Technical Report Documentation Page

1. Report No.
FHWA/TX-09/0-5656-P1

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
MOBILE RETROREFLECTIVITY BEST PRACTICES HANDBOOK

5. Report Date
October 2008
Published: July 2009

6. Performing Organization Code

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8. Performing Organization Report No.
Product 0-5656-P1

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 0-5656

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
Product:
September 2006 - 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: Serviceable Pavement Marking Retroreflectivity Levels
URL: http://tti.tamu.edu/documents/0-5656-P1.pdf

16. Abstract

This handbook documents best practices related to proper use of the mobile retroreflectometer, sampling of sites for data collection, and handling of mobile retroreflectivity data. The best practices described in this handbook are derived from the results of Texas Department of Transportation (TxDOT) Project 0-5656 and the author’s observation in using the mobile retroreflectometer. The first part of the handbook provides information on sampling of pavement markings, periodic data quality checks, and data file naming conventions. The sampling procedure described here provides a systematic way of reducing the number of samples under a constrained budget. File naming conventions suggested in this handbook will be helpful in automating mobile retroreflectivity data handling and analysis.

The second section of the handbook provides information on equipment required to calibrate the mobile retroreflectometer and collect the data. This handbook also describes the best practices for initial setup and calibration of the mobile retroreflectometer and calibration checks. Since several factors change as data are being collected, best practices for accounting for changes in variables, such as variations in vehicle speed and operating temperature, etc., are described.

The final section pertains to best practices in data handling and suggested analysis of mobile data. This handbook elaborates on the consistency of data file headers and quality checking of data. A prototype of automation for data analysis is demonstrated that will prove handy in dealing with large amounts of mobile data.

17. Key Words
Retroreflectivity, Measurement, Mobile Retroreflectometer, Mobile Retroreflectometer Calibration, Retroreflectivity Data Collection, Pavement Marking Sampling, Retroreflectivity Data Analysis, Data Automation, GIS Mapping

18. Distribution Statement
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)
Unclassified

20. Security Classif.(of this page)
Unclassified

21. No. of Pages
46

22. Price

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

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Product 0-5656-P1
Project 0-5656
Project Title: Serviceable Pavement Marking Retroreflectivity Levels

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

October 2008
Published: July 2009

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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 permitting purposes. The engineer in charge of the project was Robert J. Benz, P.E. #85382.

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

ACKNOWLEDGMENTS

This project was conducted in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration. The authors wish to acknowledge the following individuals, without whose insight and assistance the successful completion of the first portion of this research project would not have been possible:

- Mr. Richard Kirby, P.E., Texas Department of Transportation, Construction Division, Project Director;
- Mr. Carlos Ibarra, P.E., Texas Department of Transportation, Atlanta District, Project Advisor;
- Mr. Wally Shaw, Texas Department of Transportation, Traffic Operation Division, Project Advisor;
- Mr. Wade Odell, P.E., Texas Department of Transportation, Research and Technology Implementation Office, Austin, Research Engineer;
- Mr. Roy Wright, P.E., Texas Department of Transportation, Abilene District, Director of Transportation Operations;
- Mr. James Keener, Texas Department of Transportation, Houston District, Traffic Engineering Division, Special Events Coordinator;
- Mr. John Bassett, P.E., Texas Department of Transportation, Austin, Construction Division; and
- Mr. Richardo Castaneda, P.E., Texas Department of Transportation, San Antonio District.

The authors would also like to acknowledge the assistance of Paul Carlson, Greg Davis, Gene Hawkins, Dillon Funkhouser, Eun Sug Park, and Derek Ladd of the Texas Transportation Institute (TTI) at various stages of the project.

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MOBILE RETROREFLECTIVITY BEST PRACTICES HANDBOOK

The future of mobile retroreflectivity data collection will rely on the ability of the users to collect accurate and reliable data. The ability of TxDOT to plan and monitor mobile retroreflectivity data collection will impact the results and the quality of the data received to meet TxDOT's needs. An understanding of the mobile retroreflectivity equipment, data collection process, and resulting data is imperative for both planning and monitoring data collection to ensure the best possible data. This document recommends the best practices for all phases of mobile retroreflectivity data collection, from the determination by TxDOT on where to measure, to the operational aspects of the data collection, to the summary and usage of the collected data. Recommendation of these best practices is based on field experience using the mobile retroreflectometer equipment, setting up data collection, and evaluating the collected data.

INITIAL DECISION-MAKING BEST PRACTICES

There are two main purposes of mobile retroreflectivity data collection. The first is to provide quality assurance and quality control (QA/QC) of new pavement marking installations, and the second is to monitor existing pavement markings for end-of-service life purposes. Each purpose may require a different plan when deciding which markings to evaluate. Typically, for QA/QC of new pavement marking installations, evaluation of the markings is necessary to ensure that all markings meet minimum installation retroreflectivity requirements. When monitoring existing markings (excluding recently applied pavement markings), it makes practical sense to not measure every marking, but rather a sample or set of high priority markings. It is recommended that measuring only a select set of markings when monitoring existing markings can reduce costs and time. The following section presents tips and best practices on selecting roadways to collect data for monitoring service life and using sampling techniques to reduce the amount of data necessary for the sample. Also provided are recommendations on setting up field check locations to monitor the data collection.

SUGGESTED SAMPLING PLAN METHODOLOGY

The Pavement Management Information System can provide the population of roadway segments. However, due to limited resources, it may be necessary to only collect retroreflectivity data on a limited number of the roadways. Several steps to reduce the quantity of the data collection are available. It is the general premise to reduce the quantity of roads to be measured based upon expectations of the quality of the markings and planned use of the resulting retroreflectivity data.

The first step in reducing the amount of data to be collected would be to not collect data on recently striped roads other than to collect initial retroreflectivity readings for installation QA/QC purposes. In the weeks following installation, measurement of recently striped markings will be taken to ensure they meet installation minimum retroreflectivity levels. There is little benefit to measuring these roads in the months after installation. If the new markings meet the initial retroreflectivity levels they should be acceptable for at least a year if they are a durable marking. After the first year, and possibly even longer on lower volume roads, retroreflectivity measurements for monitoring performance should continue to ensure the marking is providing adequate retroreflectivity and for modeling the degradation of the markings.

The second step would be to not collect data on roadways that are scheduled to be resurfaced within the next year. Since the roadway will have a new surface, the markings will also be covered and replaced. Any data gathered on a road in its last year of service will be of little use, other than for retroreflectivity degradation modeling purposes.

The third step would be to not collect data on roads where the pavement markings received an excellent or good assessment during Texas Maintenance Assessment Program (TxMAP) inspections. These two TxMAP ratings indicate that the inspector observed that the markings were in very good or like-new condition. Therefore, TxMAP inspections and night inspections of a marking that provide a visual score of good or excellent can be expected to provide adequate retroreflectivity for another year. If funding is available, data collection for retroreflectivity degradation modeling purposes on markings receiving a good rating should be considered. Degradation models may eventually lead to more accurate decisions on when to measure and/or restripe markings.

If the quantity of data collection sample is still too large, a fourth step involving retroreflectivity degradation curves is available. A regression curve can estimate the retroreflectivity degradation of a marking. Past experience with a similar marking in a similar environment is the basis for this curve. Any data on the existing markings can also be of use to determine the expected life of the marking. Any markings that may be nearing the minimum retroreflectivity levels should be measured, but markings that are not expected to approach the minimum level may not need measuring. The regression curve concept, in the Regression Models section of this handbook and in more detail in the research report, is a systematic tool that can be used to limit the amount of data necessary to monitor the retroreflectivity levels.

In summary, the following situations may not require mobile retroreflectivity data collection for retroreflectivity monitoring purposes:

- newly striped roads (less than 12 months old or longer for low Annual Daily Traffic [ADT] roads);
- roads that are to be resurfaced within a year;
- roads where the markings receive a TxMAP visual score of good or excellent, and
- roads where the modeled retroreflectivity of the marking falls well within acceptable levels.

Other considerations are:

- urban or rural roadways;

- crash experience;
- overhead lighting present, and
- line type.

Consideration should be given for mobile retroreflectivity monitoring for all roads not included in the above criteria. Roads included in the above criteria can also be considered for mobile retroreflectivity monitoring if time and budget restraints allow. The following sections explain methods of organizing the data to be collected. Organization of the data is a key factor for successful data collection. If there is not a method to organize the data from the start, then the final data will be more difficult to analyze, which may limit its overall effectiveness.

Line Types

After selection of possible roadway segments, consideration is given to the pavement marking line types on those roads, which are centerlines, edgelines, and lane lines. Measuring each marking type is valuable but may not be necessary if reductions in quantity of data collected are still sought. In urban areas, measuring centerline markings may be less critical than in rural areas because in urban areas, there are typically curbing or traffic barriers separating directions of travel, whereas in rural areas, the centerline markings serve as the barrier. Also, in urban areas overhead lighting is common, and roads with overhead lighting may be considered as roads to not measure since the *Manual on Uniform Traffic Control Devices* does not currently mandate retroreflectivity of the markings. Each district will have to weigh these factors to determine a percentage of lane miles of line types that need to be included the sample.

There is a minimum section length of marking that will need measuring since the typical measurement unit is 0.1 mile. A segment measurement length of approximately 0.5 mile would be a sufficient minimum measurement length if only portions of the markings were evaluated. On long roads, multiple sections may need evaluation if it is anticipated that retroreflectivity may vary due to surface type or traffic condition impacts. If needed, measurements on segments shorter than 0.5 mile (e.g., spurs and ramps), using a shorter data acquire frequency (0.01 mile) and using the whole road segment may be of benefit to get a more detailed look at the marking's variability. While many TxDOT staff members have expressed concern about the amount of data, the true concern is typically over the number of roadways measured, which generates a large number of retroreflectivity data files. Utilizing automation, graphing, and mapping techniques should reduce these concerns and allow easily managed large data sets.

Naming of Files

Several aspects of the data collection will need enhancements to simplify and promote the automation of the data analysis and display. The first is the naming of files. A systematic naming convention that could relate to additional roadway segment information would allow automation. The information that would be useful would include the following:

- roadway name (e.g., Katy Freeway);
- descriptive roadway section limits (e.g., IH 610 to BW8);
- TxDOT roadway limits (control section number and/or TxDOT route sample);
- field definable measured limits (e.g., IH 10 W Antoine to Bingle);
- Key Map® , Mapsco©, or other commercial mapping products reference;
- latitude and longitude coordinates for the beginning and ending limits (use the RI convention S to N and W to E)
    - decimal degree coordinates preferred;
- heading direction for the beginning and ending points of each segment;
- what is being measured (edgeline, lane line, centerline);
- color of the marking (white or yellow);
- type of material (paint, thermoplastic, etc.);
- work zone pavement markings or permanent;
- pavement type;
- pavement condition (smooth, rough, wet, dry, etc.); and
- weather (daylight, night, cloudy, overcast, sunny).

It may be beneficial to create a database of roadway segments that are sampled over the years so that year to year comparisons can be made. A process to include some or all of the above information is required to be able to describe the marking to be measured. This information could be contained in the retroreflectivity data file or in a separate table that is related through a relational database.

REGRESSION MODELS

Logic and experience suggest that degradation in retroreflectivity of pavement markings is a result of the age of the marking and the wear caused by vehicle tires. There are also other factors that potentially influence the variability of the degradation process for a given marking, such as initial marking quality, application techniques, bead system used, road surface type, marking location, and climate. In order to develop a model that would allow maintenance personnel to predict the point at which a pavement marking should be replaced, it is necessary to examine the relationship between age and tire wear and to examine the influence of the other factors.

In the stylized depiction of the predictive model, Figure 1 indicates that, as age and volume increase, retroreflectivity decreases. The red line presents a threshold of acceptable retroreflectivity, thought to be about 100 millicandelas per square meter per lux (mcd/m^2/lux). Retroreflectivity values above this line would be less than 100 mcd/m^2/lux, and those below the threshold line would be greater. The actual location of the red line is dependent on all the variables that impact the retroreflectivity of the pavement markings. Until large volumes of data are collected on roads in a given area, the location of the red line should be based on experience and expectations.

Figure 1 also shows a dashed orange line that parallels the red threshold line. This line represents a subjective value that might trigger planning for measurements and/or to schedule re-striping jobs before the threshold of degradation. Such a model would allow an additional means of deciding when retroreflectivity measurements would need to be taken to confirm the need to replace a pavement marking.

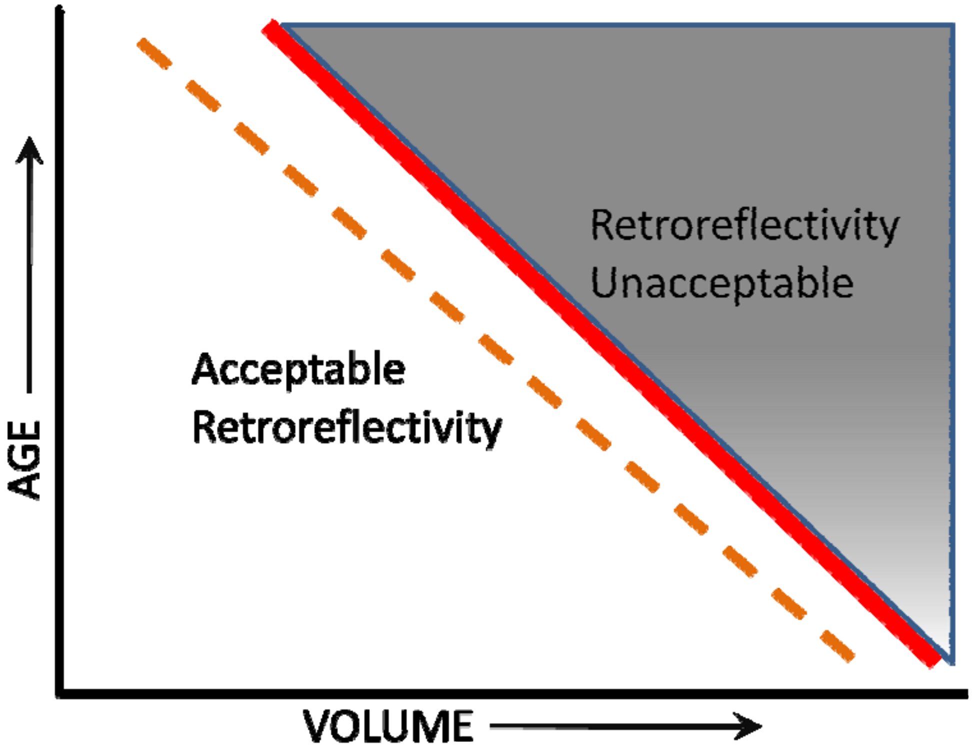


Figure 1. Predictive Retroreflectivity Model Based on Marking Age and Traffic Volume.

Method for Creating Regression Lines

First, create a list of potential segments of pavement markings to measure for the development of regression models. At a minimum, the information required for potential selection of a segment will be the age of the pavement marking and the per lane volume for the roadway on which the marking is installed. If information concerning marking type, function, and roadway type is available, these data should be collected as well. A series of curves with the following criteria will need to be developed for regression modeling.

The primary variables of interest include:

1. Age – four bins of ages will be used:
    a. 1 to <3 years,
    b. 3 to <5 years,
    c. 5 to <7 years, and
    d. greater than 7 years.
2. Volume – five bins of volumes will be used:
    a. 0 to <2 thousand vehicles per lane per day,
    b. 2 to <4 thousand vehicles per lane per day,
    c. 4 to <6 thousand vehicles per lane per day,
    d. 6 to <8 thousand vehicles per lane per day, and
    e. greater than 8 thousand vehicles per lane per day.

If available, the following will be collected:

3. Type of Marking – four types will be considered:
    a. thermoplastic,
    b. paint,
    c. tape, and
    d. epoxy/polyurea.
4. Marking Function – three types of functions will be considered:
    a. edgeline,
    b. centerline, and
    c. lane line.
5. Pavement Type – three types of pavement will be considered:
    a. concrete,
    b. asphalt, and

        - c. seal coat.
    6. Pavement Area Function – three types of areas will be considered:
        - a. tangent sections,
        - b. horizontal curve sections, and
        - c. weaving sections.

PERIODIC FIELD CHECKS AT PRE-MEASURED LOCATIONS

When creating a mobile retroreflectivity measurement contract, a provision for periodic field checks at pre-measured locations should be included. These locations are representative markings measured by TxDOT with a handheld retroreflectometer. These locations should be near where the mobile retroreflectivity data collection is taking place. TxDOT should take measurements at the test location within 10 days prior to the test. If any rain occurs between the collection of the handheld measurements and the test, the pavement markings should be remeasured. TxDOT should require the contractor to measure these markings as part of the data collection and to immediately report the results to TxDOT for accuracy verification. If the mobile measurements do not fall within ±15 percent of the pre-measured averages, further calibration and comparison measurements may be required before any further mobile data collection can continue. The mobile testing results data file from the field check should be provided with the mobile retroreflectivity data collection report for that day. TxDOT should also consider doing spot field checks while the contractor is measuring retroreflectivity and compare the readings on site. This is the best way to ensure that accurate data are collected.

MOBILE RETROREFLECTIVITY DATA COLLECTION BEST PRACTICES

Documenting the best practices with regards to the operation of the mobile retroreflectometer is essential to providing consistent and accurate retroreflectivity measurements. The lessons learned while collecting data during variable evaluations and data collection under real world conditions provide the basis for the best practice recommendations (see TxDOT Project Report 0-5656 for the variable evaluation [*1*]). These best practices may not be the only methods to collecting accurate and reliable data but should provide a minimum standard for operational procedures. All procedures should meet or exceed those in TxDOT Special Specification 8094 (*2*) and specific procedures written into the contract. This documentation of operational best practices will be most useful to TxDOT staff and contractors using mobile retroreflectometers and could potentially help develop specifications for retroreflectivity data collection contracts.

MOBILE RETROREFLECTIVITY EQUIPMENT

Mobile retroreflectivity data collection uses three main pieces of equipment, each of which plays a significant role in data collection: the vehicle for the mobile data collection, the mobile retroreflectometer, and a handheld retroreflectometer. Each of these things must be in proper working order and must be properly operated in order to collect accurate and reliable retroreflectivity data.

Mobile Vehicle

The mobile vehicle provides the platform for mounting the mobile retroreflectometer. The mobile vehicle also contains the other equipment that is necessary to conduct proper data collection. The computer used to operate the mobile retroreflectometer, the video recording system, the distance measuring instrument (DMI), and the global positioning system (GPS) device are all part of the vehicle setup.

The computer must be of sufficient capabilities to operate the software and receive the input from the mobile retroreflectometer. The computer should be up to date with the most recent version of the software to provide data that are as accurate as possible. The software also needs to be set up and operated so that variables that affect the data collection can be accounted for in the best way possible. The Accounting for Measurement Variables section of this report further describes the best operating procedures. The video recording system should be linked to the computer to provide the video overlay that displays the forward scene and data collected at the same time. The video recording system's purpose is to allow verification of data and to assist in determining discrepancies in the data.

The DMI provides the chainage (mileage) data that are associated with each measurement section. As the vehicle drives down the road, the DMI measures the distance traveled and relays that to the software, which then incorporates it into the data. Calibration of the DMI is essential for proper chainage data and for associating measurement areas with specific locations. The DMI should be calibrated on a straight section of road with a known distance. The longer the calibration section is, the more accurate the calibration will be. The distance of the section measured (greater than 1000 feet if possible) should be known to within 1 foot prior to calibrating so that the distance can be entered into the software. To check for the accuracy of the DMI, the speed and distance output by the software should be similar to that of the vehicle's speedometer and odometer when making a measurement. If there is a discrepancy, the system should be recalibrated.

The GPS device provides coordinates associated with each measurement point. The GPS device is connected to the computer and incorporated into the retroreflectometer software. Accurate GPS readings are necessary so that when used in combination with the chainage data, measurement location is apparent. To check for the accuracy of the GPS device, the GPS coordinates can be entered into any mapping software or map website. The GPS coordinate location and the measurement location should be at the same location.

Mobile Retroreflectometer

The mobile retroreflectometer is the device that transmits the light and captures the retroreflectivity of the pavement markings. Software on the computer inside the mobile vehicle controls the mobile retroreflectometer. Mounting the mobile retroreflectometer to either side of the mobile vehicle allows pavement marking retroreflectivity data collection as the vehicle travels down the road. Proper setup of the mobile device on the side of the vehicle and proper calibration are necessary to provide accurate and reliable retroreflectivity readings (see the Mobile Retroreflectometer Setup and Calibration section). There are several variables that impact the accuracy of the mobile retroreflectometer's readings (see the Accounting for

Measurement Variables section). The data collection team should try to minimize the impact of these variables as much as possible.

Within the mobile retroreflectometer is a temperature sensor that is key to compensating for changes in temperature inside the retroreflectometer. The temperature sensor should always provide temperature output to the software. The tilt motor within the retroreflectometer should also be properly working at all times. The tilt motor adjusts the measurement location to ensure the 30 meter geometry. The tilt motor should be able to hold its position during data collection so that the geometry is not changing. It is also important to ensure that all connections between the mobile retroreflectometer and the computer are secure and properly connected. To ensure all data are properly transmitted and recorded, any pins in the connecting devices that are bent or pushed in must be repaired.

When collecting mobile retroreflectivity measurements, the retroreflectometer's lens should remain free of dirt and moisture buildup. Any interference on the lens of the mobile retroreflectometer will impact the results. A steady signal received by the software is also imperative. If the internal mirrors or timing are not properly set up, the device may provide inconsistent and inaccurate information.

Handheld Retroreflectometer

The handheld retroreflectometer is essential for calibrating the mobile retroreflectometer. A properly functioning and calibrated handheld retroreflectometer is the only means of ensuring accurate calibration of the mobile retroreflectometer (see the Mobile Retroreflectometer Setup and Calibration section). Calibrate the handheld retroreflectometer according to the manufacturer's specifications. The handheld retroreflectometer should be able to maintain this calibration throughout the data collection process. When collecting handheld retroreflectivity measurements, the retroreflectometer's lens should remain free of dirt and moisture buildup. Any interference on the lens of the handheld retroreflectometer will impact the results. All handheld readings should be measured in accordance with American Society for Testing and Materials (ASTM) standards (*3*).

MOBILE RETROREFLECTOMETER SETUP AND CALIBRATION

The most critical aspect of mobile retroreflectivity data collection is properly setting up and calibrating the retroreflectometer. If the setup is not correct or the calibration is not good, the resulting data will be neither accurate nor reliable. This section describes the best practices with regards to setup and calibration of the mobile retroreflectometer.

Measurement Geometry

The mobile retroreflectometer needs to be set up to measure at the standard 30 meter geometry, which is the same geometry as handheld retroreflectometers. The mobile retroreflectometer should be set up according to the manufacturer's specifications. When setting up the retroreflectometer height, it is imperative that the vehicle load is as similar as possible to when data collection is going to take place, which is having people and equipment in place in the vehicle to where they will be during data collection. Any changes in the weight distribution in the vehicle will cause a change in the measurement geometry. Shifting weight distributions will impact each vehicle and its suspensions differently. It may be necessary to keep the gas tank within a certain range (e.g., no less than half full, between ¼ and ¾ full, etc.) during data collection so that changes in the amount of fuel minimize the impact on the vehicle's geometry.

The mobile retroreflectometer geometry should be set up on a level surface so that body pitch and roll do not impact the setup conditions. Similar to weight distribution within the vehicle, if the vehicle is on a slope, the vehicle's weight will shift, thereby throwing off the alignment. A level surface will also provide the ideal location for calibrating the mobile retroreflectometer. Calibration of the mobile retroreflectometer takes place at a distance of 10 meters. Calibration at a level location and a distance of exactly 10 meters is critical, so the measurements are still at 10 meters when conducting data collection. The researchers recommend slightly angling the retroreflectometer outward when mounting it to the vehicle. This slight angle will allow the driver to travel closer to the center of the travel lane instead of driving right on the pavement marking, which could cause operational or safety issues.

Calibration Panel

The calibration panel used for calibrating the mobile retroreflectometer should be consistent in retroreflectivity along its length, but especially in the middle portion where the calibration will take place. Place the calibration panel so that the center of the panel is 10 meters in front of the mobile retroreflectometer. Handle the calibration panel with care and keep the panel free of debris so that its retroreflectivity will remain consistent and change as little as possible. Verify the retroreflectivity of the calibration panel by measuring it with a handheld retroreflectometer. The exact retroreflectivity of the calibration panel at the location where the mobile retroreflectometer is measuring is critical. Often, there will be some slight variation in the retroreflectivity of the calibration panel. In this case an average of the values in the calibration area should be used. If there is much variation in the calibration panel's handheld measurements, a different calibration panel may be necessary.

Measurement Linearity

The mobile retroreflectometer is subject to bias when measuring a very large range of retroreflectivity values. When calibrating the mobile retroreflectometer, it is best to calibrate close to the retroreflectivity level of the markings to be measured. If the markings being measured are old, it is best to calibrate using a low retroreflectivity calibration panel, and vice versa for markings with higher retroreflectivities. If a calibration panel of a similar retroreflectivity level is not available, a slight compensation based on the calibration check may be necessary (see the Calibration/Dynamic Check section). If measuring a large range of retroreflectivities, spot checks to verify accuracy as the retroreflectivity levels change may be necessary (see the Calibration/Dynamic Check section).

Calibration

As described in the previous three sections, the setup geometry, calibration panel, and calibration retroreflectivity level are all important when calibrating the mobile retroreflectometer. Calibration should take place on a level surface, with all equipment and personnel who will be present during data collection in the vehicle. Measure the calibration panel with the handheld retroreflectometer to ensure calibrating to the correct value. The calibration panel should be similar in retroreflectivity to that anticipated to be measured on the road. Calibrate the retroreflectometer as close to the middle (position 100) as possible to help compensate for measurement differences across the measurement window.

Reset the calibration in the software prior to a new calibration, and input the retroreflectivity value of the calibration panel into the software. Calibration can then take place. Run the software after finishing the calibration to make sure the proper retroreflectivity level is measured. The researchers recommend a dynamic calibration check after the static calibration is complete (see the Calibration/Dynamic Check section). The dynamic calibration check is the only method to ensure that the mobile retroreflectometer is properly calibrated. Calibration of the retroreflectometer and/or spot checks of the retroreflectometer's accuracy should be conducted at a minimum of every four hours of operation to ensure that the retroreflectometer is still providing accurate data. When ambient light conditions change (i.e., day versus night) the mobile retroreflectometer will need to be recalibrated. That means when measuring during the day, the mobile retroreflectometer must be calibrated during the day, and when measuring at night, the mobile retroreflectometer must be calibrated at night.

Calibration/Dynamic Check

After the static calibration, it is important to verify that the retroreflectometer will provide accurate readings while taking measurements driving down the road. The calibration check should take place on a marking and road surface similar to that which will be measured during the data collection. A short section of road should be measured with the handheld retroreflectometer, and this same section should be measured with the mobile retroreflectometer. The researchers recommend selecting a section of road with retroreflectivity values similar to those that are expected on the actual roads that will be measured. The researchers also recommend selecting a section of road that has a small variability because large variability can impact the accuracy of the readings.

The section of road measured with the handheld retroreflectometer and mobile retroreflectometer does not need to be long in length, but the longer the section, the more accurate the results will be. The researchers recommend measuring a section approximately 0.05 to 0.1 mile in length, and setting the acquire frequency to 0.01 when conducting the calibration check. There should be a minimum of 20 handheld readings along the section, but again, more readings will provide a more accurate average value of the retroreflectivity along the section.

The average of the handheld readings and the mobile readings along the calibration check section should be compared to each other. TxDOT would like to see all measurements with ±15 percent from the handheld retroreflectivity value. Since this is an initial calibration check, it should be as accurate as possible so that over time, there is more leeway for some variation, yet it will still be within the required accuracy range. Ideally the calibration check should be within ±5 percent and subsequent checks throughout the day be within ±15 percent.

If the calibration check does not fall within the necessary range, the system will need to be adjusted and recalibrated. Experience will make this process quicker and more accurate. Checking the calibration of the mobile unit is very important and should be conducted each time the mobile retroreflectometer is calibrated. The researchers recommend conducting spot checks of the accuracy of the mobile retroreflectivity readings at a minimum of every four hours. These spot checks should be conducted in the same way that the calibration check is carried out.

ACCOUNTING FOR MEASUREMENT VARIABLES

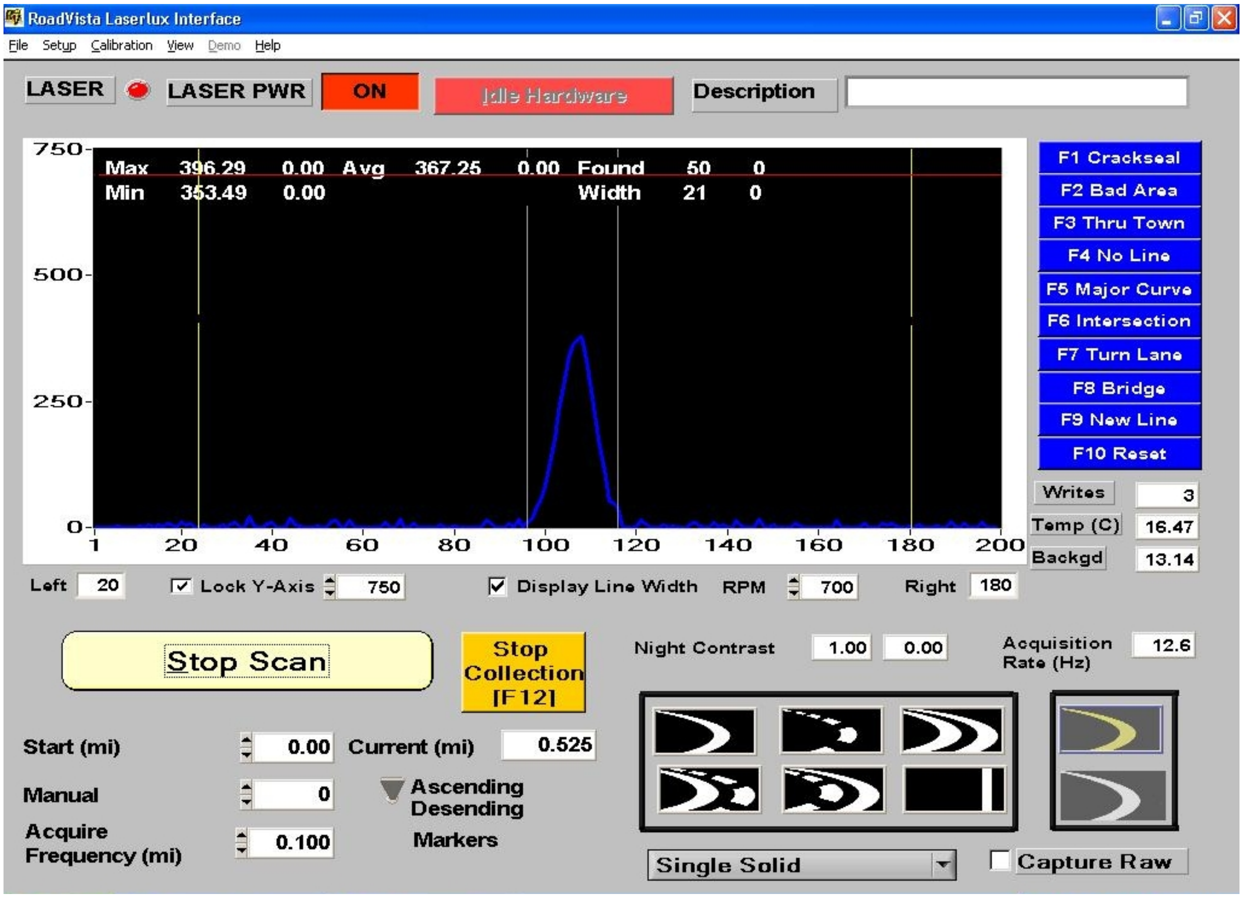
The best practices for conducting accurate mobile retroreflectivity data collection start with proper calibration procedures and a calibration check, as discussed in the previous section. With proper calibration, the mobile retroreflectometer can collect accurate retroreflectivity readings if nothing changes from when the calibration took place. When collecting data, conditions are going to change, so measures need to be taken to address these changes in the best way possible to minimize their effect. The following sections will describe methods to best account for changes from some major variables that impact the accuracy of mobile retroreflectivity data collection.

General Software Setup

The mobile retroreflectometer software has several user adjustable settings on the main screen and several more in the various drop-down menus. Properly setting up the software by adjusting these settings can help provide more consistent and accurate data collection. This section will describe the software settings in general, while several settings are described in more detail in subsequent sections.

Two of the basic settings are the calibration color and the line type. Figure 2 provides a screenshot of the mobile retroreflectometer software. The calibration color and line type are in the lower right-hand portion of the software. The calibration color selection makes sure the correct calibration value is used since the retroreflectometer needs to be calibrated separately for white and yellow markings. The researchers recommend measuring all white markings off the right-hand side of the vehicle and all yellow markings off the left side. This will make for more consistent collection of the white pavement markings when measuring lane line markings. The pavement marking line type should be changed as the markings on the road change. The data output from the software are tagged by the selected line type, so when measuring a variety of markings, the line type can help distinguish between the different markings.

Within the measurement window (the black area of Figure 2), there are several settings to adjust how the data display and output. The left and right values (seen below the measurement window) control the position of the vertical bars on the measurement window (seen in Figure 2 at positions 20 and 180). The function of these bars is to reduce the size of the measurement window by removing the outer portions so that only measurements taken near the middle are recorded. A later section will describe the measurement position in greater detail, but the bars can serve to provide more accurate data due to the change in retroreflectivity that is experienced across the measurement window. Also on the measurement window are vertical bars that display the line width (seen in Figure 2 near positions 100 and 120). The software displays the line width bars when a retroreflective line of appropriate size is within the measurement window. The function of these bars is to indicate the approximate width of the line being measured and to let the operator know when data are being collected. The blue line between the bars is the retroreflectivity of the marking. The lock y-axis value controls the scale on the y-axis. The y-axis value should be greater than the retroreflectivity of the markings being measured but low enough that the magnitude of the marking's retroreflectivity can be clearly seen in the measurement window.



LASER PWR ON

Idle Hardware

Description

Max 396.29 0.00 Avg 367.25 0.00 Found 50 0

Min 353.49 0.00 Width 21 0

Writes 3

Temp (C) 16.47

Backgd 13.14

Left 20

☑ Lock Y-Axis 750

☑ Display Line Width

RPM 700

Right 180

Night Contrast 1.00 0.00

Acquisition Rate (Hz) 12.6

Start (mi) 0.00

Current (mi) 0.525

Manual 0

Acquire Frequency (mi) 0.100

Ascending
Desending
Markers

Single Solid

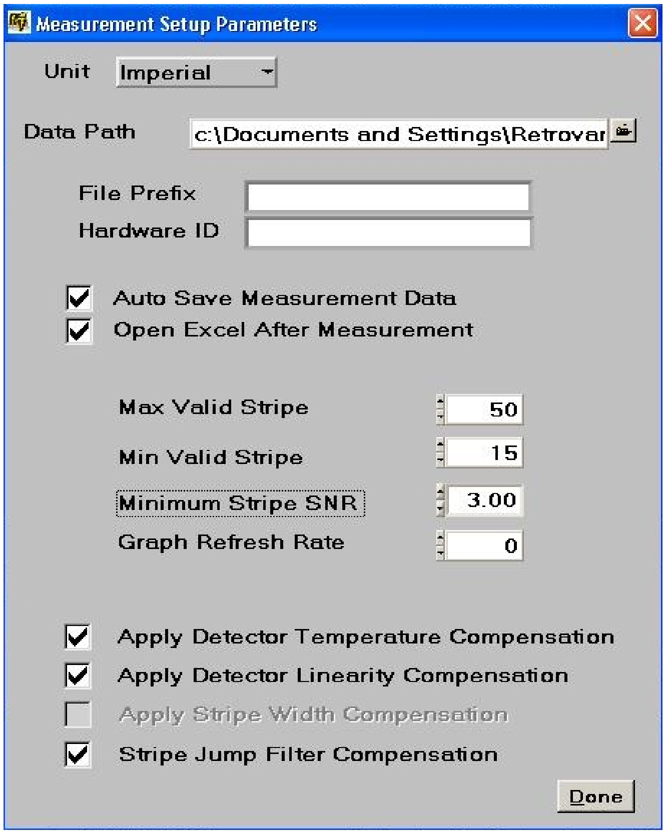
☐ Capture Raw

Figure 2. Mobile Retroreflectometer Software.

The road condition settings (see the blue F buttons located to the right in Figure 2) are user adjustable and are used to mark the data to note certain road features or abnormality within the data. The data for the section whose button is pressed will be marked with what the button displays. Marking the data with the road condition buttons is a good way to keep track of odd areas within the data while conducting the data collection. These odd areas can later be removed, separately analyzed, or left alone.

In the setup drop-down menu is an option to adjust the measurement parameters (see Figure 3). These parameters determine the data measured and if compensation is applied or not. The minimum and maximum valid stripe width filter out measurement noise that may occur during data collection. By setting the minimum line width slightly below the standard line width (typical 4-inch line width is 20-25) and the max line width slightly above the standard line width, the majority of the readings will come only from the pavement marking. The minimum line width is important to help filter out little spikes that may occur due to retroreflection off aggregate or debris in the roadway. The max line width helps filter out transverse markings and horizontal signage.

There are several other settings that play an important role in setting up the software and collecting accurate retroreflectivity readings. The following sections describe the user adjustable values of acquire frequency, retroreflective raised pavement marker (RRPM) level, signal to noise ratio (SNR) value, measurement position compensation, and temperature compensation.



Unit Imperial

Data Path c:\Documents and Settings\Retrovar

File Prefix

Hardware ID

☑ Auto Save Measurement Data
☑ Open Excel After Measurement

Max Valid Stripe 50
Min Valid Stripe 15
Minimum Stripe SNR 3.00
Graph Refresh Rate 0

☑ Apply Detector Temperature Compensation
☑ Apply Detector Linearity Compensation
☐ Apply Stripe Width Compensation
☑ Stripe Jump Filter Compensation

Figure 3. Setup Parameters for the Mobile Retroreflectometer.

Data Collection Speed

The data collection speed can influence the retroreflectivity readings in several ways. One way that speed influences the readings is that the faster the data collection vehicle is going, the fewer the number of data points per collection area. This is due to the fact that the mobile retroreflectometer can only collect a certain number of readings per second. Therefore, data collected at X speed will have approximately twice as many data points collected as data collected at 2X speed. The mobile retroreflectometer is able to collect data at a great enough rate that even at highway speeds, it is still collecting large amounts of data. The impact on the accuracy of the mobile readings at different but constant speeds is minimal.

Another way that data collection speed can influence the accuracy of the readings is if there are large speed fluctuations (i.e., acceleration or deceleration). These large changes in speed will cause the vehicle to pitch forward or back, which in turn changes the measurement geometry. This change in geometry will significantly affect the results, typically rendering them invalid. All data collection should take place at a constant speed, and preferably with the cruise control set. If a constant speed cannot be maintained, the driver should try to have smooth speed transitions so that the vehicle dynamics are minimally impacted. If large speed fluctuations occur, the data should be marked and/or the measurement scan should be stopped.

Data Collection Acquire Frequency

The acquire frequency is the distance over which the retroreflectivity readings are averaged (see lower left side of Figure 2). This is a user adjustable value that is typically 0.1-miles or longer. The acquire frequency is a means of reducing the number of data points to make the data more manageable. When the acquire frequency is set to 0.1 mile, the data collected over that distance will be averaged and output as a single retroreflectivity value. The standard deviation, maximum, minimum, and number of actual points that created the average are also outputs for that 0.1-mile segment.

The advantage of a longer acquire frequency length is that fewer data points are produced, so the files do not look as big and the data are easier to look at quickly. The disadvantages are that it is more difficult to identify isolated areas and that larger areas are averaged together, so bad data along a short area will influence a much longer section.

Testing has shown that the acquire frequency has little impact on the average retroreflectivity value collected along a segment. Whether the segment is broken up into many parts or just one, the results are similar. This is the case for good markings on a tangent and proper data collection along the length of the section. Markings in a curve, markings with large variability, and areas where data collection is not conducted properly are likely to show differing results.

Signal to Noise Ratio and RRPM Level

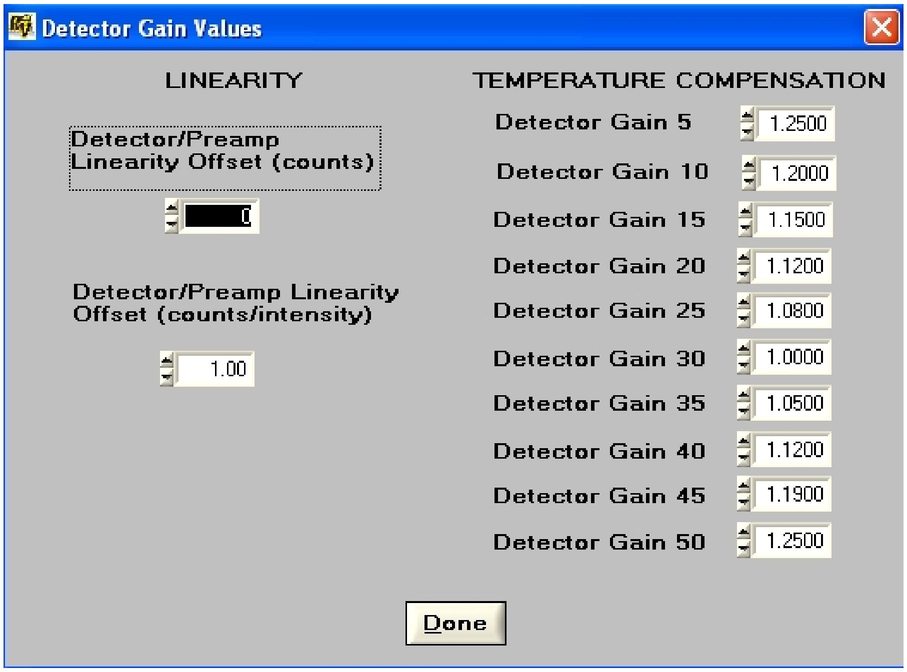
The SNR and the RRPM level are the two threshold levels for minimum and maximum retroreflectivity, respectively. The SNR value, in conjunction with the measured background retroreflectivity value, determines the minimum acceptable retroreflectivity level. This value needs to be set high enough so that background noise is not recorded but not so high as to throw out valid readings. The SNR value will need adjustment as the measurement conditions change. For low retroreflectivity markings, the SNR value may need to be lowered so that the retroreflectivity values can be captured, whereas for higher retroreflectivity markings, the SNR value can be set higher to ensure no background noise is recorded. Roads that produce a lot of background retroreflectivity may also require a high SNR value to make sure that none of the road noise is recorded. The researchers recommend paying very close attention to the minimum retroreflectivity values that are recorded. If the minimum retroreflectivity value is consistently much different than the average value for the marking and is in general very low (i.e., < 40 mcd/m^2/lux), then the SNR value should be raised until an appropriate level is reached. The SNR value is more of a factor when measuring lane lines than edgelines because of the lack of marking for 75 percent of the distance traveled.

The RRPM level determines the maximum allowable value the software will record. This value is called the RRPM level because its purpose is to keep RRPM data from being incorporated into the pavement marking data. The RRPM value should be above the maximum retroreflectivity level being recorded from the pavement markings. The researchers recommend setting the RRPM level as low as possible but still leave at least 100 mcd/m^2/lux between the average value and the RRPM level. Adjustments to the RRPM level as the measurement conditions change are often necessary.

Unit Operating Temperature

Research has indicated that the internal temperature of the mobile retroreflectometer can significantly influence the mobile retroreflectivity data. Due to the impact that the changes in temperature can have on the retroreflectivity measurements, actions to address the issue are necessary. There are three options for dealing with temperature changes. Option one is to install a thermostat-controlled thermoelectric cooler on the mobile unit to keep the operating temperature constant. Option two is to recalibrate at fixed temperature change intervals that have been predetermined based on testing to maintain accurate data. Option three is to conduct temperature testing of the mobile retroreflectometer (see the Compensation Testing section) and incorporate the results into the temperature compensation algorithm that is built into the data collection software (see Figure 4).

All three options are effective means to control the effect of the temperature change. Option one will obviously require an initial expense to get the cooler operational and to maintain it, but should provide for the best compensation since temperature can be held relatively constant. Option two will address the temperature change issue somewhat, but there is still a margin of error between calibrations as the temperature changes. Option two will also require much more down time of the data collection team to recalibrate instead of continuously collecting data. Option three is a viable alternative if option one is not feasible. After the initial temperature testing to determine the correction values, there is little else to do except test the correction values periodically. All these options assume calibration checks at a minimum of every four hours.



Detector/Preamp Linearity Offset (counts): 0

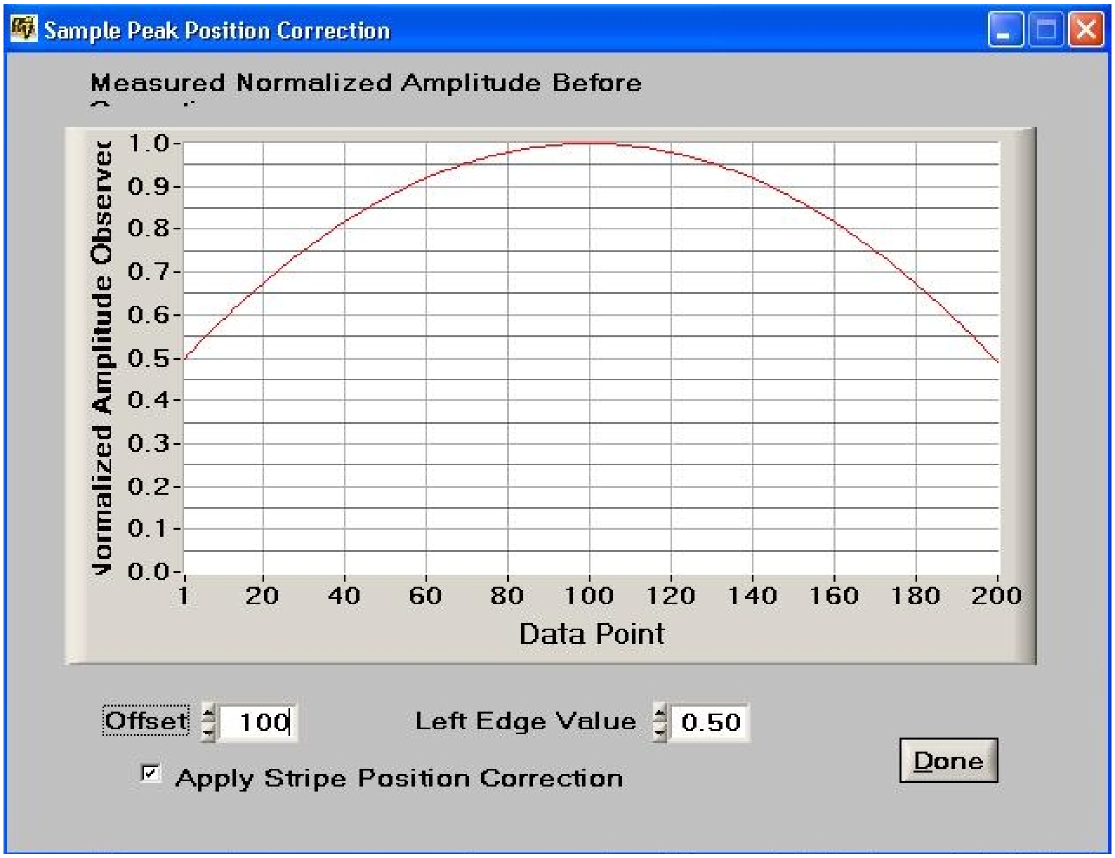
Detector/Preamp Linearity Offset (counts/intensity): 1.00

Detector Gain 5	1.2500
Detector Gain 10	1.2000
Detector Gain 15	1.1500
Detector Gain 20	1.1200
Detector Gain 25	1.0800
Detector Gain 30	1.0000
Detector Gain 35	1.0500
Detector Gain 40	1.1200
Detector Gain 45	1.1900
Detector Gain 50	1.2500

Figure 4. Temperature Compensation Input Screen.

Measurement Position

Measurement position refers to the location across the measurement window where the retroreflectivity reading occurs. There are 200 measurement points across the measurement window, with position 100 being in the middle. Ideally, as the measurements move away from the center, the retroreflectivity value would remain the same. However, research has shown that this does not appear to be the case. To compensate for the differences across the measurement window, there is a correction factor algorithm built into the program that is user adjustable (see Figure 5). Through testing (see the Compensation Testing section), the peak location of the measurements and the fall off on either side can be found and corrected.



Offset 100

Left Edge Value 0.50

☑ Apply Stripe Position Correction

Figure 5. Measurement Position Compensation Input Screen.

Figure 6 displays the laser pattern when mounted on the left side of the vehicle. This pattern is not symmetric about the center of the measurement area. When mounted on the right side of the vehicle, the laser pattern is symmetric about the center of the measurement area. The researchers recommend testing of the mobile retroreflectometer on both sides of the vehicle while loaded with the data collection team. This will ensure that the calibration for each side of the vehicle is correct. Even though the position compensation can greatly reduce the effect of measuring away from the center position, the researchers recommend trying to measure as close to the center position as possible.

Figure 6. Laser Pattern.

Double Line Data Collection

Double line data collection typically will only include measuring yellow pavement markings. The difficulty in measuring the double yellow pavement markings is that the markings are spaced apart from one another. The spacing makes it more difficult to keep both markings within the measurement window at the same time, much less near the center of the window, especially when navigating curves. When only one of the markings is measured, it will default to the left location (unless the broken left solid right marking type is selected). This will always result in a greater number of left measurements than right measurements. The researchers recommend taking care with the positioning of the measurements when measuring double lines so that both markings are measured. The same holds true for broken/solid and solid/broken yellow lines as well.

Nighttime Data Collection

Nighttime data collection is a viable alternative to collecting data during the heat of the day, making up for lost work, and avoiding heavy traffic conditions. Nighttime data collection does not differ much from daytime data collection. When measuring at night the mobile retroreflectometer must be calibrated at night. The mobile retroreflectometer should be calibrated with the mobile vehicle's low headlight beams on to reduce error caused by the constant light source.

EQUIPMENT TESTING

Both the mobile and handheld retroreflectometers should be tested periodically to make sure that they are still properly functioning and that compensation values are still accurate. The handheld retroreflectometer can be tested by comparing it to another handheld retroreflectometer and/or by measuring a known standard that is in excellent condition. The mobile retroreflectometer needs to be able to collect accurate data, without irregularities or lots of low readings.

Compensation Testing

Testing the mobile retroreflectometer to determine the compensation values is an important process if accurate retroreflectivity data is to be achieved. Both the temperature of the mobile retroreflectometer and the measurement position across the measurement window need to be tested to determine the compensation values that are to be input into the correction software. Both of these variables are unique to each individual mobile retroreflectometer. The measurement position variable is unique to each side of the vehicle that the mobile retroreflectometer is attached to. An environment that is as controlled as possible to reduce the influence of other variables is the optimal testing location (e.g., garage, warehouse, etc.).

Temperature

The mobile retroreflectometer manufacturer can conduct temperature testing when servicing the unit. The user can also conduct temperature testing. In either case the goal of the testing is to evaluate how the mobile retroreflectometer measures a known marking as the temperature changes. Temperature testing should be conducted in a static condition with constant light conditions and no changes to the weight in the vehicle or the position of the marking being measured.

To test the temperature sensitivity of the mobile retroreflectometer, any heat source (e.g., the summer sun or a heater) can be used to heat the retroreflectometer. Care should be taken to not heat the system too quickly and to not overheat the system. Multiple trials can be run to ensure that a good sensitivity curve is achieved. A trial consists of measuring a marking of known value as the temperature of the retroreflectometer changes across the typical measurement temperature conditions. The resulting measurements can be plotted on a curve of retroreflectivity versus temperature.

The retroreflectometer software takes correction inputs at 5 °C increments. Using the sensitivity curve, the correction factors can be input into the software. The researchers recommend retesting the system with the temperature compensation running and tweaking the corrections to make it as accurate as possible. Figure 4 displays the compensation for one mobile retroreflectometer tested. The compensation values are greater than 1 so that the retroreflectivity values are corrected higher (without compensation, the retroreflectivity value decreased) as the temperature moves away from 30 °C. The temperature change may impact each individual retroreflectometer differently. The temperature impact may steadily increase or decrease retroreflectivity or increase and then decrease retroreflectivity as the temperature increases.

Measurement Position

Measurement position testing should be conducted with the retroreflectometer mounted on the mobile vehicle in the typical data collection position. The vehicle should be loaded as it would normally be during data collection. This testing should be conducted inside a garage or building to reduce the effects of other variables. Conducting the testing at a location that also allows for the laser beam to be seen is also necessary. Each side of the vehicle should be tested separately. This will result in two sets of compensation values, one set for each side. During data collection, the appropriate compensation factors for each side of the vehicle need to be used to correct for measurement variations due to measurement position.

Measurement position testing requires measuring a pavement marking of known retroreflectivity at various locations across the measurement window. The marking being measured should be very uniform so that the marking itself does not add variability to the measurements. The researchers recommend measuring the retroreflectivity of the marking starting at the center position (position 100) with the laser path falling on the center of the marking. This is the standard calibration location and the point where the laser should be measuring exactly 10 meters in front of the retroreflectometer. At least four other locations should be measured to make sure that an appropriate compensation curve is set up. These locations should be near the ends of the measurement window, approximately at positions 30 and 170, and midway between the end and middle locations, approximately at positions 65 and 135. Figure 7 shows an illustration of the 200 points on the curve with positions for testing measurement position. The position references refer to the numbers along the x-axis in Figure 2. To conduct the measurements at locations other than the center position, the pavement marking needs to be repositioned so that the laser path falls on the center of the marking and the marking is at the correct measurement position. This will require placing the pavement marking at a different distance away from the retroreflectometer. Realignment of the laser is not necessary. Placing the marking at a different distance is due to the arc created by the laser (see Figure 6).

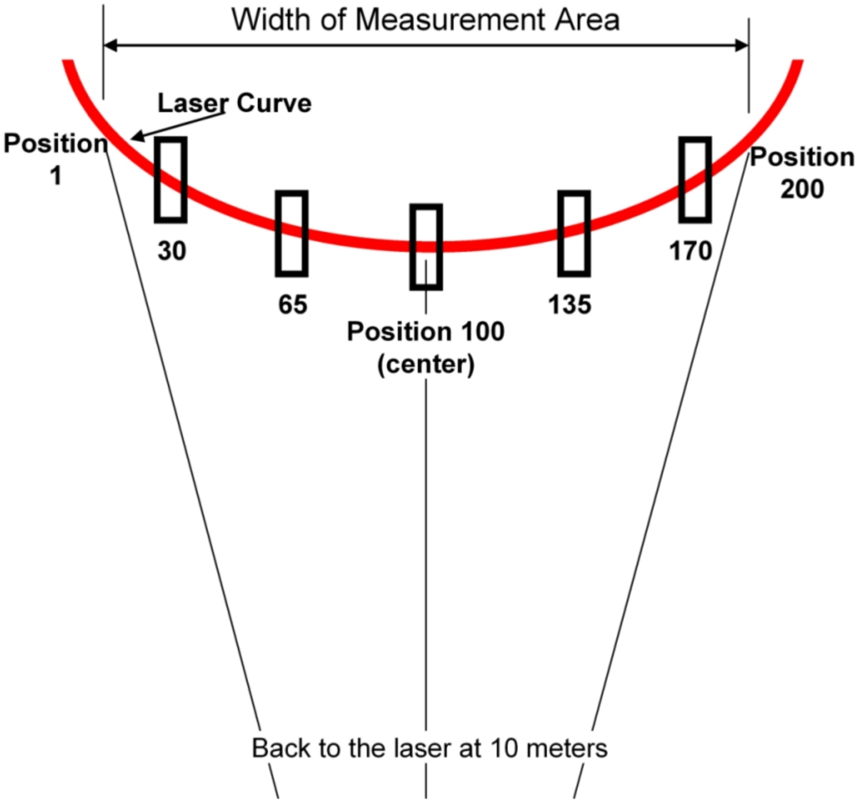


Figure 7. Schematic Drawing of Measurement Position.

After the testing is complete, the results at each location should be compared to determine how they relate to one another. Using the relationships gathered from the testing, the measurement position can be set to most accurately represent compensation for the position effect. Figure 5 displays the measurement position compensation tool. Set the offset and left edge values so that the resulting line intersects as closely as possible to the calculated percent at each test location. From Figure 5, the compensation is symmetric about the center point with approximately 75 percent of the center retroreflectivity at positions 30 and 170. The compensation would increase the retroreflectivity values at these locations by 25 percent so that each location across the measurement window would measure similar to the center position. The compensation should be activated and tested to ensure proper values are being used. The researchers recommend actual road testing on both sides of the mobile vehicle to make sure that dynamic measurements are properly corrected. The researchers also recommend periodic static/dynamic checks of the compensation values to make sure they remain accurate. The appropriate set of offset and left edge values for each side of the vehicle should be used when collecting mobile retroreflectivity data.

PAVEMENT MARKING MANAGEMENT SYSTEM BEST PRACTICES

The following section provides concepts and practices to aid in understanding the retroreflectivity data quality, data analysis, and long-term monitoring. During collection of pavement marking retroreflectivity data, some level of quality control checks should be conducted to ensure that the data collected are of sufficient quality. Data analysis techniques can be used to assess the condition of pavement markings on a given roadway and over an entire area. Long-term analysis of these types of data can provide better methods to determine if certain types of markings are better suited for given conditions and to aid in regression modeling of pavement marking retroreflectivity degradation. For instance, are more durable markings warranted in high weave areas, such as near interchanges? Can awarding small contracts be a cost effective way to install markings in these small areas? Also, additional information is provided on organization and automation of the retroreflectivity data files.

DATA QUALITY

If a contractor is utilized to supply retroreflective data or if data are collected in-house, some initial checks should be conducted to ensure that the contractor has delivered the correct data and a quality product. Initial checks should take place at the beginning and periodically throughout the contract to make sure that data are received in the format and condition that is desired. Periodic data checks should also be conducted to make sure acceptable data files are submitted. It is recommended to check not only the summary files that the contractor may provide, but also the raw data files. The raw data files will contain much more information than the summary data files and can help determine if appropriate settings and data collection procedures are being used.

Various items to check for in the data files are as follows:

- Compare data files with assigned roadways for roadway names, roadway limits, and roadway marking segment length;
- Plot the data by GPS coordinates on a map to verify the location and direction of the data collection;
- Verify that the data files contain retroreflectometer temperature information;
- Verify that areas where double lines were to be measured have both a left and right reading;

- Verify that the maximum values are within the expected range and that they are not too far from the average value. If the maximum retroreflectivity value is much larger than the average and higher than what would be expected on that type of marking, then the data may include too many data points from RRPMs, and the contractor should lower the RRPM level so that they are not included with the data;
- Verify that the minimum values are within the expected range and that they are not too far from the average value. If the minimum retroreflectivity value is a lot lower than the average value for the marking and is in general very low (i.e., < 40 mcd/m^2/lux), then the contractor should raise the SNR value until an appropriate level is found;
- Verify that standard deviation values are somewhat consistent. This is in relation to the previous two points. If a lot of high or low readings that are not related to the marking's actual retroreflectivity are recorded, the standard deviation will be much higher than it should be;
- Verify that skip line areas have approximately 25 percent the number of data points as solid line areas when measured at similar speeds;

Expectations are that some sections may have an outlier or two in the data set. It is when there are consistent high or low outliers that there is a problem that needs to be addressed. All GPS coordinates should relate to the actual roads measured. When these points are plotted on a map, they should nearly match the location of the specified roads. All data files should be appropriately named and contain the required information so that the data can be organized. Proper organization can allow for automation and easier analysis of the data.

DATA ANALYSIS

The data quality checks should review the data to make sure the data are collected properly and that appropriate information is provided. Staff should address anything that does not look correct as soon as possible and correct the problem. When appropriate data are received, several steps can be conducted to analyze the data. The actual analysis of the data will depend on the planned use of the data (e.g., QA/QC, deciding which markings to restripe, determining marking degradation, etc.).

Prior to analysis, the data should be screened to remove any data points that contain zero readings and any data points that have data that would be considered poor or that are marked with a roadway condition that could influence the data. Poor data would be points containing too many high or low readings, which would create a high standard deviation for that point. Data marked with specific roadway conditions should also be considered for removal. If the data point is marked as wet road, construction area, major curve, intersection, or any other specific condition, the data may need to be removed or analyzed separately because they could misleadingly influence the average readings along the section.

The main values of concern are the average retroreflectivity value and the standard deviation of the retroreflectivity. These two values provide a good estimation of the quality of the pavement marking with respect to nighttime visibility. The retroreflectivity value will not provide an indication of the daytime visibility, the width of the marking, or the marking color. The video associated with the data collection may provide an indication as to the visual appearance of the markings during the daytime. The standard deviation of the retroreflectivity value will provide a reference as to how consistent the retroreflectivity of the marking is. The larger the standard deviation, the more variable the marking's retroreflectivity is. A large standard deviation also increases the uncertainty of the average retroreflectivity value. Typically, on lane line markings, the standard deviation will be slightly higher than on a similar solid edgeline marking. This difference is due to fewer data points collected on lane lines and the tendency to record more invalid readings due to RRPMs and road or background retroreflectivity between the skips.

The average retroreflectivity of the pavement marking can be determined in several ways. The data output itself summarizes the data for each of the measurement lengths; typically 0.1-mile segments unless another distance is specified. These values themselves can be used to evaluate the marking's retroreflective condition. On the other hand, it may be beneficial to average the retroreflectivity values over a longer length, possibly every mile or the entire road section. To average over a longer section, the number of data points (left points) in each measurement length (chainage of approximately 0.1 mile each) should be multiplied by the average retroreflectivity in that length. The sum of the data points multiplied by the average retroreflectivities can be divided by the sum of the data points to determine the retroreflectivity average for any given length of data. Table 1 provides a sample data file and the average over the length of the approximately, 1.25-mile-long section.

Table 1. Mobile Retroreflectivity Data Analysis.

Chainage	Left Points	Left Maximum	Left Minimum	Left Average	Left Standard Deviation	Left Points*Left Average
0.107	82	396	265	331.24	28.68	27162
0.214	84	396	247	307.99	32.29	25871
0.322	84	351	236	287.88	24.59	24182
0.428	84	382	242	298.32	28.54	25059
0.535	76	399	92	318.27	43.54	24189
0.642	83	424	242	328.89	36.79	27298
0.749	84	440	271	351.84	38.41	29555
0.857	84	417	289	353.14	25.92	29664
0.965	83	422	273	332.85	31.35	27627
1.066	84	390	239	320.43	30.62	26916
1.172	82	409	247	322.53	33.09	26447
1.277	83	371	256	305.32	24.81	25342
Chainage is in miles. Left Points is the number of readings in an individual measurement length. Max, Min, and Average are R_L in mcd/m^2/lux.				Sum of Left Points*Left Average		319310
				Sum of Left Points		993
				Section Average		322 mcd/m^2/lux

WAYS TO USE THE DATA

The retroreflectivity data can be used to determine if the markings are meeting minimum installed retroreflectivity levels or minimum maintained retroreflectivity levels. The retroreflectivity data can also be used to prioritize roads for restriping based on measured retroreflectivity levels. Mapping and graphing the data can be useful tools for visualizing the marking's retroreflectivity level. Mapping data from numerous roads can provide a view of overall quality of the pavement markings. The data can also simply be viewed in spreadsheet format and analyzed as described in the previous section. Roadways could then be rank-ordered based on retroreflectivity averages and any other criteria, such as roadway classification or ADT, and striping plans could then be prioritized based on the retroreflectivity summary list. The retroreflectivity data can also be used with previous data to create degradation curves for the markings in an effort to better estimate the expected life of the markings in various conditions.

Color-coded sections on a map can display retroreflectivity data based on retroreflectivity level. Color coding could be as follows: adequate (above 150 mcd/m^2/lux), needing attention in the near future (100 mcd/m^2/lux to 150 mcd/m^2/lux), and needing replacement (below 100 mcd/m^2/lux). These maps would provide a quick, clear view of what areas need the most attention and overall pavement marking conditions. The color coding and retroreflectivity levels can be adjusted to include different and/or more or fewer levels.

A common problem with mobile retroreflectivity data is the quantity of data that can be captured and the number of associated data files. Increasing the acquire frequency to a longer length will decrease the number of individual data points on a road but will not reduce the number of files, and the increased length decreases the ability to look at small segments. Tools are needed for processing, viewing, analyzing, and displaying the retroreflectivity information. Tools to manage the data and extract the desired results from the data are the key to creating useful information from large amounts of data. The following sections outline processes and prototype tools to aid in these efforts. More sophisticated analyses and linkages to other TxDOT databases will be beneficial to provide decision makers with the ability to make informed decisions and better manage the states' pavement marking assets.

RETROREFLECTIVITY DATA FILE HEADERS

The current version of the Laserlux® software does not contain any fixed fields that will enable ease of automation. Nor does the software contain a menu system to allow the user to enter various preloaded roadway and marking information. To automate the processing of data files, some information is needed about the file on the road segment on which the data are being collected. Figure 8 shows a prototype menu-driven application that will enable the labeling of data files. This prototype allows users to put data files in a directory and then systematically label those files. Ideally, the user would complete this process at the end of the day when routes and details are fresh.

A TxDOT district office will typically select a sample of roads to be measured with most of the roadway, section, and marking information available. In addition to the roadway descriptive elements, the TxDOT control section milepost, Texas Reference Marker number, and other terminology will typically be with these data. A standard spreadsheet format that would feed the menu system is assumed and/or could be easily developed. Pull-down menus provide consistent spelling and naming, etc. Once the file has consistent header information, the ability to batch process an unlimited number of files is possible.

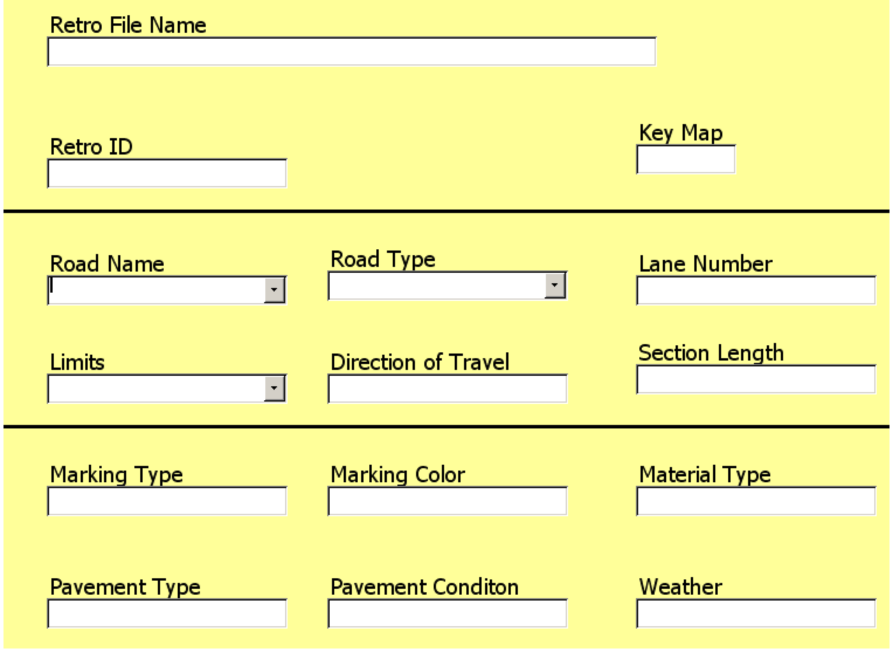


Figure 8. Menu-Driven Retroreflectivity Data File Header Input Screen.

The attributes that can be labeled are (examples given):

- roadway name (Katy Freeway, TxDOT name – IH0010);
- roadway type (main lanes, frontage road, arterial, etc.);
- roadway lane number (which lane is being measured);
- travel direction (NB, SB, EB, WB);
- section limits (IH 610 to BW8);
- section length (6.21 miles);
- marking type (edgeline, centerline, lane line);
- marking color (yellow or white);
- type of material, if known (thermoplastic, tape, etc.);
- pavement type (concrete, asphalt, chip seal, etc.);
- pavement condition (wet, dry, puddles, etc.);
- weather (sunny, overcast, night, etc.); and
- other (other informational fields and or comment fields).

PROTOTYPE IN AUTOMATION

Once the header information is consistent, a number of quality assurance and quality control steps can be completed. A series of tables, graphs, and maps are used to conduct the QA/QC process and to view and evaluate the retroreflectivity data.

Figure 9 shows an example of an automated graph of retroreflectivity. In addition, the files can be aggregated into a single file and/or database, which will allow more efficient access to the information. The process of gathering the files involves opening each file and pulling the data into a single file or database and associating the retroreflectivity data to the roadway link, marking type, color, etc. This process could also be done by linking tables in a relational database.

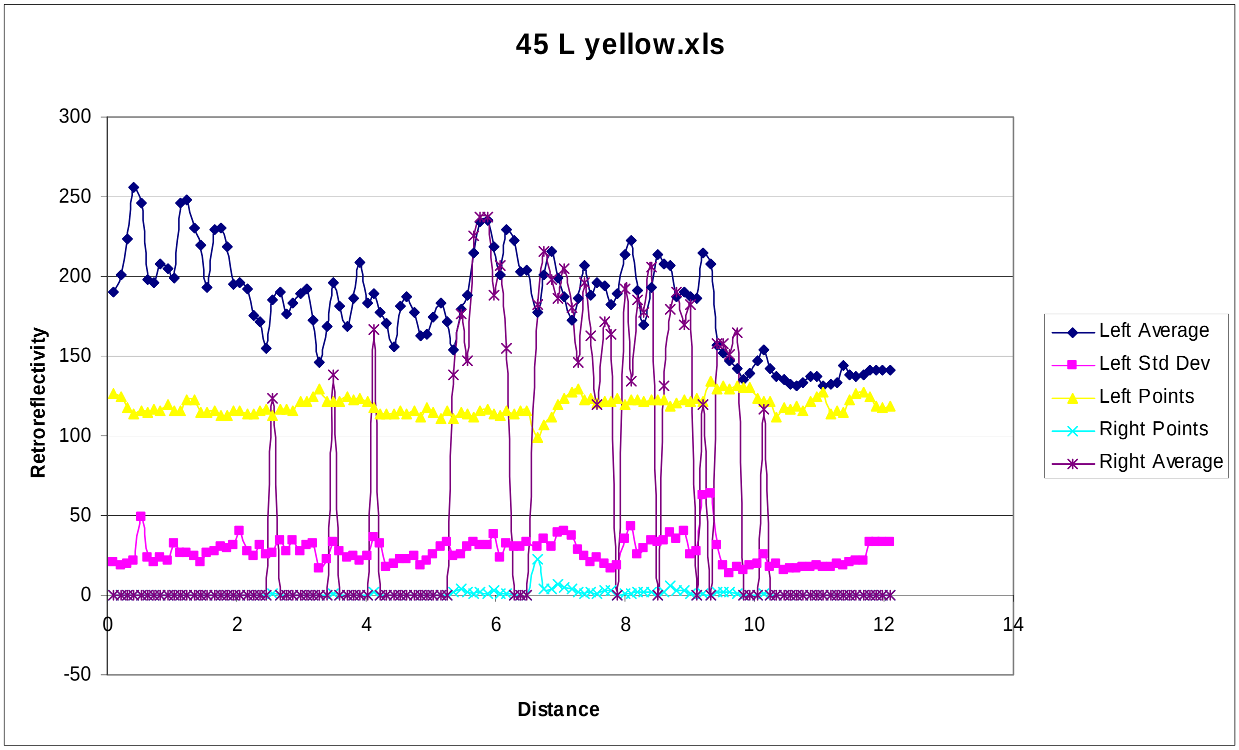


Figure 9. Example of Retroreflectivity Graph Automated QA/QC.

In addition to providing ease of access to the retroreflectivity data, using one file simplifies the Geographic Information System (GIS) process described in detail in the full report (*1*). Figure 10 provides an example of the resulting GIS map. The process to pull the retroreflectivity files into GIS is fairly involved. However, batching or grouping the files limits the number of times the process is required. Steps that could automate the process further are described in the full report, and as the process evolves, these procedures and techniques will be refined.

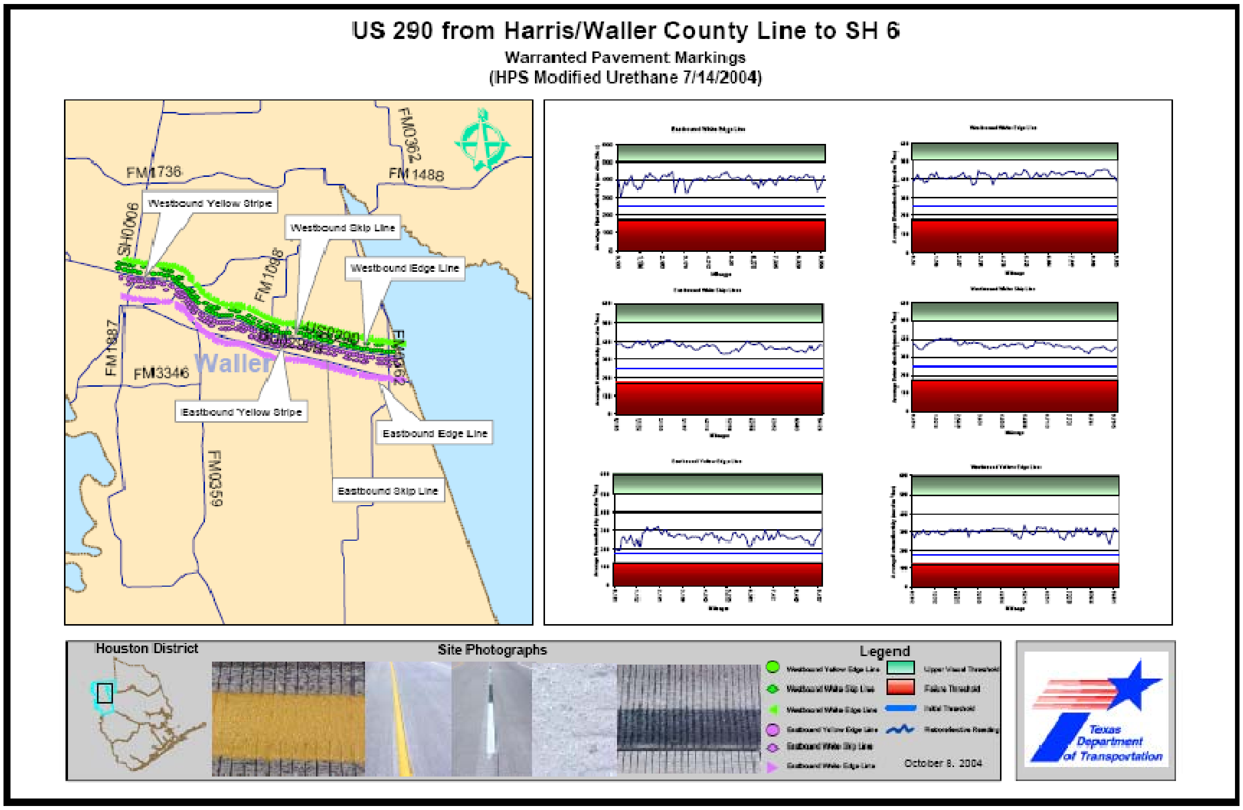


Figure 10. GIS Map of Retroreflectivity Values.

The automation process should follow the process outlined in Figure 11. These steps consist of documenting the retroreflectivity data file, batching the retroreflectivity files together, and mapping the data using GIS. Once the retroreflectivity data are linked to the TxDOT roadway network, a vast array of analyses can be performed by linking to TxDOT databases, such as the Pavement Management Information System. These procedures could also be developed for the handheld retroreflectivity data files.

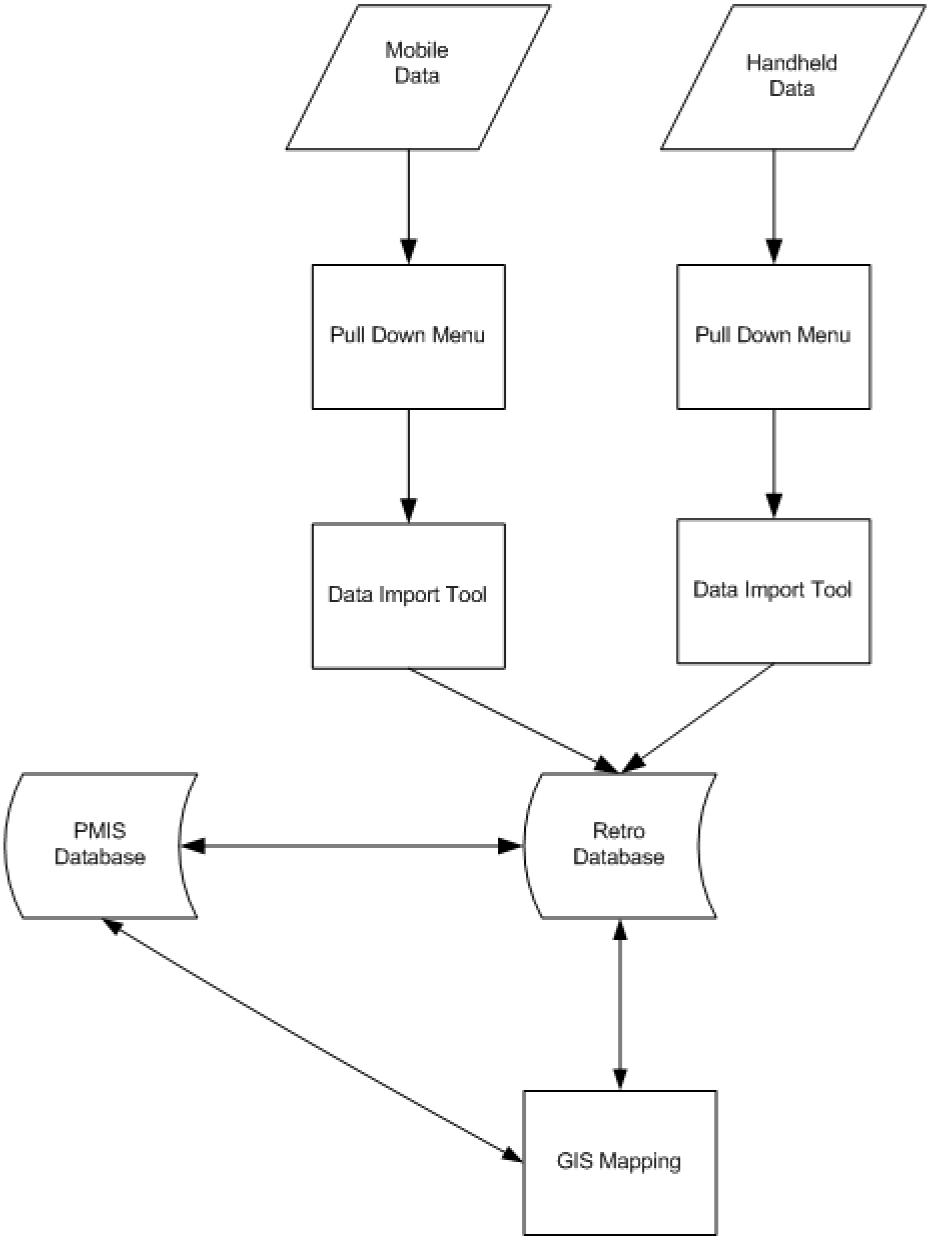


Figure 11. Flowchart Showing High Level of Automation.

REFERENCES

1. Benz, Robert, Pike, Adam, Kuchangi, Shamanth, and Brackett, Quinn. *Serviceable Pavement Marking Retroreflectivity Levels: Technical Report.* Report Number FHWA/TX-09/0-5656-1. Texas Transportation Institute, College Station, TX. March 2009

2. TxDOT Special Specification 8094. *Mobile Retroreflectivity Data Collection for Pavement Markings.* 2004 Specifications, Last update May 2008. ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2004/spec/ss8094.pdf

3. ASTM International. *Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer*. Designation E1710-05. West Conshohocken, PA, 2005.