, researchers developed a preprocessing routine to simplify the data entry process. Researchers also conducted field tests at two field sites to validate the effectiveness of the system.

IMPROVING PROGRAMS

The researchers began this activity by developing a preprocessing routine (user interface) that presented a user-friendly procedure for entering the collected data and creating the input file for the no-passing zone program.

User Interface Design

The MCR installer and the no-passing zone program are used in the process of identifying the start and end of no-passing zones based on GPS data. Prior to running the no-passing zone program, it is necessary to prepare the input file for the program. Previously, when creating the input file for the no-passing zone program, the user had to deal with copying and pasting a lot of data in different Excel worksheets, which involved several steps. First, the data from the GPS run had to be imported into an Excel worksheet (raw data). Then, the raw data had to be cleaned using the pre-written macro to eliminate extra data points. The macro had been written based on the assumption of collected data every one second. If GPS data had collected a value other than 1 Hz (one time per second) during the data collection, the written macro had to be changed and written again. After cleaning the data, several steps had to be conducted with the

Excel sheets, using copy and paste, to convert the GPS latitude/longitude data into northing, easting, and station data. All of these steps were complicated for the user and created the likelihood of making a mistake. The GPS conversion program was developed to facilitate the creation of the input file for the no-passing zone program.

GPS Conversion Program

The purpose of the GPS conversion program is to process raw data collected from straight alignments and to generate the input file for the no-passing zone program. The GPS conversion program eliminates the extra data points and cleans the data, converts GPS coordinates (longitude and latitude values) to northing and easting values, calculates stations and elevations for the segment of the roadway, and generates the no-passing zone input file. The following steps explain how this program works.

The data file that is retrieved from the GPS instrument after data collection may include different types of information, based on the type and the model of the instrument. But the only data needed for the GPS conversion program are time of collection, longitude, latitude, and elevation. The retrieved data should be opened in Excel to delete extra information. The final format of the Excel file should be in four columns—time, longitude, latitude, and elevation—in sequence, numeric only, without any labels (see Figure 2-1). In the file, the latitude and longitude values are required to be in the format of "minutes.decimal minutes" (mm.mm) and elevation values are required to be shown in meters. Then the Excel file should be saved as a text file (tab delimited) with any name.

After saving the file, the user can run the GPS conversion program by double clicking on the GPS_conversion executable file. This opens the main window of the program (see Figure 2-2).

By clicking on the Read Input Data button and giving the address of the text file (see Figure 2-3), the GPS data can be loaded into the program, as shown in the left box of the main window (see Figure 2-4).

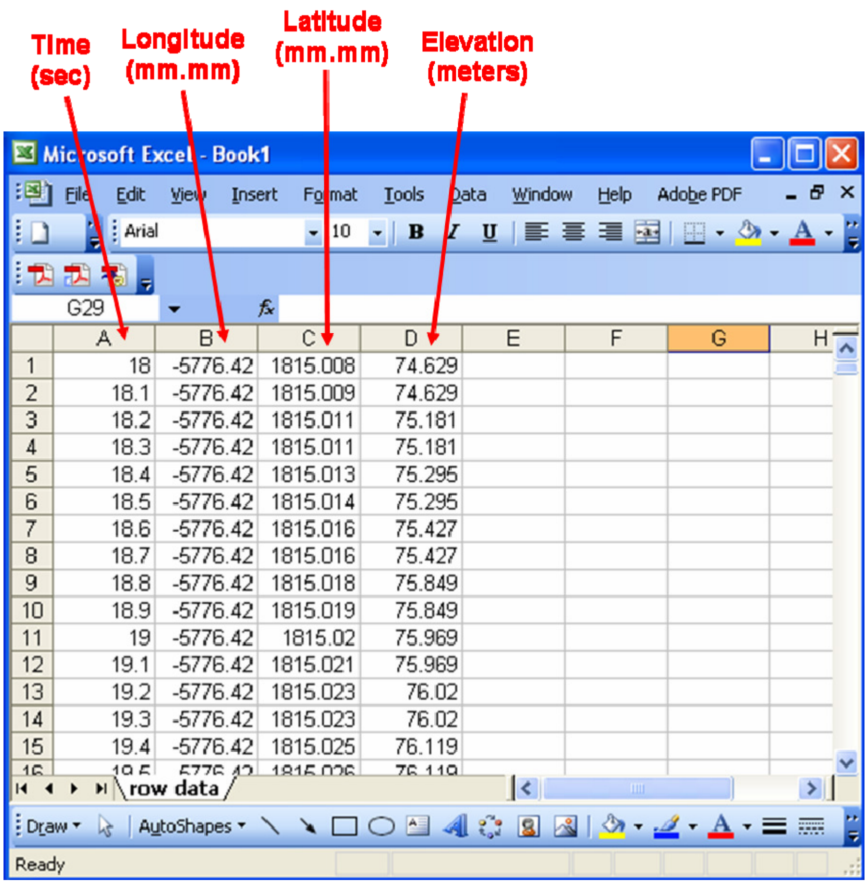


Figure 2-1. Eliminating Extra Data in Excel File.

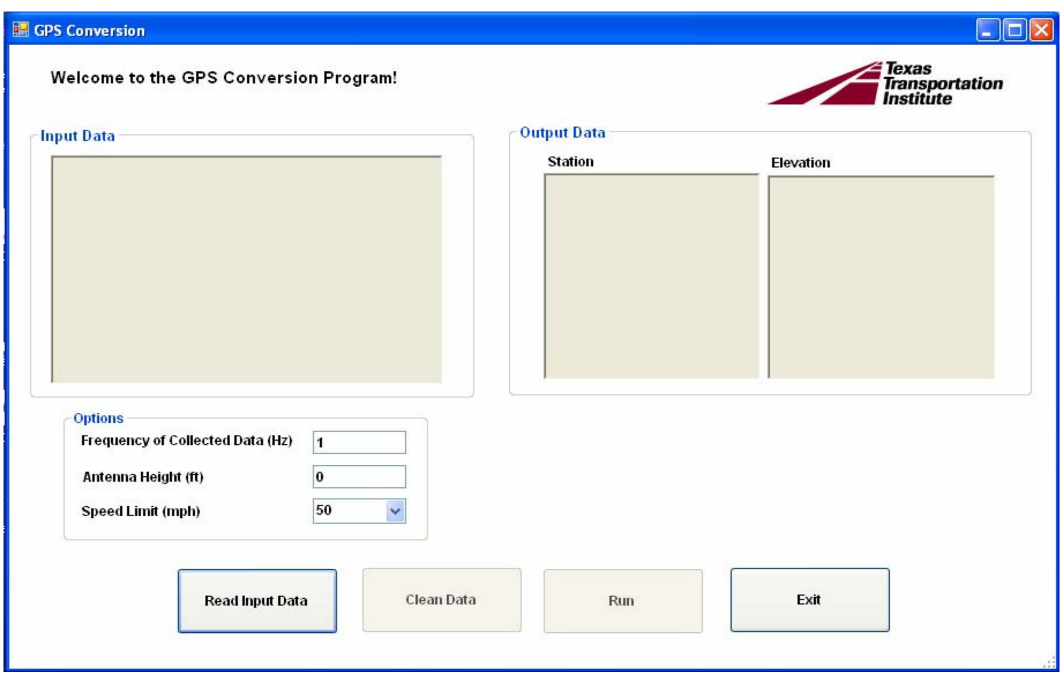


Figure 2-2. Main Window of GPS Conversion Program.

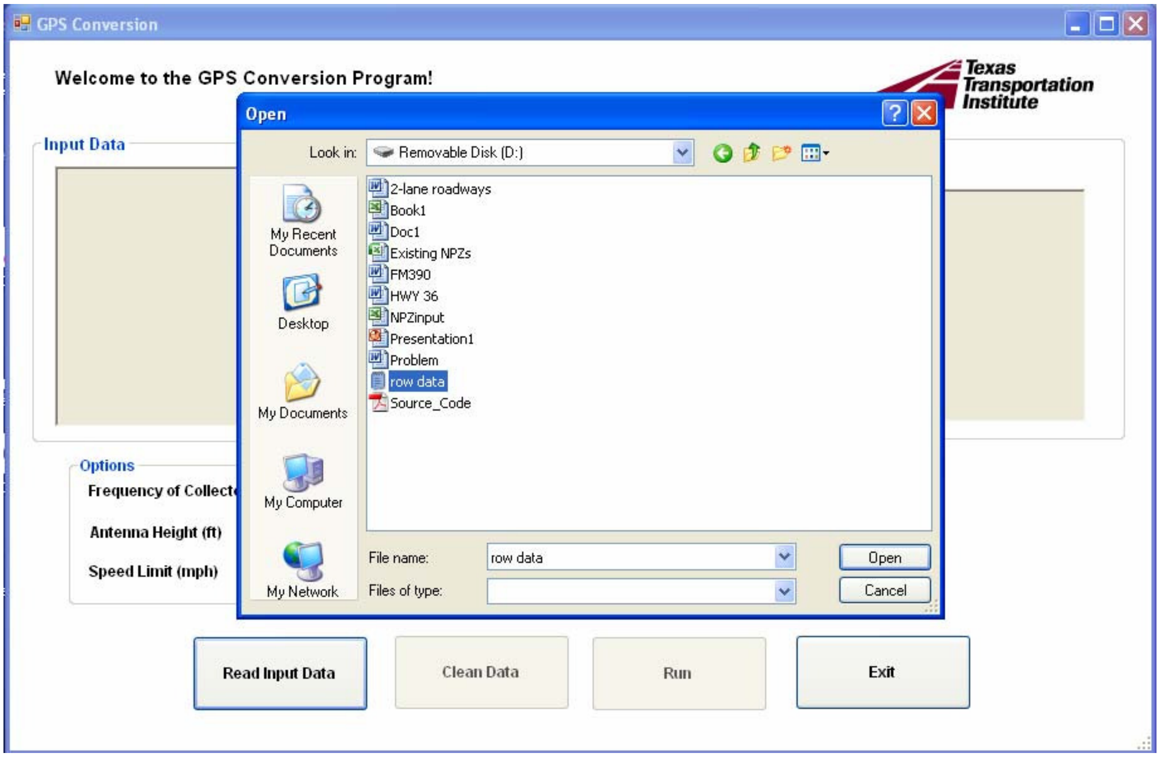


Figure 2-3. Addressing the Text File and Reading Input Data.

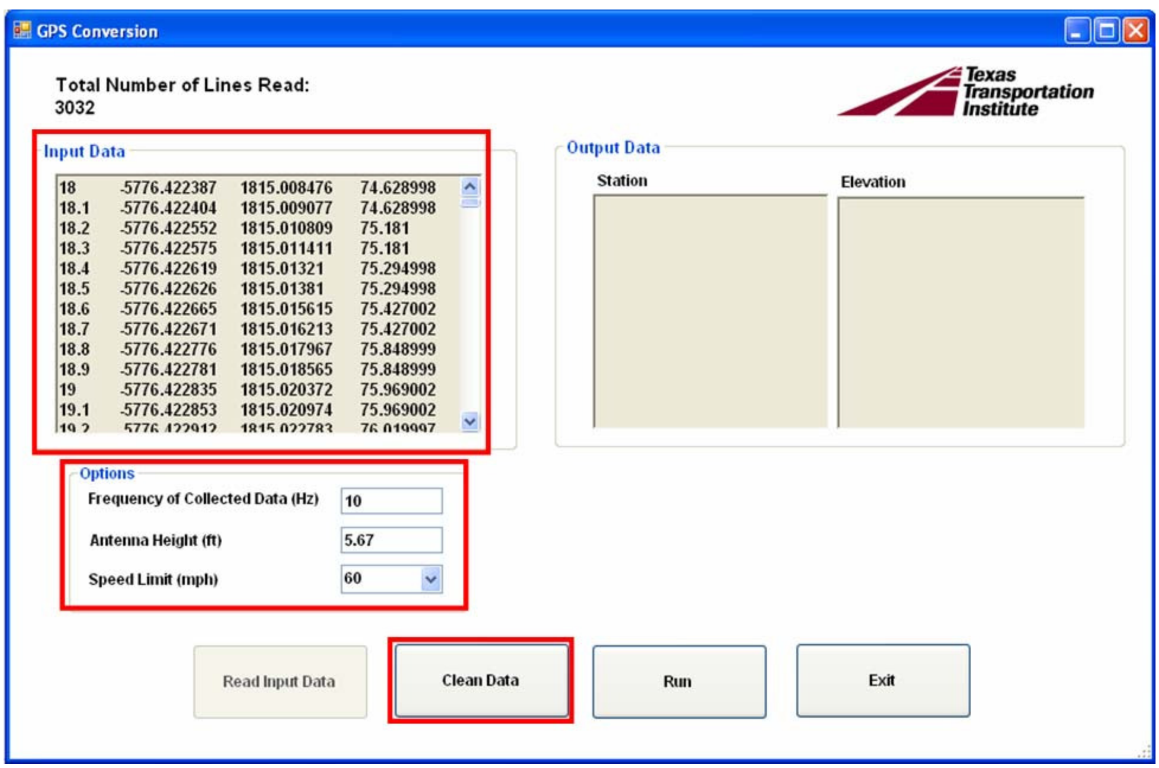


Figure 2-4. Loading Input Data for the GPS Conversion Program.

After the data are loaded, the frequency of the collected data should be entered in the options part of the main window. The no-passing zone algorithm written in the no-passing zone program is based on the data collected every one second. If GPS data collected a value other than 1 Hz (one time per second) during the data collection, the related frequency should be entered. Additionally, the height of the antenna of the GPS instrument during data collection and the design speed/speed limit of the roadway should be entered (see Figure 2-4). If the user does not change the default frequency and goes to the next step, the program confirms that he/she has not forgotten to enter the frequency value by giving a warning (see Figure 2-5). After the user enters the values and clicks on the Clean Data button (see Figure 2-4), the extra data points are eliminated so that the only data points left are one second apart, and the left box of the main window is updated, including the clean data (see Figure 2-6).

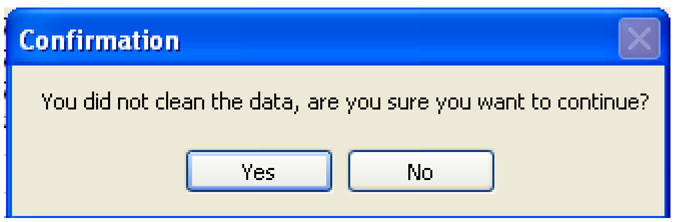


Figure 2-5. Warning Message.

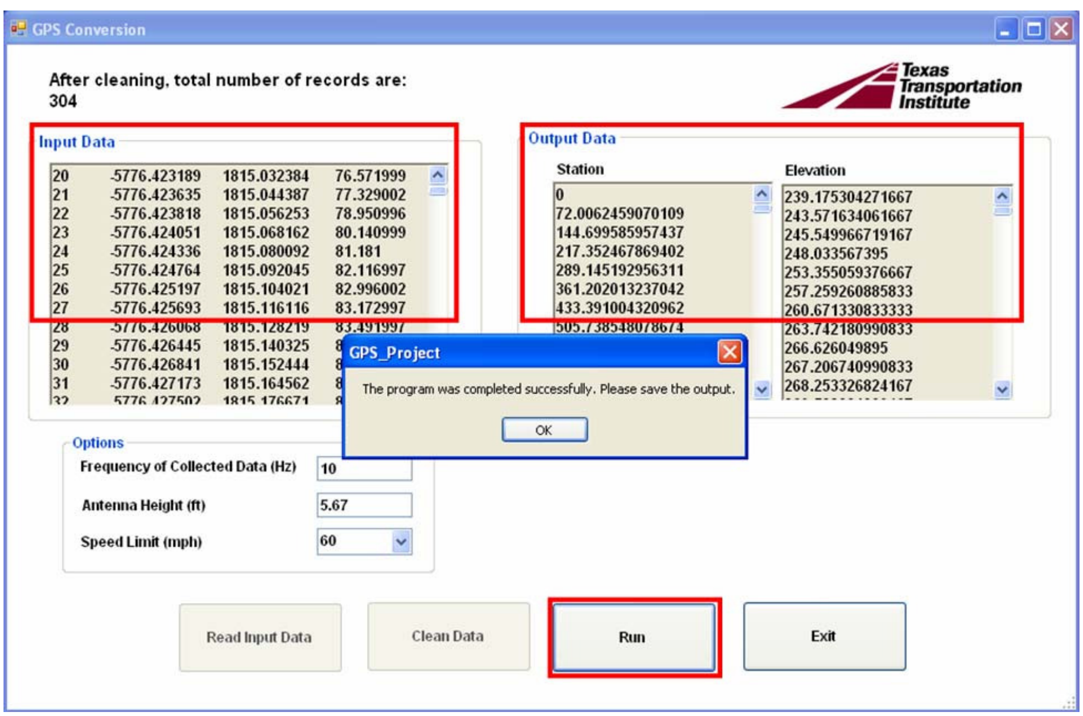


Figure 2-6. Running the Program and Getting the Results.

Next, by clicking on the Run button, the longitude and latitude values are converted to northing and easting values, the stations and elevations of the segment of the roadway are calculated, and the results, which can be used as the input file of the no-passing zone program, are shown in the right box of the main window (see Figure 2-6). Then a window is automatically opened to save the results in an Excel file. The important items in this step are the name and location of the file to be saved. The name of the file must be typed as "NPZinput," and it should be saved in the folder where the no-passing zone program (NoPassing_Final.exe) is located. Finally, by clicking the Exit button, the user can terminate the GPS conversion program.

MCR Installer

In order to run the no-passing zone program, the computer must either have MATLAB software installed or, if a machine does not have MATLAB, the MCR installer must be loaded in order to execute the no-passing zone compiled program. The MCR installation process needs to be done only once. By double clicking on the MCR installer, which is an executable file, the user can install the program on the computer. It should be noted that administrative rights are required to install the MCR installer program on the computer. Otherwise, the MCR installer will not be able to make the necessary changes in order for the compiled program to run. As was explained before, if the computer has the MATLAB software already installed, the user should ignore installing the MCR installer.

No-Passing Zone Program

The no-passing zone program smoothes inaccurate vertical elevation data and evaluates roadway profiles for possible sight restrictions that indicate where no-passing zones should be located. The user can run the no-passing zone program by double clicking on the NoPassing_Final executable file. A command prompt box will appear, run, and disappear. When the command prompt box closes, the program has finished running, and results are automatically saved in the file named NPZoutput, in the same folder in which the program is located. The file includes the starting points, the ending points, and the lengths of the calculated no-passing zones (in the first worksheet); the stations and elevations of the roadway (in the second worksheet); and the graphical profile of the roadway (in the third worksheet). Dimensions are given in feet and are measured from the beginning of the collected data. It is important to remember that before running the program, the user should make sure that the data in the worksheets of the existing NPZoutput.xls file have been deleted if any previous data existed.

VALIDATION OF PROGRAMS

The second major effort of this activity was a field evaluation of the updated system, which included a comparison of the calculated no-passing zone results with the actual no-passing zone markings in the field at two sites.

Site Selection and Data Collection

Since no-passing zones caused by sight restrictions in the vertical profile were the focus of the study, ideal sites for testing needed to have straight alignments and significant enough elevation changes in the vertical profile to require no-passing zones. Researchers identified three roadways as candidates for testing and validation: State Highway (SH) 36, Farm-to-Market Road (FM) 390, and SH 105. After driving the candidate sites and visiting the locations, researchers observed that major parts of the straight segment of SH 105 included two-way left-turn lanes, for which there are no no-passing zones. Therefore, SH 36 and FM 390 were selected as the roadways for actual field testing.

SH 36

The SH 36 study site is in Burleson County, northwest of Caldwell, Texas (see Figure 2-7). It is a two-lane road with a shoulder and is approximately 8 miles long. The horizontal alignment of this test section is straight, and there are no horizontal curves (see Figure 2-8). The posted speed limit is 70 mph on this roadway. The dots in Figure 2-8 represent the beginning and the end of the roadway segment evaluated. Researchers made five runs in each direction of the roadway. But after retrieving the GPS raw data, one of the runs was rejected because the collected data were corrupted.

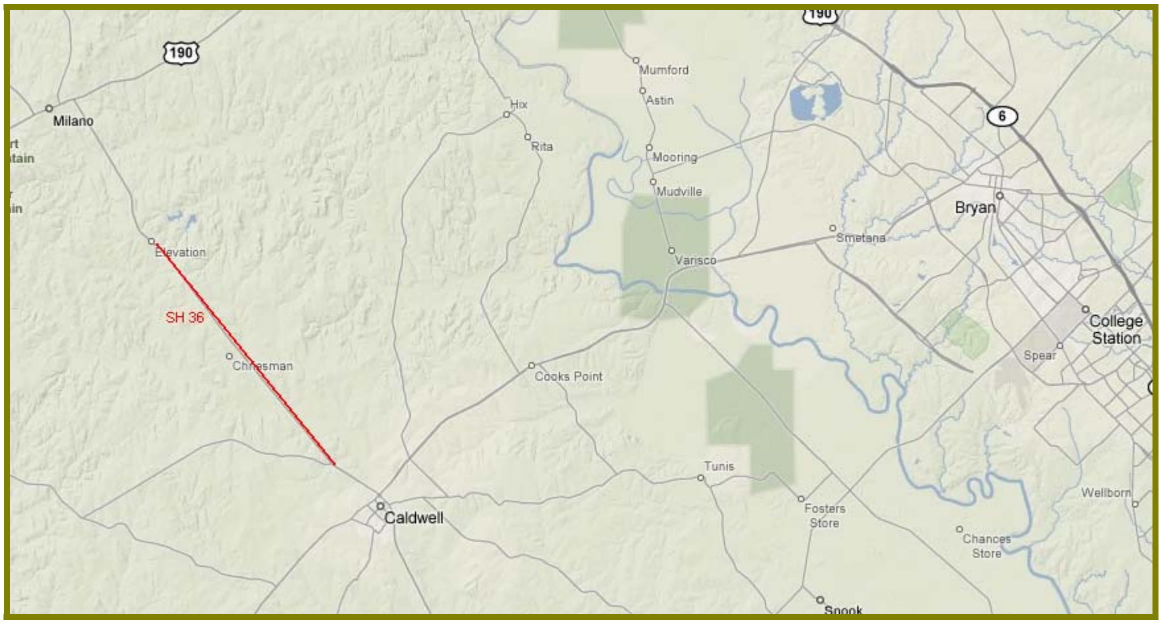


Figure 2-7. Location of the Study Section of SH 36.

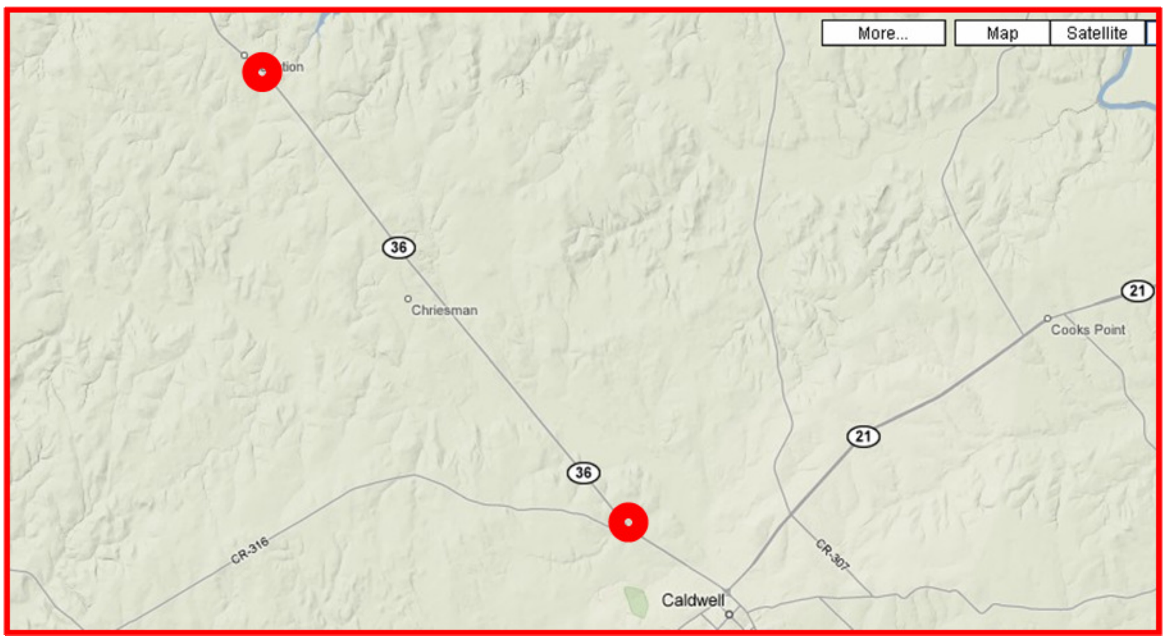


Figure 2-8. SH 36 Alignment.

FM 390

The FM 390 site, designated as a scenic route by the state of Texas, is located in Washington County. The roadway starts at SH 105 northeast of Brenham and ends at US 290 in Burton. It is a two-lane roadway with no shoulder, and the roadway speed limit is 60 mph. The study segment is the part of FM 390 that begins at SH 105 and runs northward approximately 4 miles (see Figure 2-9). The horizontal alignment of this test section is straight, and there are no horizontal curves (see Figure 2-10). The dots in Figure 2-10 represent the beginning and the end of the roadway segment evaluated. Researchers made four runs in each direction at this sign. But after retrieving the GPS raw data, one of the runs was rejected because the collected data were corrupted.

Figure 2-9. Location of the Study Section of FM 390.

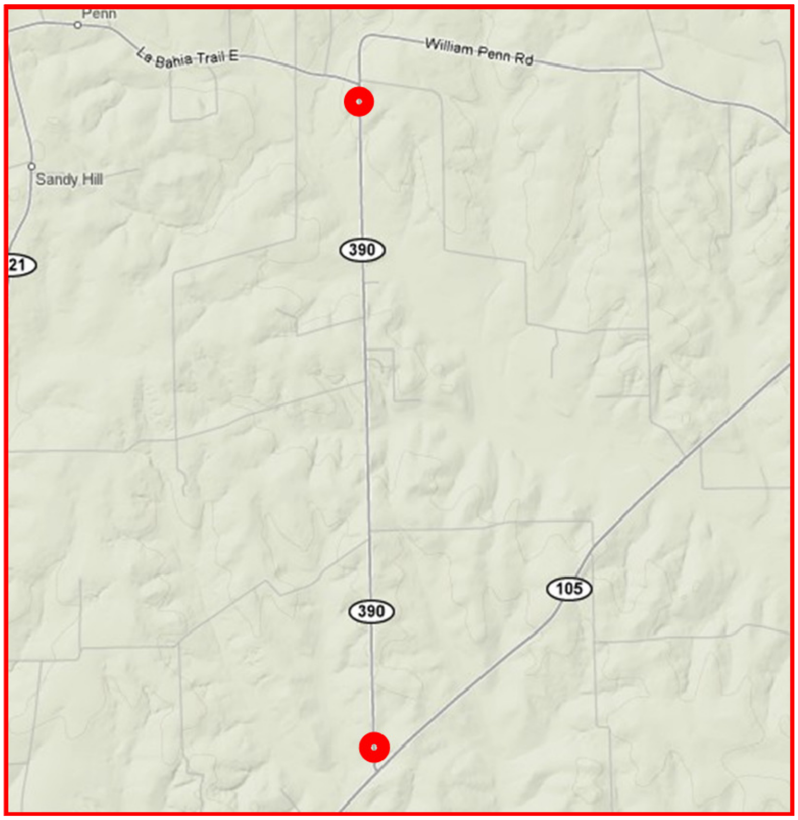


Figure 2-10. FM 390 Alignment.

Results

The GPS raw data for each run underwent preprocessing using the GPS conversion program, and the stations and elevations were calculated. Then the results of the preprocessing steps for all of the runs for each direction of the roadways were combined and sorted based on the station in order to create input files for the no-passing zone program. After the no-passing zone program was run for each direction, the lengths and the locations of no-passing zones were calculated, and the profiles of the roadway were plotted.

Figure 2-11 shows the profile of SH 36 in the northbound direction, along with the calculated no-passing zones (NPZ). It also shows the existing no-passing zones whose information was collected during the site visit. There is a continuous centerline at the beginning of the northbound direction of the study segment of SH 36 (as can be seen in Figure 2-11) due to the existing two-way left-turn lane (TWLTL) that is located before the starting point of the segment. Figure 2-12 shows the profile of SH 36 in the southbound direction, along with the calculated and existing no-passing zones.

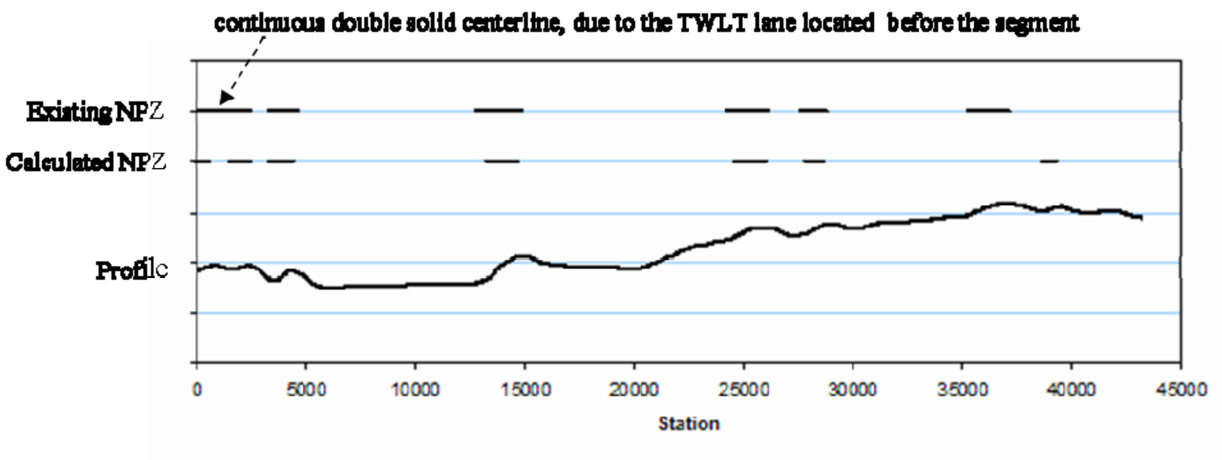


Figure 2-11. SH 36 Northbound.

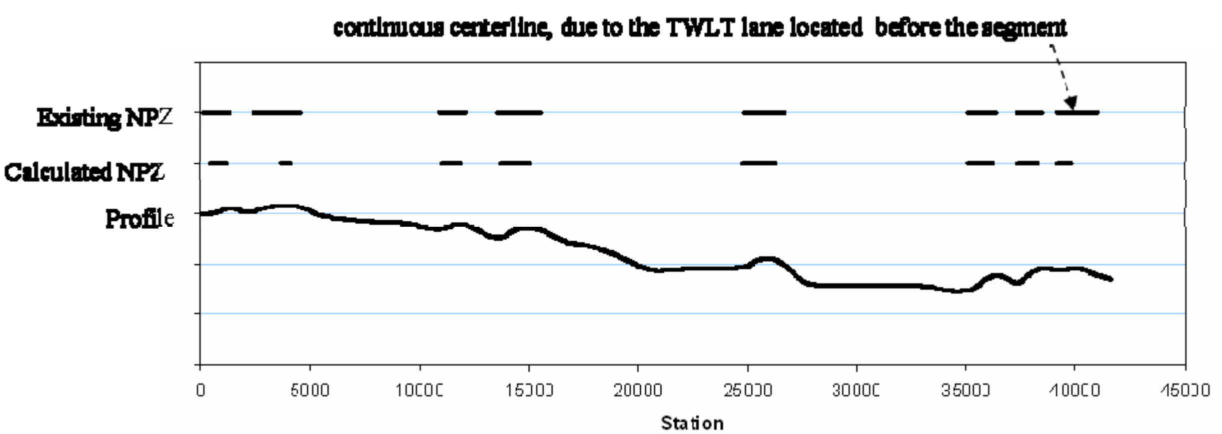


Figure 2-12. SH 36 Southbound.

Figure 2-13 shows the profile of FM 390 northbound, along with the calculated no-passing zones and the existing no-passing zones, whose information was collected during the site visit. According to the MUTCD, where the distance between successive no-passing zones is less than 400 feet, no-passing markings should connect the zones. The no-passing zone program automatically checks this guideline, and the output results are based on it. Figure 2-13 illustrates that for some part of the segment, the program has calculated short, individual no-passing zones, but in the field, the existing no-passing markings are continuous in those locations. To validate the program, the distances between the short no-passing zones were calculated and confirmed to be no shorter than 400 feet. Therefore, it is concluded that at this site, the adjacent no-passing zones that are close together have been connected in the field, even if they are more than 400 feet apart. Figure 2-14 shows the profile of FM 390 in the southbound direction, along with the calculated and existing no-passing zones.

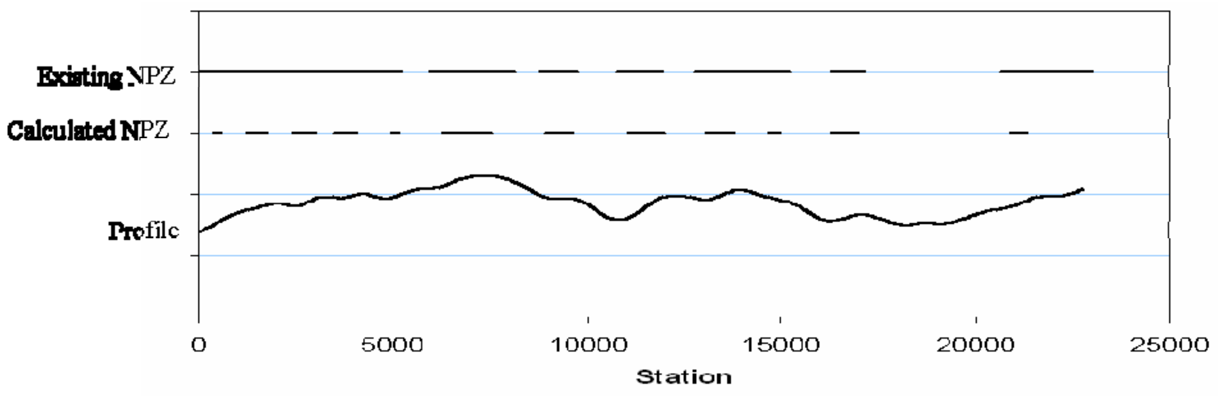


Figure 2-13. FM 390 Northbound.

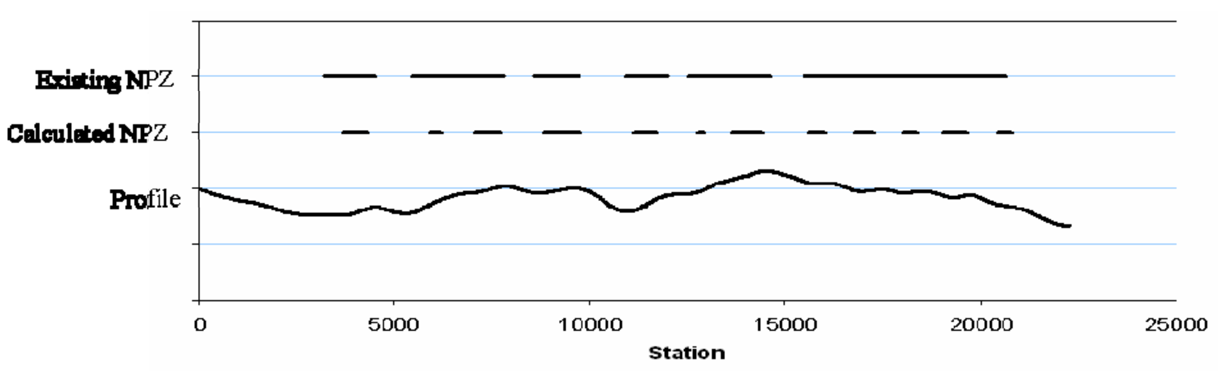
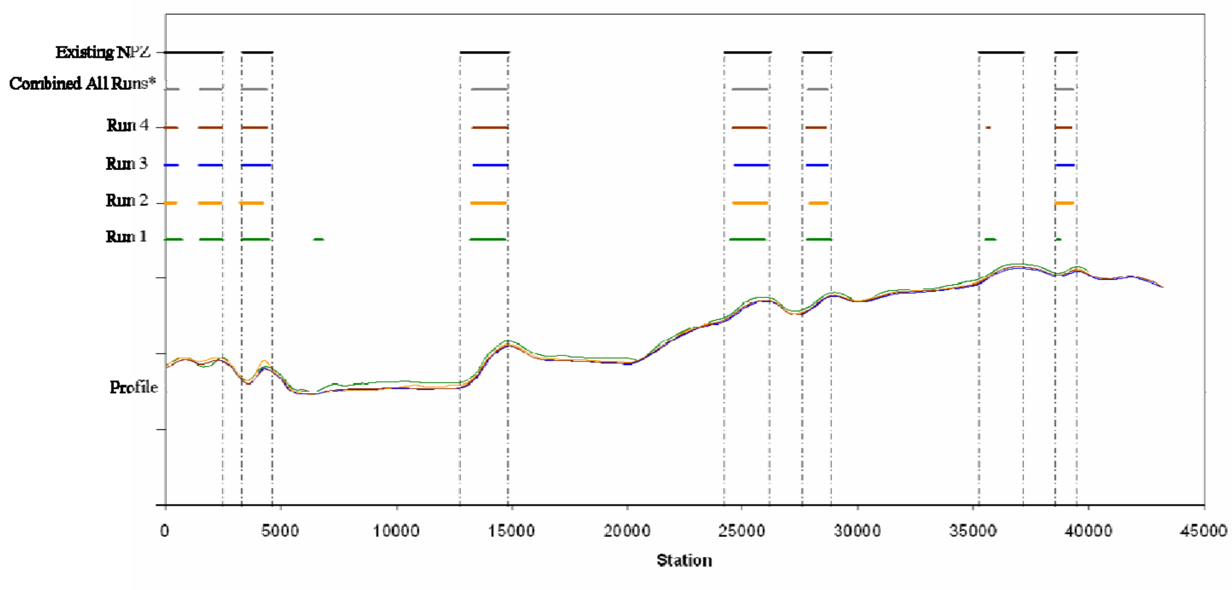


Figure 2-14. FM 390 Southbound.

SUMMARY

In addition to calculating no-passing zones based on the combined runs of collected data, as was explained previously in the report, researchers calculated no-passing zones based on the individual runs for each direction of the test roadways. Figures 2-15 to 2-18 illustrate the graphs that show existing no-passing zones and calculated no-passing zones based on the individual and combined runs. Comparing all the results to the existing ones, it seems that existing no-passing zones in the field are conservatively longer than what they should be based on the recommendation. Additionally, some adjacent no-passing zones are close enough that they are connected in the field, even though they may be far enough apart to exist as separate no-passing zones according to the MUTCD.



Note: * Data from all runs were combined, and NPZs were calculated based on the combined profiles.

Figure 2-15. SH 36 Northbound (Existing NPZ, All Individual Runs, and Combined Run).

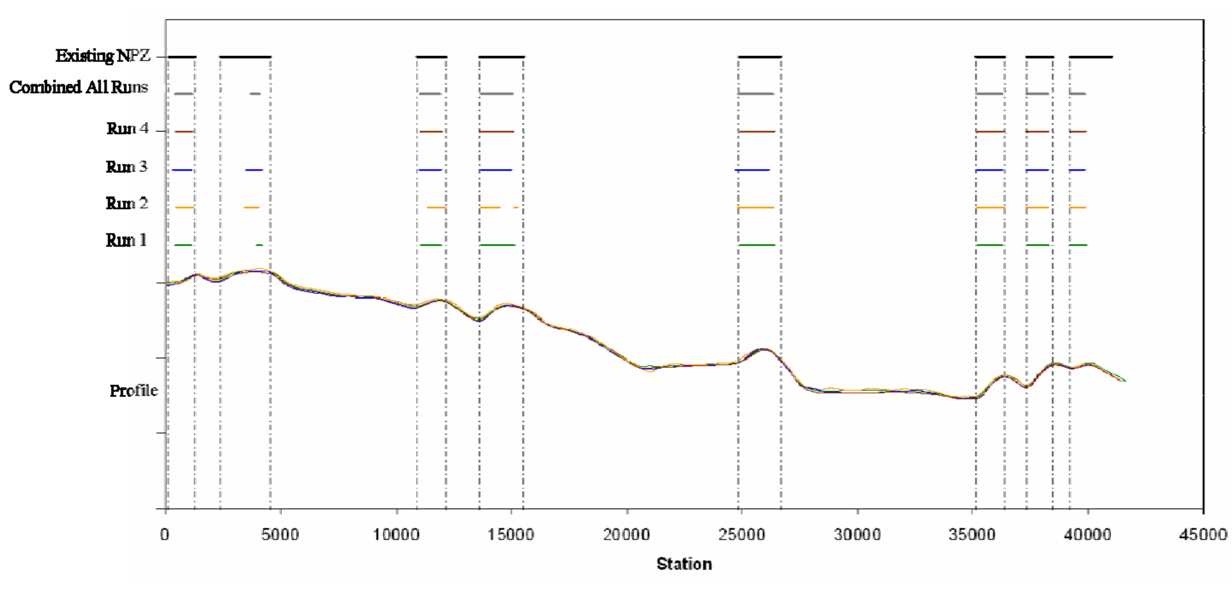


Figure 2-16. SH 36 Southbound (Existing NPZ, All Individual Runs, and Combined Run).

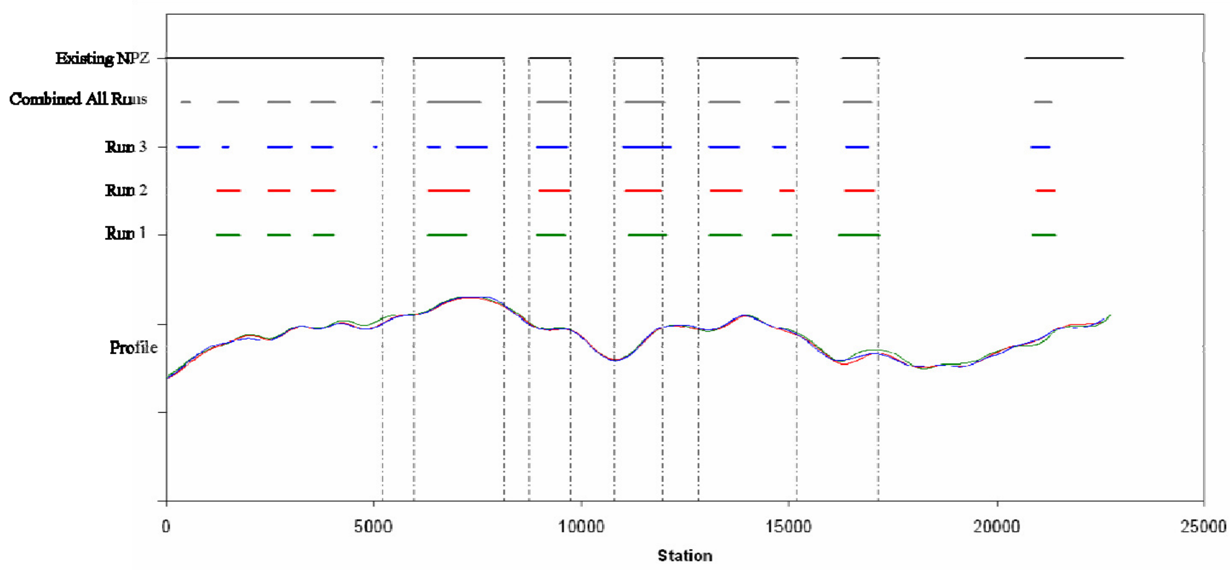


Figure 2-17. FM 390 Northbound (Existing NPZ, All Individual Runs, and Combined Run).

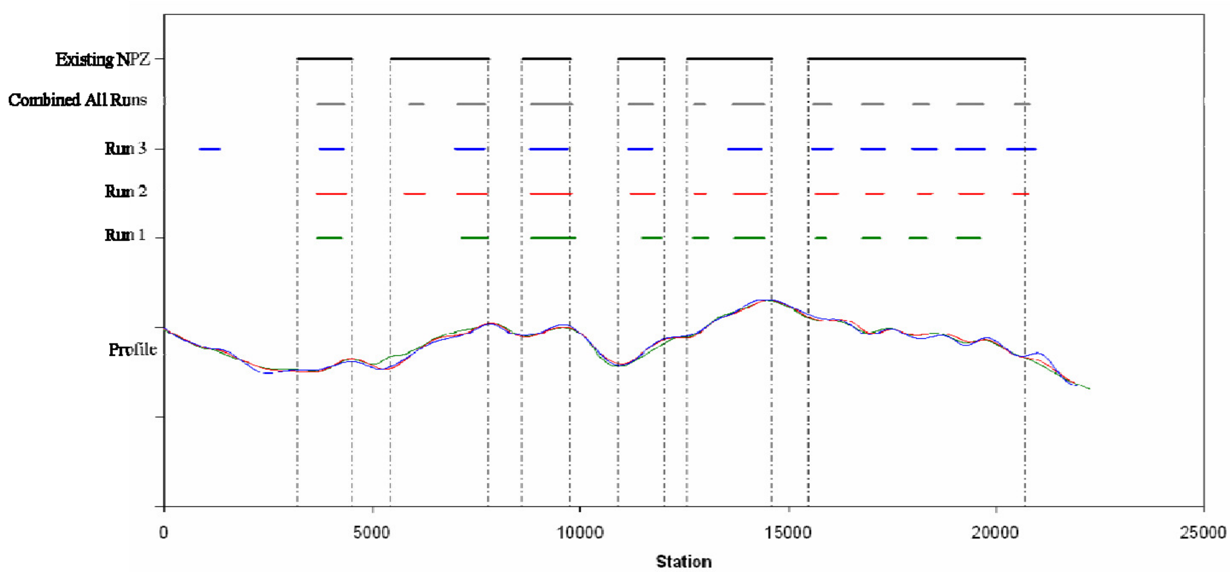


Figure 2-18. FM 390 Southbound (Existing NPZ, All Individual Runs, and Combined Run).

CHAPTER 3:
EVALUATION OF LEAD-FREE THERMOPLASTIC PAVEMENT MARKING MATERIAL

BACKGROUND

The Texas Department of Transportation (TxDOT) departmental material standard (DMS) for thermoplastic pavement marking material is DMS-8220, Hot Applied Thermoplastic. This specification indicates that the pigment should be "*a heat-resistant, double-encapsulated medium chrome yellow or other approved heat-resistant pigment*" that is 5 to 10 percent by weight of the total material (*1*). The chrome yellow pigment contains lead, but the lead is considered safe because it is encapsulated. Even so, Texas is in the minority of state transportation agencies that use a leaded pigment in the marking material specification. There are numerous reasons supporting the use of leaded pigments in yellow markings; the most significant is the concern that organic pigments do not provide sufficient yellow color to be perceived by drivers as yellow in all conditions.

The concern over the color performance of yellow pavement markings led to a research project sponsored by the National Cooperative Highway Research Program (NCHRP). NCHRP Project 5-18, Color Effectiveness of Yellow Pavement Marking Materials, evaluated many different aspects of yellow markings, including human factors evaluations of driver recognition of various yellow pavement markings, field evaluations of yellow pavement marking materials, and recommendations for yellow pavement marking color coordinates (*2*). The recommendations from the research modified both the yellow and white nighttime color boxes, while the daytime color boxes remained unchanged. Table 3-1 illustrates the modified nighttime color box coordinates. The objective of these recommended nighttime color boxes is to reduce the confusion between white and yellow markings, and to include the areas that the subjective testing indicated as having favorable color response.

Table 3-1. NCHRP Nighttime Color Box Recommendations.

NCHRP Project 5-18 Color Box Recommendation			
White		Yellow	
x	y	x	y
0.45	0.42	0.53	0.47
0.41	0.40	0.49	0.44
0.43	0.38	0.50	0.42
0.47	0.40	0.51	0.40
0.46	0.42	0.57	0.43

STUDY DESIGN

In the summer of 2007, TxDOT began experimenting with the use of lead-free thermoplastic pavement markings. In July 2007, TxDOT requested that Texas Transportation Institute (TTI) researchers assist in the evaluation of field applications of lead-free thermoplastic markings. Accordingly, TTI researchers observed the installation of lead-free markings at the two sites listed below.

- US 79 in Franklin, Texas, new surface treatment (seal coat) surface, and
- SH 21 just east of the Brazos River, new surface treatment (seal coat) surface.

The US 79 site included both lead-free and standard yellow thermoplastic materials that were installed on consecutive days in a two-way left-turn lane in the city. The SH 21 site consisted only of lead-free thermoplastic installed as the left edge line on a divided highway, transitioning to a double solid centerline on an undivided highway (see Figure 3-1). The US 79 section has approximately 6000 average daily traffic (ADT), and the SH 21 section has approximately 10,000 ADT. At each site, researchers measured retroreflectivity and color. The initial measurements were made at the time of installation, and then at approximately 3, 7, and 11 months after installation.

Figure 3-1. SH 21 Lead-Free Thermoplastic Installation.

Measurements

Researchers measured three attributes of the yellow markings at each site. These attributes and the instruments used to measure the attributes are 30 meter retroreflectivity, 30 meter nighttime color, and 45°/0° daytime and nighttime color. Table 3-2 summarizes key elements of these measurements.

Table 3-2. Lead-Free Yellow Thermoplastic Pavement Marking Measurements.

Attribute	Measurement Geometry	Instrument	Description
Retro-reflectivity	30 meter	LTL 2000Y	A measure of the amount of light retroreflected to the driver from the pavement marking.
Nighttime Color	30 meter	LTL 2000Y	A measure of the nighttime color of the pavement marking as viewed by the driver.
	45°/0°	BYK Gardner Color Guide	A measure of color using Illuminant A and the standard color measurement geometry. The measurement was made on a section of markings where there were beads and no beads.
Daytime Color	45°/0°	BYK Gardner Color Guide	A measure of color using Illuminant D65 and the standard color measurement geometry. The measurement was made on a section of markings where there were beads and no beads.

The measurements were then compared to minimum retroreflectivity levels and color boxes where appropriate. The minimum retroreflectivity level of 175 mcd/m^2/lx for yellow markings is contained in Special Specification 6110, Reflectorized Pavement Markings with Retroreflective Requirements (*3*). Several different color boxes exist for pavement markings. The TxDOT color box for yellow markings is contained in DMS-8220, Hot Applied Thermoplastic (*1*), and is based on a D65 illuminant and standard observer of 10°. This is the color box that would apply to the sample measured with the BYK Gardner Color Guide. The appropriate yellow color box for the 30 meter color measurements is contained in the July 31, 2002, Final Rule by the FHWA, which established daytime (45°/0°) and nighttime (30 meter) color boxes for traffic materials (*4*). The color boxes recommended in the NCHRP 5-18 project are also used for comparison. Table A-1 and Table 3-1 provide the specific x and y values for these color boxes.

RESULTS

The summary of the retroreflectivity and color measurements are all given in Appendix A (see Tables A-2, A-3, and A-4). The significance of the results is summarized below.

Retroreflectivity

The retroreflectivity (R_L) measurements were made with the LTL 2000Y retroreflectometer. All of the initial measurements on both the leaded and lead-free material were above the 175 mcd/m^2/lx minimum level required in the TxDOT specification. It is worth noting that the markings measured on the pavement were applied to surface treatment (seal coat). This surface represents a very rough pavement surface, which may have an impact on the measured retroreflectivity. However, there were no application sites included where the lead-free marking material was applied to a smoother pavement surface.

As seen in Figure 3-2 the retroreflectivity at each location decreased as the markings aged. A greater decrease in retroreflectivity is observed at the US 79 site than at the SH 21 site. The ADT on US 79 is less than that on SH 21, but since the marking is a two-way left-turn lane, it is subject to more turning movements and traffic than the marking on SH 21. The leaded and lead-free markings on US 79 are decreasing at similar rates, with the lead-free marking losing retroreflectivity slightly quicker.

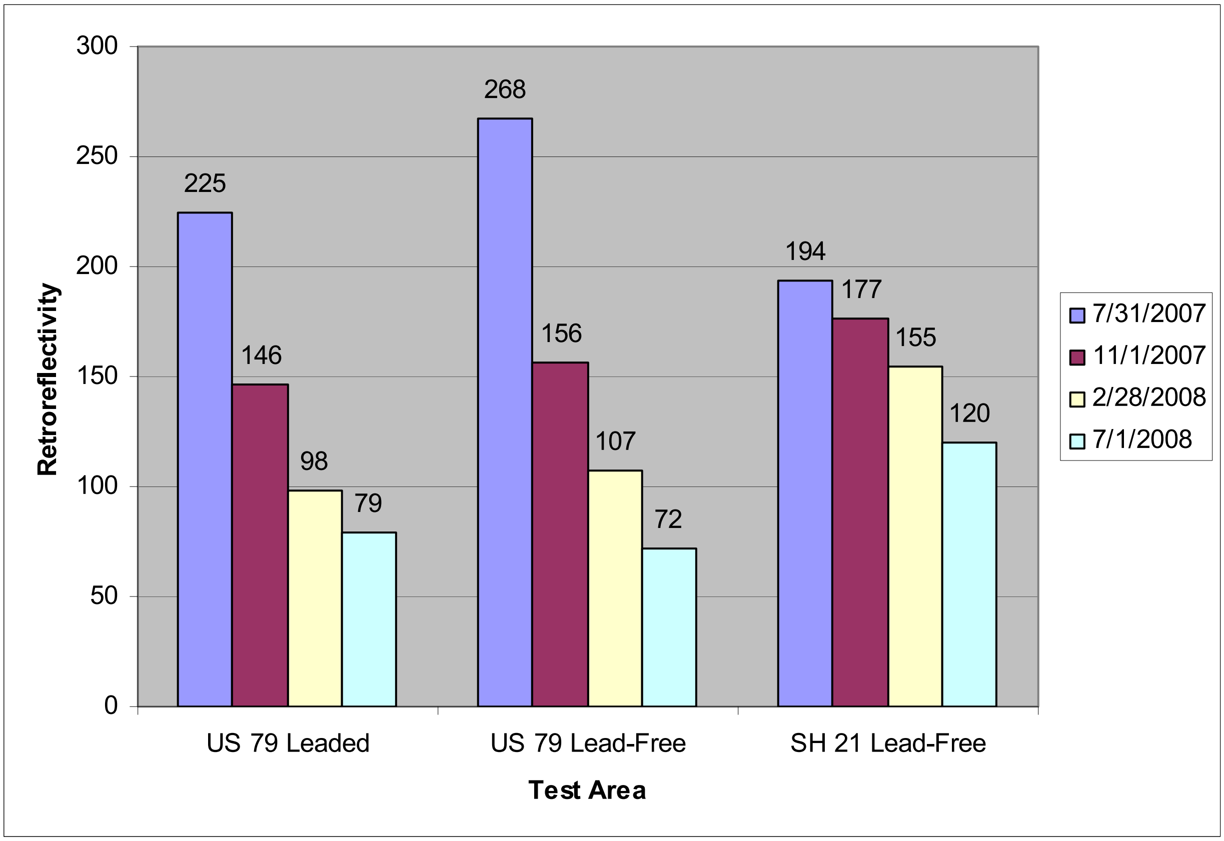


Figure 3-2. Yellow Thermoplastic Retroreflectivity Summary.

Color—30 Meter

The average 30 meter color values from each data collection period were plotted against the x-y points defining the color box from the FHWA final rule on marking color. This color box is based on Illuminant A and a viewing geometry that is the same as the 30 meter retroreflectivity geometry. The NCHRP recommended color box is also illustrated to show the difference. Figures 3-3 and 3-4 illustrate the plot of the average color points for the color measurements with the LTL 2000Y at both sites. All of the average measurements from each data collection period on both the leaded and lead-free markings are within the FHWA color box. It is worth noting that the markings measured on the pavement were applied to surface treatment (seal coat). As with the retroreflectivity measurement, this surface represents a very rough pavement surface, which may have an impact on the measured color. However, there were no application sites included in the initial evaluation where the lead-free marking material was applied to a smoother pavement surface.

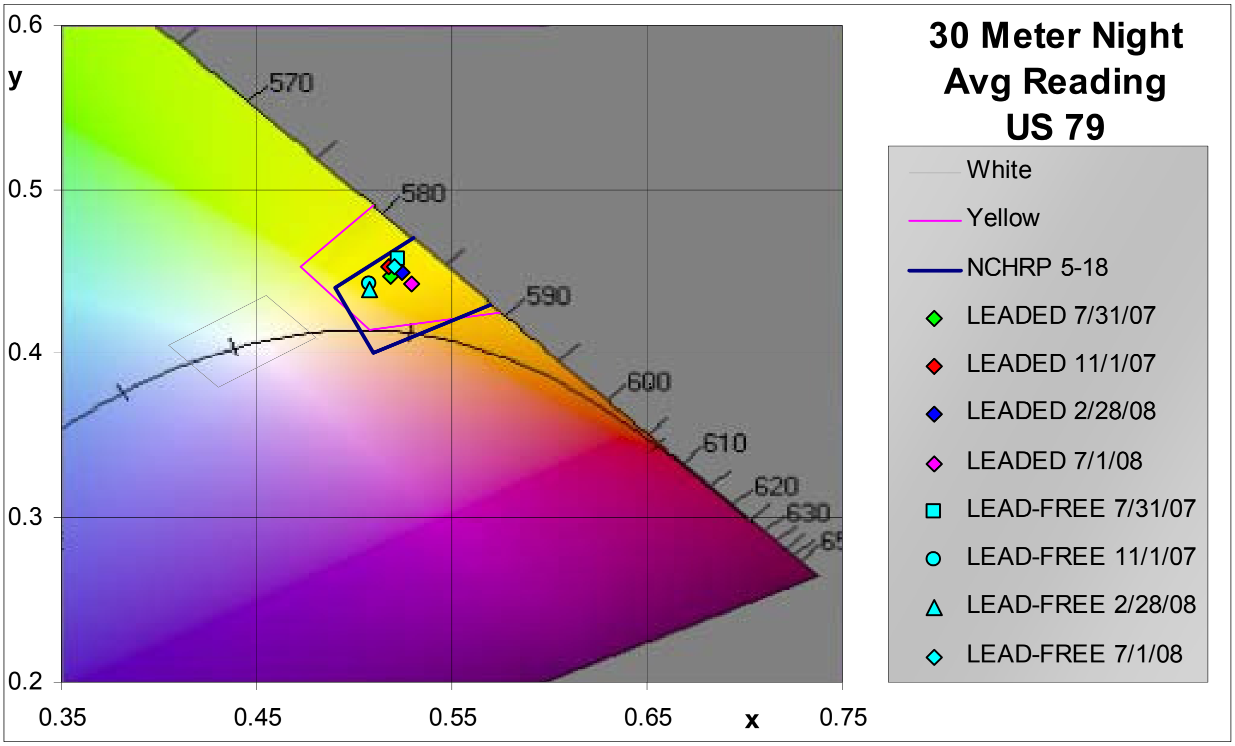


Figure 3-3. Average 30 Meter Night Color of Both Thermoplastic Materials at US 79 Site.

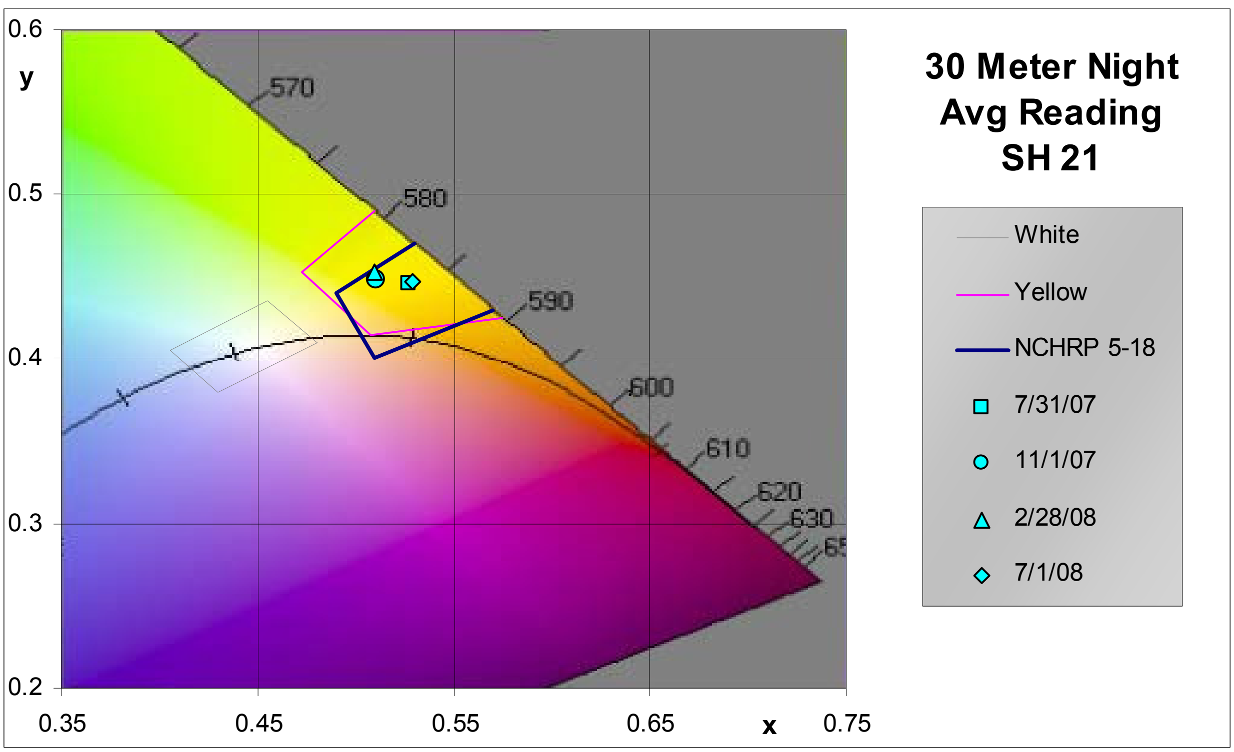


Figure 3-4. Average 30 Meter Night Color of Lead-Free Thermoplastic at SH 21 Site.

Color—45°/0°

The researchers also measured the color of the yellow thermoplastic marking materials containing beads and no beads using a range of illuminants and standard observers at a 45° illumination geometry and a 0° observation geometry. The color measurements on the beaded and non-beaded sections were pooled together after little difference was found between the two measurement sets. The average color values for each of the illuminants and standard observers for each measurement period at both locations are indicated in Figures 3-5 through 3-10. These points were plotted with the appropriate day or night color boxes. The TxDOT color box from DMS 8220 was used for the D65 10° standard observer measurements.

All of the initial measurements were within the TxDOT and FHWA color boxes for both standard observers. All of the Illuminant A 2° standard observer average readings at both sites for each data collection period were within the FHWA nighttime color box. For the daytime color measurements using Illuminant D65, some average measurements have fallen outside of the color box requirements. The D65 10° measurements of both the leaded and lead-free material at both sites fall outside of the TxDOT color box. The leaded material was outside of the box but much closer to the box than the lead-free material was. The D65 2° measurements of the leaded material all fall within the FHWA color box, but the lead-free material color readings do not at the US 79 site. At the SH 21 site, the lead-free color readings all fall within the FHWA color box but are trending away from the center of the box. It should be noted that the TxDOT color box is much smaller than the FHWA color box.

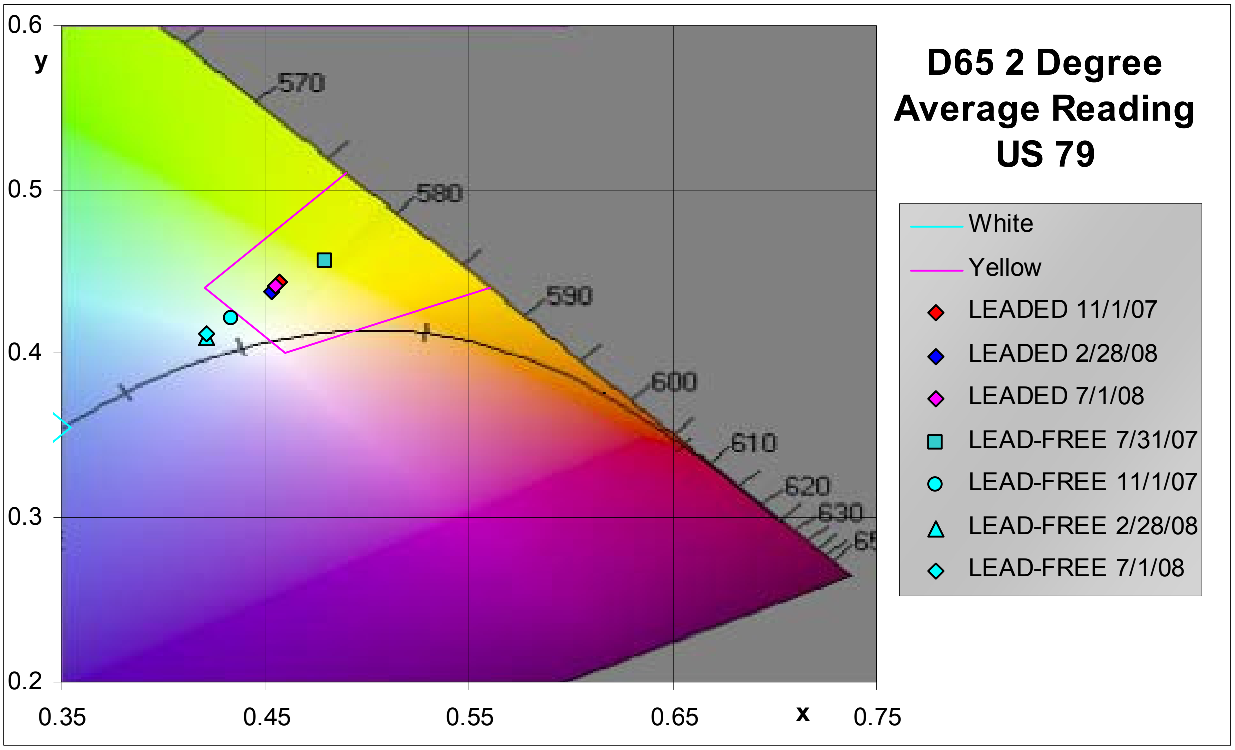


Figure 3-5. Average Daytime Color with 2 Degree Standard Observer at US 79 Site.

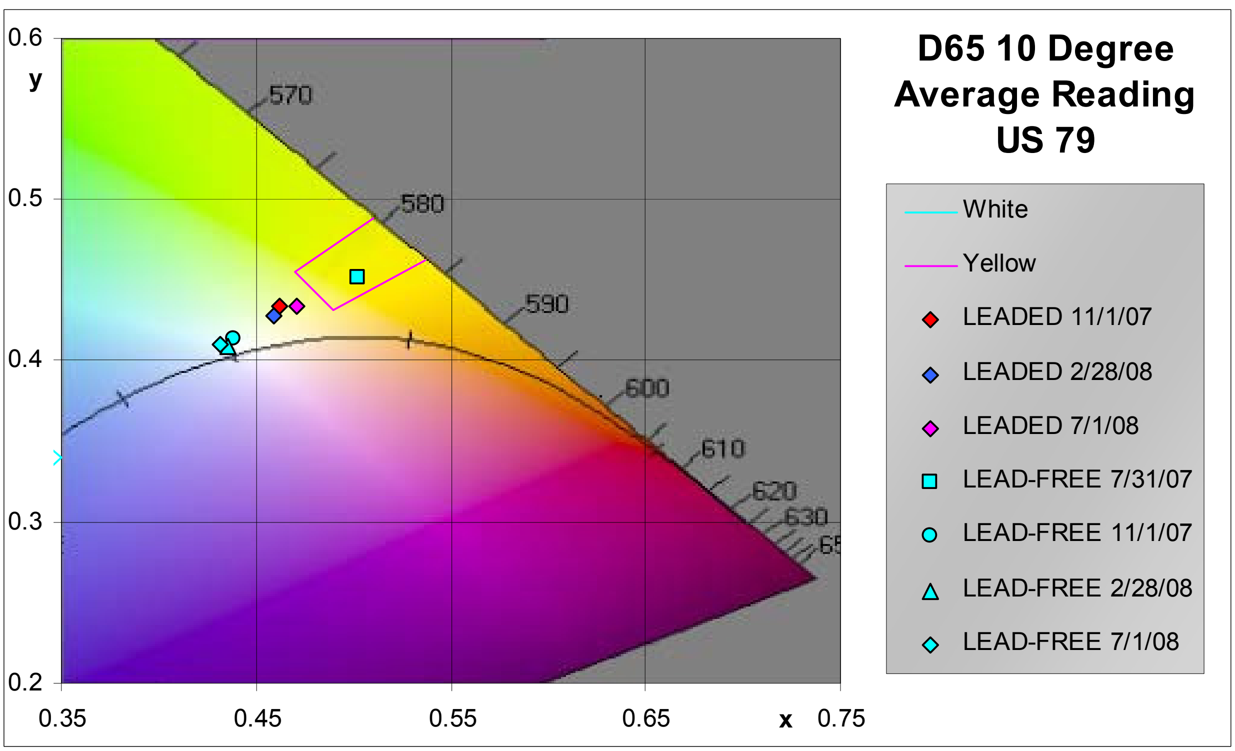


Figure 3-6. Average Daytime Color with 10 Degree Standard Observer at US 79 Site.

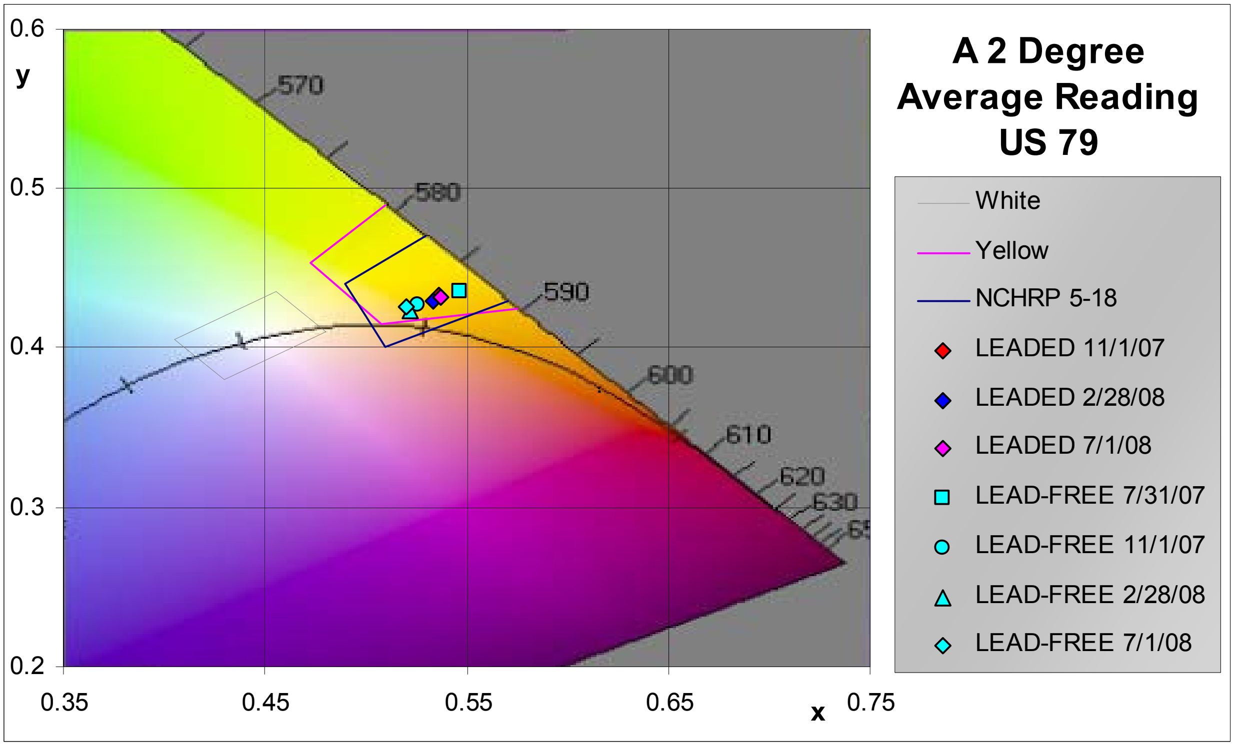


Figure 3-7. Average Nighttime Color with 2 Degree Standard Observer at US 79 Site.

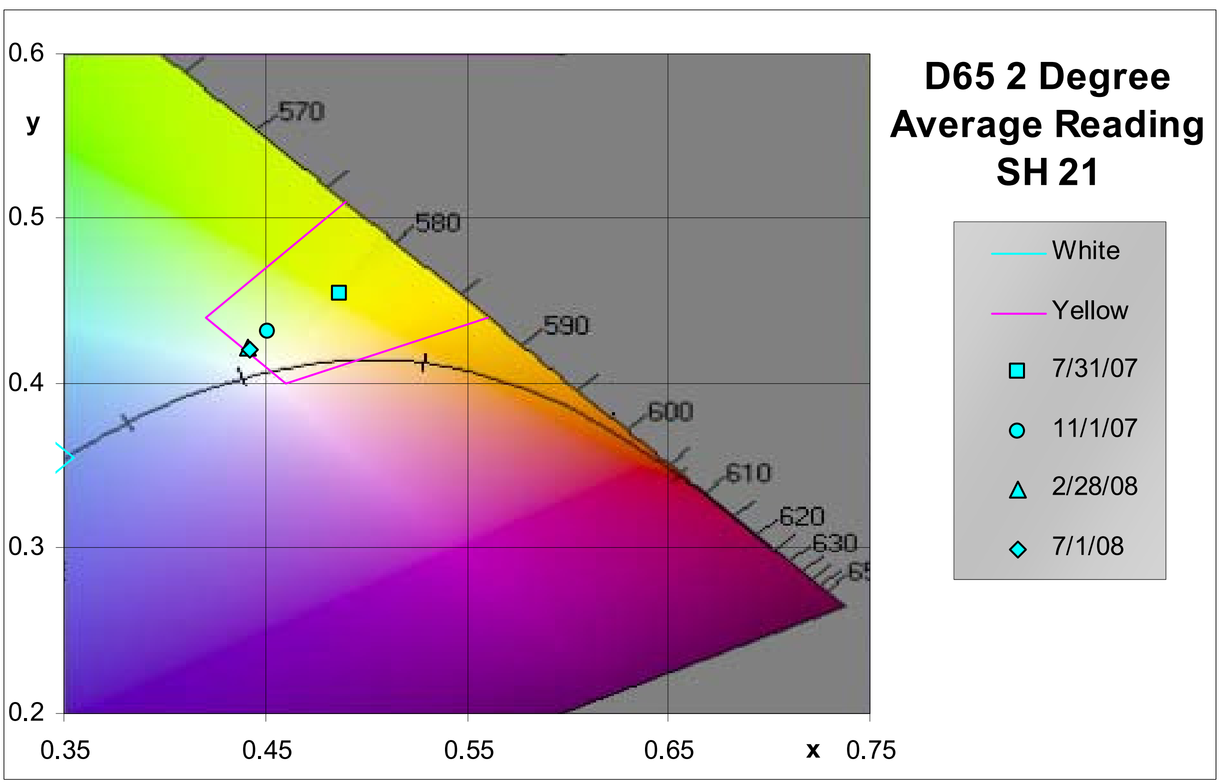


Figure 3-8. Average Daytime Color with 2 Degree Standard Observer at SH 21 Site.

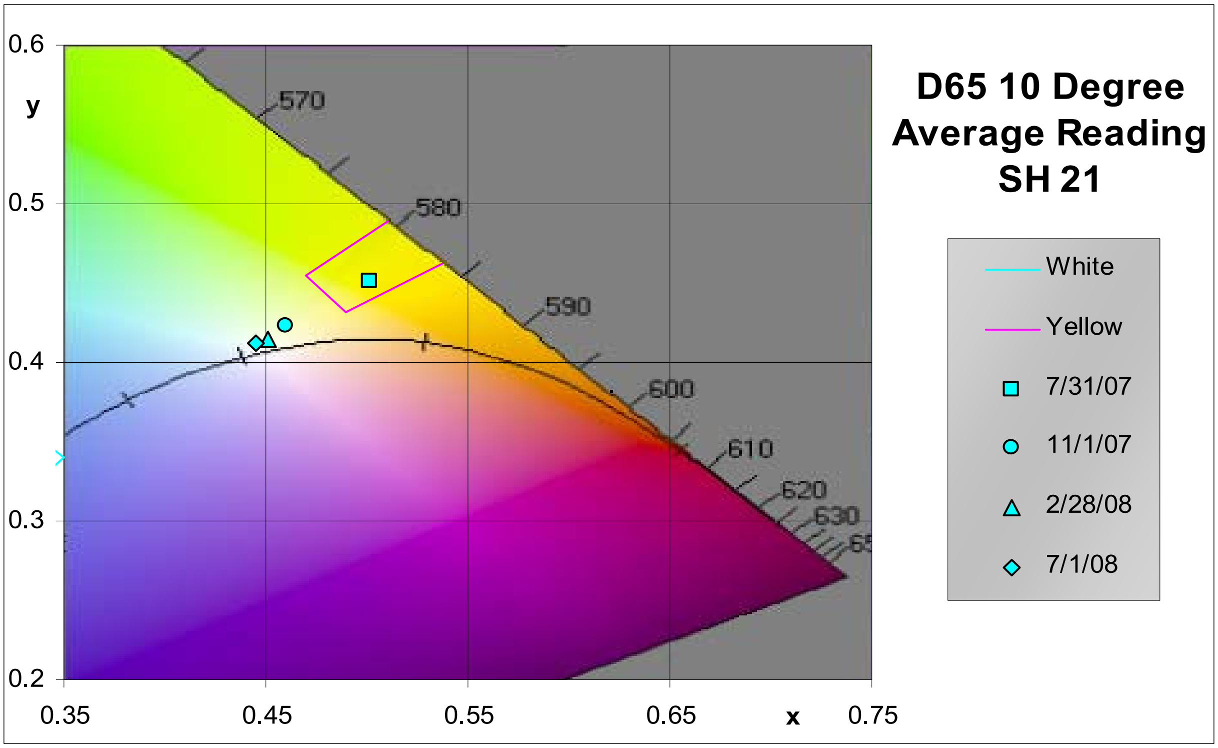


Figure 3-9. Average Daytime Color with 10 Degree Standard Observer at SH 21 Site.

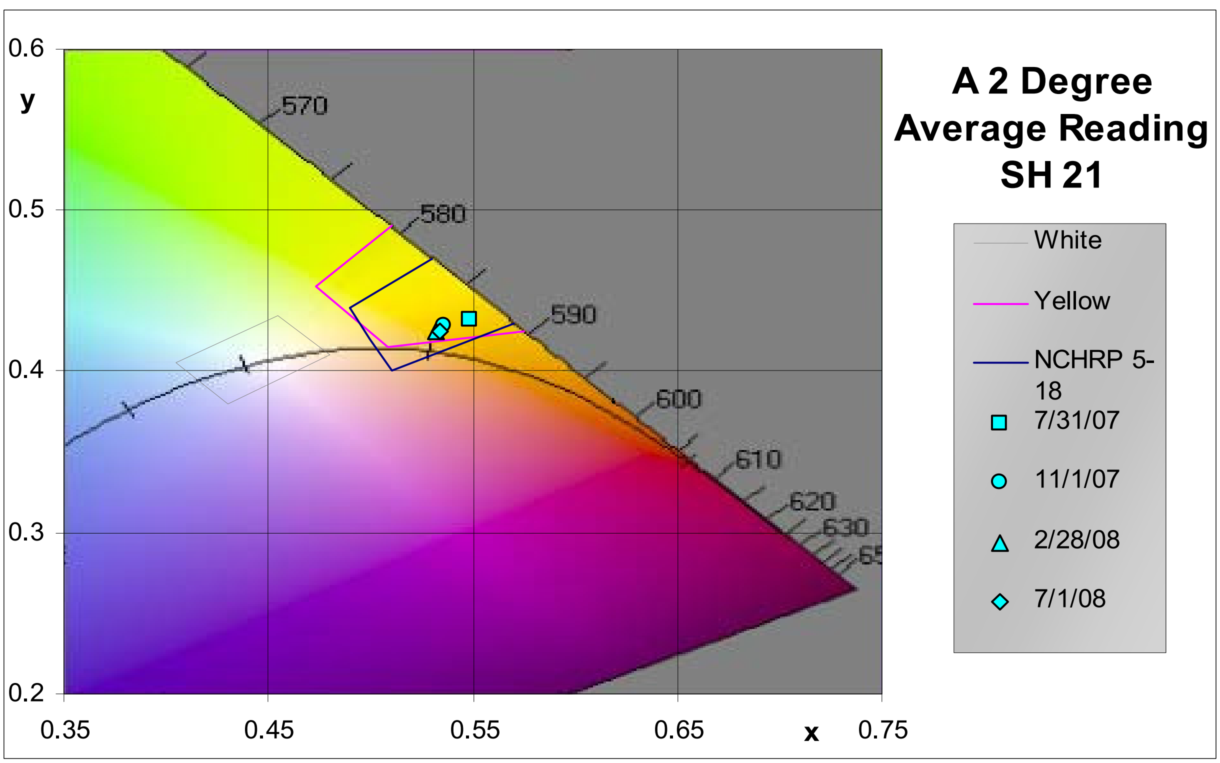


Figure 3-10. Average Nighttime Color with 2 Degree Standard Observer at SH 21 Site.

Subjective visual inspection of color during the data collection indicated a reduction in the yellow quality of the marking. This daytime visual inspection would seem to match the D65 color data that were collected on the markings, as the color data showed that the markings were moving away from yellow and toward white during daytime conditions. Figure 3-11 shows three images taken while conducting data collection. In the pictures, the color change and fading of the marking is noticeable. It should be noted that some of the color change is due to the accumulation of dirt, but some of the color change is also due to the aging of the marking and its pigments.

30 METER NIGHTTIME COLOR INSTRUMENT EVALUATION

Two LTL 2000Y retroreflectometers were tested to compare the repeatability and reproducibility of their retroreflectivity and color measurements. Researchers measured 15 pavement marking samples, 8 white and 7 yellow, with each device. Three sets of data were collected with each retroreflectometer on each pavement marking sample. Prior to the measurement of the pavement marking samples, each unit was calibrated. A separate calibration was conducted for each set of data. The first two sets of calibration were conducted with the calibration blocks that were associated with that particular retroreflectometer. The third calibration was conducted with the calibration blocks from the other retroreflectometer. Calibrating with the other retroreflectometer's calibration blocks was conducted to see if the calibration blocks were biasing the readings in any way.

Small movements along a marking may cause changes in color and/or retroreflectivity. Therefore, to minimize the impact of measurement location, the retroreflectometer was butted up to the end of the marking sample and centered on the line. The readings were recorded, and then the second retroreflectometer was aligned in the same manner. After measuring all 15 samples, the units were recalibrated, and the second set of data was collected. This process was then repeated for the third set.

7/31/2007 Initial Install SH 21

11/12/2007 SH 21

7/1/2008 SH 21

Figure 3-11. Images of SH 21 Pavement Marking Color Change.

Figure 3-12 and Table A-5 indicate the retroreflectivity results of the testing. The retroreflectivity values are the average value of the three measurements made with each device. It can be seen that the TxDOT retroreflectometer generally gave higher retroreflectivity values than the FHWA retroreflectometer. The TxDOT retroreflectometer measured 6 of the 15 markings greater than 10 percent higher than the FHWA retroreflectometer. The TxDOT retroreflectometer measured 2 of the 15 markings lower than the FHWA retroreflectometer. Within the three measurements for each device on each sample, the measurements were typically within 10 percent of each other and within 3 percent of the average value.

The results of the 30 meter nighttime color measurements with each device can be seen in Figure 3-13, Figure 3-14, and Table A-5. Again, a general bias between the devices can be seen in the data. The FHWA unit typically has coordinates that are farther down and to the right compared to the TxDOT device (closer to the red spectrum and more saturated). The average magnitude of the difference is about 0.002 in both the x and y directions with no bias toward color. Within the three measurements for each device on each sample, the measurements were typically within 3 percent of each other and within 2 percent of the average value.

It should be noted that the yellow marking with no beads (Yellow 2) had significantly different color coordinates between the retroreflectometers, whereas the retroreflectivity values on this marking only differed by 1 between the retroreflectometers. The actual readings that are output from the retroreflectometer that are then converted into the color coordinates also typically only differed by 1. The problem lies in that the values were very low, so a difference of 1 is a large percent, and the uncertainty created by not displaying a decimal place when taking the readings plays a significant role. The units tested only display whole number output values.

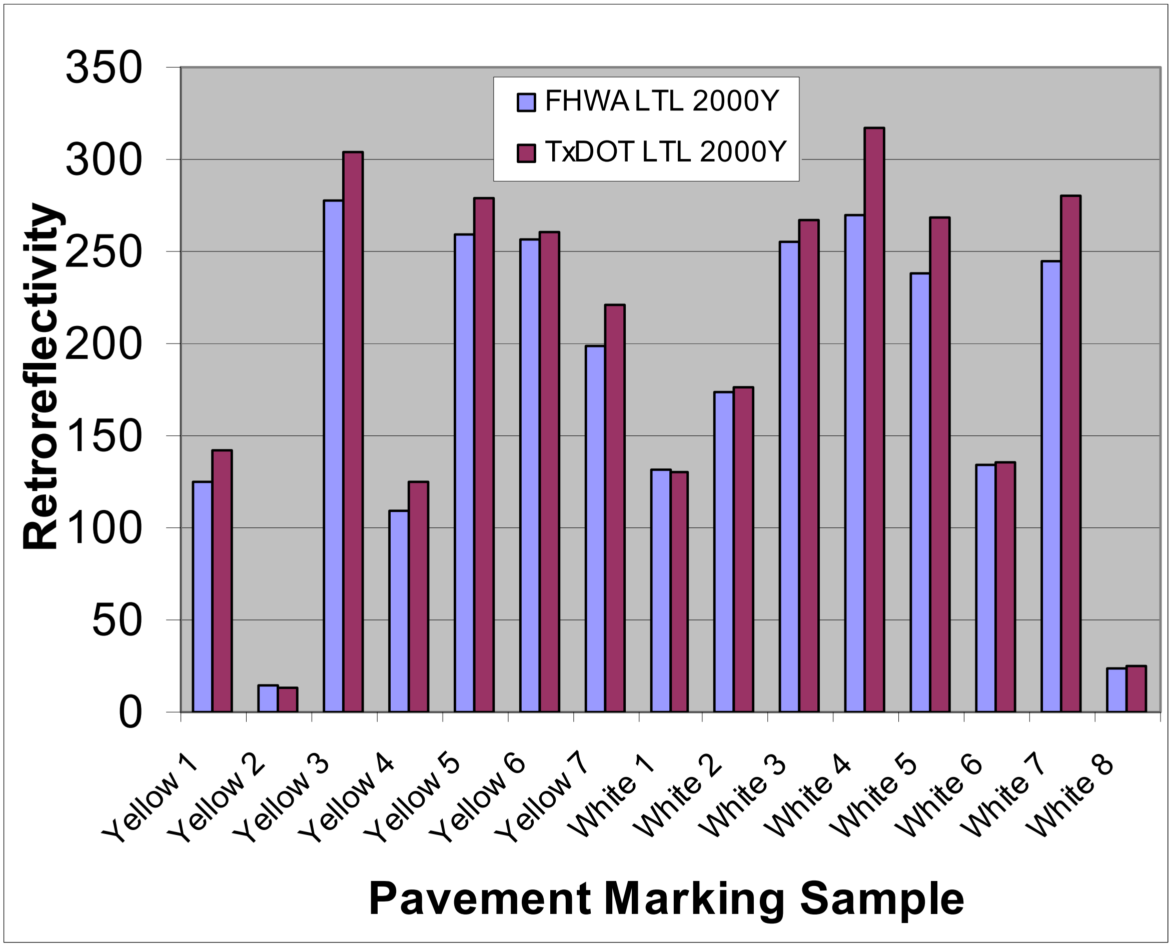


Figure 3-12. Retroreflectivity Summary of LTL 2000Y Comparison.

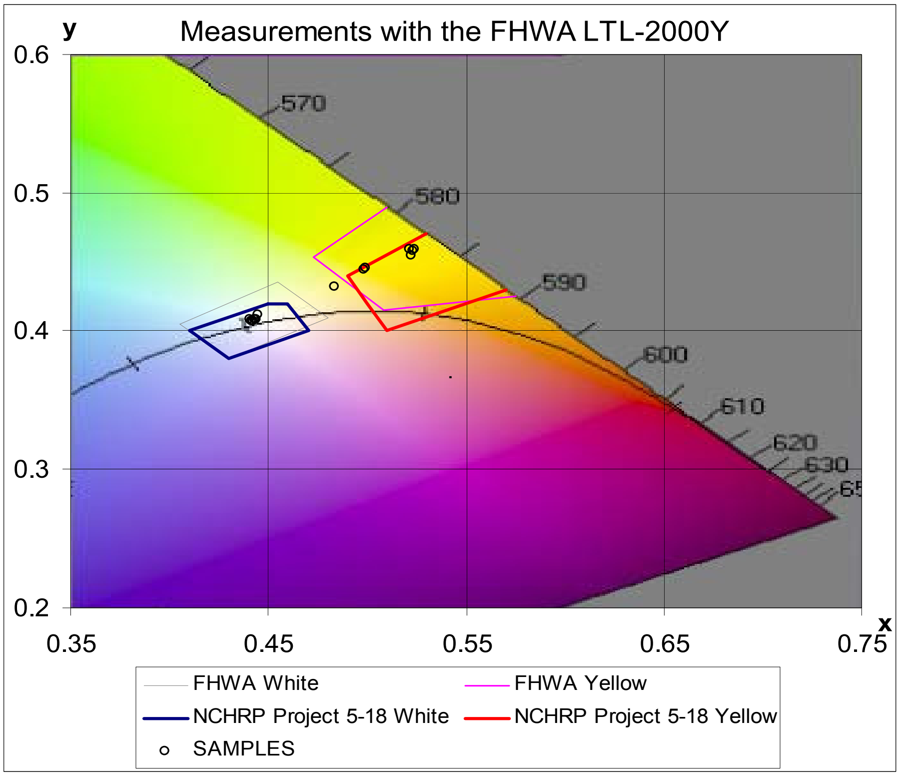


Figure 3-13. FHWA LTL 2000Y 30 Meter Nighttime Color Data Summary.

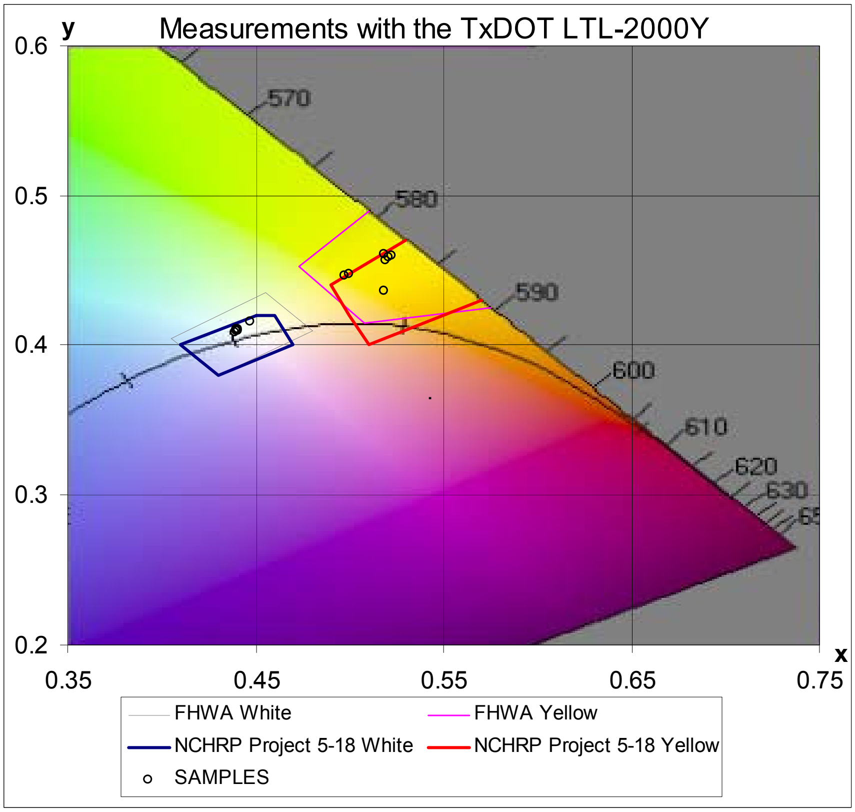


Figure 3-14. TxDOT LTL 2000Y 30 Meter Nighttime Color Data Summary.

FINDINGS

Based on the results of the one-year study presented above, the researchers offer the following findings regarding retroreflectivity and color of the lead-free thermoplastic pavement marking materials and the 30 meter nighttime color measuring device. It is worth noting that, if funding is available, further evaluation will be conducted to assess the long-term (greater than one year) implications of using lead-free yellow thermoplastic material.

- Retroreflectivity
  - The initial retroreflectivities of both the leaded and the lead-free thermoplastic applications are above the minimum level specified by TxDOT. At the location that provided the ability to measure leaded and lead-free materials on the same pavement surface, the lead-free material had a higher initial retroreflectivity level. The initial retroreflectivity of the lead-free material appears to be acceptable.
  - The retroreflectivity of the lead-free thermoplastic over the one-year study period indicates that the material behaves similarly to leaded material based on the results of the comparison on US 79. The one-year retroreflectivity at the US 79 site for both the leaded and lead-free material was similar, but it was below what may be considered a desirable level. This low level of retroreflectivity is likely due to the high number of turning movements over the test area. The one-year retroreflectivity at the SH 21 site is still acceptable. The one-year retroreflectivity of the lead-free material appears to compare acceptably to the leaded material.
  - Retroreflectivity values can vary significantly from one location to another. A few of the factors that can cause variation in measured retroreflectivity include marking pigment; difference in pavement surface smoothness; type, density, and embedment of the beads; marking thickness; and accumulation of dirt on the marking. Differences in retroreflectivity between the leaded and lead-free marking samples may be due to factors other than the pigment.
- 30 meter nighttime color
  - The retroreflective color measurements (at 30 meter geometry) for both the leaded and lead-free materials are located in the center of the FHWA color box

for 30 meter yellow marking materials. The initial measurements are also within the recommended color box from the NCHRP 5-18 project but not in the center of the box. The initial 30 meter nighttime color of the lead-free thermoplastic marking material appears to be acceptable.

    - The 30 meter nighttime color measurements of the lead-free thermoplastic over the one-year study period indicate that the material behaves similarly to leaded material based on the results of the comparison on US 79. For both materials the color measurements remained within the color boxes, with similar coordinates. The results from the SH 21 test area also show that the lead-free thermoplastic material remained within the color box. The one-year 30 meter nighttime color of the lead-free thermoplastic marking material appears to compare acceptably to the leaded material.

- 45°/0° color
    - The standard color measurements using Illuminants D65 and A of the leaded and lead-free material were initially found to be within the FHWA and TxDOT color boxes for yellow markings. The initial 45°/0° color of the lead-free marking material appears to be acceptable.
    - The 45°/0° Illuminant D65 color of the lead-free thermoplastic over the one-year study period indicates that the material has trended toward white more rapidly than the leaded material. The 2° standard observer measurements on the leaded material remained within the FHWA color box, whereas the lead-free material was outside of the box at the US 79 site. At the SH 21 site, the 2° standard observer measurements remained within the FHWA box but were near the edge. The 10° standard observer measurements on the leaded material were not within the TxDOT color box. The lead-free material was also outside of the TxDOT box at the US 79 site but was farther away than the leaded material. At the SH 21 site, the 10° standard observer measurements remained outside the TxDOT box but were not quite as far away. The one-year 45°/0° color of the lead-free thermoplastic marking material appears to be closer to white than the leaded material.

    - The 45°/0° Illuminant A color of the lead-free thermoplastic over the one-year study period indicates that the lead-free material behaves similarly to the leaded material. All readings remained within the color box, which is acceptable for the lead-free material.
- 30 meter nighttime color instrument evaluation
    - The two retroreflectometers tested showed varying levels of agreement with regards to retroreflectivity. Of the 15 marking samples, the TxDOT retroreflectometer measured 13 of them higher than the FHWA retroreflectometer. Of the 13 markings, 6 measured more than 10 percent higher with the TxDOT retroreflectometer.
    - The retroreflectometers showed more consistency with regards to 30 meter nighttime color. On average the instruments differed by approximately 0.002 in both the x and y directions. There was one exception (a marking that had no beads on it) that varied significantly, most likely due to the device's uncertainty, as described in the next bullet.
    - Both instruments tested have large uncertainty in the color measurements due to the number of digits displayed when taking a reading. The units only display whole numbers with no decimal points. This leads to a possibly large error, as the uncertainty of the unit is large compared to the color boxes' small areas. Newer versions of the 30 meter color instruments are supposed to display the first decimal place, thus greatly reducing the uncertainty, but this instrument was unavailable for testing at the time of this data collection.

SUMMARY

Initial measurements of the lead-free yellow thermoplastic pavement marking material indicate that the material is able to meet all retroreflectivity and color requirements. The nearly one-year-long evaluation of the lead-free material indicates that the lead-free material is able to retain its retroreflectivity as expected, maintaining nighttime color at 30 meters and 45°/0°, but is unable to remain within the 45°/0° Illuminant D65 daytime color box.

The lead-free material appears to perform in a manner that is consistent with the standard TxDOT leaded material with respect to retroreflectivity, nighttime 30 meter color, and 45°/0°

Illuminant A color readings. The lead-free material appears to differ in 45°/0° Illuminant D65 daytime color readings from the leaded material; the difference is that the lead-free material color is closer to white than the leaded material.

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3. *Special Specification 6110, Reflectorized Pavement Markings with Retroreflective Requirements*. Texas Department of Transportation, Austin, Texas, March 2005. ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/spec/ss6110.pdf. Accessed August 31, 2007.
4. Traffic Control Devices on Federal-Aid and Other Streets and Highways; Color Specifications for Retroreflective Traffic Signs and Pavement Marking Materials. *Federal Register*, Vol. 67, No. 147, Docket FHWA-99-6190, U.S. Government Printing Office, Washington, D.C., July 31, 2002, pages 49569-49575.

CHAPTER 4:
ADDITIONAL WORK ACTIVITIES

INTRODUCTION

There were two fifth-year activities that are different from the other fifth-year activities in that their results cannot be described as a chapter in the annual research report. In both cases, these activities resulted in a manual-type document for the Texas Department of Transportation (TxDOT). The two document efforts undertaken during the fifth year are an update of the TxDOT *Sign Crew Field Book* and the creation of the TxDOT *Work Zone Implementation Handbook*.

SIGN CREW FIELD BOOK

The Texas MUTCD provides valuable guidance about all aspects of traffic signing. However, MUTCD guidelines are developed primarily by and for engineers. When it comes to field personnel installing signing, it can be difficult for them to get the needed information from the MUTCD for a variety of reasons. The need for signing guidelines targeted specifically to field crews was recognized as part of research project 0-1373, which identified the need to improve sign placement for guide signs on conventional highways. As part of that research project, Texas Transportation Institute (TTI) researchers and TxDOT staff worked together to create the *Sign Crew Field Book* (SCFB). This document uses illustrations to establish target sign placement criteria for sign height, sign lateral offset, and sign longitudinal placement on the approach to, and departure from, an intersection. The intersection sign placement guidelines emphasize the treatment of the signs on the approach and departure as a system of signs rather than a collection of individual signs that are placed at inconsistent distances from one intersection to another. The field book also contains information on: the arrangement of components within a guide sign assembly, sign placement for divided highway intersections and crossovers, delineator and object markers, markings for bridges and guardrails, and mailboxes. The first edition of the SCFB was published in 1997, and the last update was in 2000. Since that time, there have been numerous changes in traffic signing standards, including the publication of the 2006 Texas MUTCD and revisions of many traffic engineering standard sheets. As a result, many aspects of the SCFB were out of date. In this activity, TTI researchers updated the SCFB to be consistent with current TxDOT signing practices and formatted the content so that it could be provided online.

In updating the SCFB, the researchers reformatted all of the previous content to be consistent with current TxDOT publication standards (the previous editions had been prepared before TxDOT standardized software aspects of the publication format), reviewed the previous content and identified items that needed to be revised, prepared the revised material, developed new material, and worked closely with TxDOT personnel during the development process to get review comments and input.

During the second half of the revision process, researchers conducted web conferences with TxDOT Traffic Operations Division staff every two to three weeks to review revisions and identify additional items that needed to be addressed. Researchers posted drafts of SCFB chapters online to make them available to staff throughout TxDOT for review. Researchers also conducted two webinars with TxDOT staff to review the draft chapters, seek input on revisions made to date, and identify future revisions.

The researcher team made many minor revisions throughout the SCFB to bring the previous SCFB material up to date. The researchers also made several more significant changes to the SCFB, which include the following:

- added a new chapter that addresses the advance placement of warning signs;
- added toll road signing where appropriate;
- added figures to the guide sign chapter that address:
  - cardinal directions on a loop,
  - use of the double-headed arrow sign, and
  - use of the Texas Reference Marker;
- made major revisions to the drawings for divided highways and crossovers, which included changes to previous figures and the addition of new figures;
- completely rewrote the roadside marker chapter with changes to previous material and the addition of new material; and
- completely rewrote the mailbox chapter to reflect changes in TxDOT standards that have been implemented since the Maintenance Division assumed responsibility for mailbox installation and maintenance.

WORK ZONE IMPLEMENTATION HANDBOOK

In September 2004, the Federal Highway Administration (FHWA) published a final rule establishing new procedures related to assessing the safety and mobility impacts of work zones on the traveling public. The rule applies to all state and local governments who receive federal-aid funding for highway projects. The rule requires work zone impacts to be identified and addressed as part of a transportation management plan that begins at project development and proceeds through construction, including an after-implementation review and assessment element. The transportation management plan for a given project is expected to address temporary traffic control, transportation operations, and public information aspects for the project. The overall goal of the rule is to improve work zone safety and mobility by creating a mechanism to establish good policy and practices that consider the broader safety and mobility impacts of work zones. The compliance deadline for the new rule was October 12, 2007.

Overall, implementing the new rule is both a challenge and an opportunity. As written, the work zone assessment process is a multifaceted procedure that must identify impacts, address those limitations, examine resources and costs, perform periodic evaluations, and address implementation and training needs. To assist TxDOT in implementing the work zone impacts rule, researchers developed a *Work Zone Implementation Handbook* that provides the information needed for TxDOT staff and consultants to understand and implement the rule at the project level. The handbook provides an overall perspective of the final rule, provides the TxDOT policy for the rule, and presents many strategies that are applicable to work zone impact mitigation. The overall goal of the *Work Zone Implementation Handbook* is to provide the guidance and knowledge for TxDOT personnel to create the transportation management plans required by the rule. The handbook is intended to be an explanatory reference, not an encyclopedia of all work zone knowledge.

During the fifth year of this project, the research team continued the development activities that were initiated in the third and fourth years. They met with a panel of TxDOT work zone experts to review drafts of the handbook and refined the handbook based on the panel's comments.

APPENDIX A:
LEAD-FREE PAVEMENT MARKING MEASUREMENTS

The tables in this appendix give the detailed results of the color and retroreflectivity measurements for the yellow thermoplastic markings with and without lead.

Table A-1. Color Specification for Yellow Pavement Markings.

Agency	Specification	1		2		3		4	
		x	y	x	y	x	y	x	y
TxDOT	DMS-8220	0.470	0.455	0.510	0.489	0.490	0.432	0.537	0.462
FHWA	Nighttime 30 Meter	0.473	0.453	0.510	0.490	0.508	0.415	0.575	0.425
FHWA	Daytime 45°/0°	0.498	0.412	0.557	0.442	0.479	0.520	0.438	0.472

Table A-2. SH 21 Lead-Free Thermoplastic Data Summary.

Attribute	Measurement Date	R_L	x	y
30 Meter Retroreflectivity and Nighttime Color	7/31/2007	194	0.5268	0.4458
	11/1/2007	177	0.5102	0.4477
	2/28/2008	155	0.5096	0.4522
	7/1/2008	120	0.5290	0.4465
Attribute	**Measurement Date**	**Y**	**x**	**y**
Daytime Color D65 2°	7/31/2007	44.92	0.4870	0.4546
	11/1/2007	33.79	0.4511	0.4313
	2/28/2008	30.47	0.4415	0.4220
	7/1/2008	30.29	0.4426	0.4212
Attribute	**Measurement Date**	**Y**	**x**	**y**
Daytime Color D65 10°	7/31/2007	43.05	0.5020	0.4516
	11/1/2007	31.81	0.4603	0.4232
	2/28/2008	28.95	0.4511	0.4149
	7/1/2008	29.25	0.4454	0.4117
Attribute	**Measurement Date**	**Y**	**x**	**y**
Nighttime Color A 2°	7/31/2007	52.78	0.5484	0.4324
	11/1/2007	39.25	0.5362	0.4289
	2/28/2008	33.41	0.5316	0.4255
	7/1/2008	35.10	0.5336	0.4251

Table A-3. US 79 Lead-Free Thermoplastic Data Summary.

Attribute	Measurement Date	R_L	x	y
30 Meter Retroreflectivity and Nighttime Color	7/31/2007	268	0.5227	0.4573
	11/1/2007	156	0.5074	0.4431
	2/28/2008	107	0.5114	0.4385
	7/1/2008	72	0.5201	0.4527
Attribute	**Measurement Date**	**Y**	**x**	**y**
Daytime Color D65 2°	7/31/2007	45.62	0.4800	0.4561
	11/1/2007	26.49	0.4334	0.4213
	2/28/2008	25.27	0.4214	0.4099
	7/1/2008	23.89	0.4211	0.4126
Attribute	**Measurement Date**	**Y**	**x**	**y**
Daytime Color D65 10°	7/31/2007	43.05	0.5020	0.4516
	11/1/2007	24.27	0.4389	0.4135
	2/28/2008	24.88	0.4355	0.4094
	7/1/2008	24.00	0.4318	0.4097
Attribute	**Measurement Date**	**Y**	**x**	**y**
Nighttime Color A 2°	7/31/2007	53.42	0.5465	0.4359
	11/1/2007	28.81	0.5261	0.4276
	2/28/2008	27.38	0.5221	0.4237
	7/1/2008	26.71	0.5202	0.4253

Table A-4. US 79 Leaded Thermoplastic Data Summary.

Attribute	Measurement Date	R_L	x	y
30 Meter Retroreflectivity and Nighttime Color	7/31/2007	225	0.5187	0.4472
	11/1/2007	146	0.5174	0.4528
	2/28/2008	98	0.5249	0.4494
	7/1/2008	79	0.5294	0.4428
Attribute	**Measurement Date**	**Y**	**x**	**y**
Daytime Color D65 2°	7/31/2007	-	-	-
	11/1/2007	30.19	0.4567	0.4442
	2/28/2008	33.26	0.4530	0.4385
	7/1/2008	29.06	0.4553	0.4409
Attribute	**Measurement Date**	**Y**	**x**	**y**
Daytime Color D65 10°	7/31/2007	-	-	-
	11/1/2007	26.65	0.4623	0.4338
	2/28/2008	30.58	0.4588	0.4276
	7/1/2008	27.57	0.4707	0.4341
Attribute	**Measurement Date**	**Y**	**x**	**y**
Nighttime Color A 2°	7/31/2007	-	-	-
	11/1/2007	34.37	0.5364	0.4334
	2/28/2008	34.56	0.5333	0.4293
	7/1/2008	31.85	0.5369	0.4312

Table A-5. LTL 2000Y Comparison Data Averages.

Marking Sample	FHWA LTL 2000Y			TxDOT LTL 2000Y		
	R_L	x	y	R_L	x	y
Yellow 1	125	0.499	0.445	142	0.498	0.446
Yellow 2	14	0.483	0.432	13	0.519	0.436
Yellow 3	277	0.523	0.458	304	0.521	0.458
Yellow 4	109	0.500	0.446	125	0.500	0.448
Yellow 5	259	0.524	0.459	279	0.522	0.460
Yellow 6	256	0.521	0.459	260	0.519	0.461
Yellow 7	199	0.522	0.455	221	0.519	0.456
White 1	132	0.441	0.408	130	0.440	0.411
White 2	174	0.443	0.408	176	0.440	0.411
White 3	255	0.441	0.408	267	0.440	0.410
White 4	270	0.443	0.408	317	0.439	0.409
White 5	238	0.443	0.408	269	0.440	0.410
White 6	134	0.444	0.409	135	0.441	0.411
White 7	245	0.443	0.407	280	0.441	0.409
White 8	24	0.445	0.412	25	0.447	0.416