Estimating the Lifecycle of Pavement Markings on Primary And Secondary Roads in South Carolina

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South Carolina Department of Transportation
Research and Development

Final Report
Project: SPR 669 Guidelines for Pavement Marking Applications

February 1, 2012

Technical Report Documentation Page

1. Report No. FHWA-SC-12-01	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Estimating the Lifecycle of Pavement Markings on Primary and Secondary Roads in South Carolina		5. Report Date February 1, 2012
		6. Performing Organization Code
7. Author(s) Wayne Sarasua, William Davis, and Lansford Bell		8. Performing Organization Report No.
9. Performing Organization Name and Address Glenn Department of Civil Engineering Clemson University 110 Lowry Hall Clemson, SC 29634		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. SPR No. 669
12. Sponsoring Agency Name and Address South Carolina Department of Transportation Office of Materials and Research 1406 Shop Road Columbia, SC 29201		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes SCDOT Project: SPR 669 Guidelines for Pavement Marking Applications		

16. Abstract

The absence of systematic procedures and standardized methods to quantitatively evaluate pavement marking materials on South Carolina's primary and secondary roads has made it difficult for the South Carolina Department of Transportation (SCDOT) to track performance and determine lifecycle duration of pavement markings from installation to eventual restriping applications. In 2008, SCDOT issued a problem statement for research supporting development of guidelines for pavement marking applications. Objectives of this research focused on determination of evidence-based guidelines and recommendations to support pavement marking best practices for consistent implementation across the state. Through the use of a data-driven research methodology and measured retroreflectivity values systematically collected at selected representative control sites, lifecycle models and degradation models were determined for waterborne, high-build and thermoplastic pavement marking applications for the State's primary and secondary road network. A comparison of marking lifecycles was performed and recommendations regarding material selection for typical applications were developed. This report summarizes findings of a three-year research project and includes a literature search, discussion of data collection and analysis, development of retroreflectivity degradation models, comparison of marking materials, and identification of recommended guidelines.

17. Key Words Pavement Marking Retroreflectity, Pavement Markng Lifecycle, High-build	18. Distribution Statement No restrictions.		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. Of Pages 147	22. Price

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

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ACKNOWLEDGEMENTS

The research team acknowledges the South Carolina Department of Transportation and the Federal Highway Administration for supporting and funding this project. We extend our thanks to the project Steering and Implementation Committee members:

Jim Feda, Director of Maintenance (Chair)

Terry Rawls -- Traffic Services Mgr.

Robert Dickinson – DME, District 1

Nick Boozer -- Traffic Engineering

Efrem Dantzler -- DME, District 7

Scott Bowles, FHWA

The authors would like to thank the many civil engineering students who worked on this project: Joshua Johnson, Sudhakar Pandurangan, Joseph Robertson, B.K. Aton, Cheng Sun and Kelly Sprague.

Their tireless efforts were instrumental in the successful outcome of this research. This research resulted in three Master's Theses written by Joshua Johnson, Sudhakar Pandurangan, and Joseph Robertson.

EXECUTIVE SUMMARY

The absence of systematic procedures and standardized methods to quantitatively evaluate pavement marking materials on South Carolina's primary and secondary roads has made it difficult for the South Carolina Department of Transportation (SCDOT) to track performance and determine lifecycle duration of pavement markings from installation to eventual restriping applications. An agency need was identified for creation of an efficient and economical means for determining a numeric-based periodic replacement schedule based on retroreflectivity degradation and desired threshold values. A related need focused on establishing a method to analytically determine the service life for different types of commonly used pavement marking materials. Results could be used to address existing shortcomings in evaluation of pavement markings as well as help prepare for impending federal minimum retroreflectivity pavement markings requirements that will likely call for adoption of statewide pavement marking application guidelines.

In 2008, SCDOT issued a problem statement for research supporting development of guidelines for pavement marking applications. Objectives of this research focused on determination of evidence-based guidelines and recommendations to support pavement marking best practices for consistent implementation across the state. Through the use of a data-driven research methodology and measured retroreflectivity values, systematically collected at selected representative control sites, lifecycle models and degradation models were determined for waterborne, high build and thermoplastic pavement marking applications for the State's primary and secondary road network. A comparison of marking lifecycles was performed and recommendations regarding material selection for typical applications were developed. This report summarizes findings of a three-year research project and includes a literature search, discussion of data collection and analysis, development of retroreflectivity degradation models, comparison of marking materials, and identification of recommended guidelines.

Recommended guidelines for selection and application of pavement markings were developed to assist engineers and designers in determining the most appropriate pavement marking material to apply for given roadway conditions. Based on field-collected data from the project, recommended criteria for selection of white edge pavement markings are summarized in the table below. The average life span for yellow markings would be roughly half of the white edge markings but this is greatly dependent on the initial retroreflectivity of the markings. Yellow markings tend to have much lower initial values and higher degradation rates than white markings.

Traffic Volume (veh/day)	**Recommended Marking**	**Avg. Estimated Lifespan (Years)**	**Cost/LF/year ($)**
< 1000	Waterborne	3.5 - 4.5	0.026 - 0.020
500 – 2000 +	High-Build	5 +	< 0.036
> 2000	Thermoplastic	5 +	< 0.060

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1.0 INTRODUCTION

1.1 Introduction and Problem Statement

Longitudinal pavement markings, which include lane edge lines, skip lines, and centerlines, are the most widely employed traffic control devices. These markings, found on nearly all paved roads and streets in the United States, separate lanes, divide traffic in opposing directions, and identify locations on two-lane roads where passing is allowed. The condition and effectiveness of pavement markings degrade over time due to a variety of factors, as identified by Sarasua and Clarke `(2003). These factors include traffic volumes, the presence of heavy vehicles, weather/climate, quality control in the application of the marking material, age, and the type of pavement surface. Eventually, a marking is no longer effective and must be replaced. When installing pavement marking materials, the challenge for transportation agencies is to reconcile the different service lives and costs of the various pavement marking materials with the remaining service life of the existing pavement surface, while maintaining an acceptable level of performance for road users.

In 1998, engineers with the South Carolina Department of Transportation (SCDOT) recognized that a formalized system for evaluating pavement markings could have both safety and economic benefits. The marking replacement strategy employed at that time was not performance based, and SCDOT felt that many markings were being replaced before the end of their useful life. Other markings may have remained longer than intended. To implement a marking management system, the Department investigated research of pavement marking practices on the Interstate system in South Carolina. In 2008, SCDOT initiated a project to research pavement marking practices on primary and secondary roads throughout the state. Clemson University was tasked with conducting the research. The research team is made up of researchers from Clemson's Department of Civil Engineering, and The Citadel's Department of Civil and Environmental Engineering.

As outlined in the SCDOT research problem statement, the SCDOT was interested in developing a set of guidelines that can be used to determine the frequency of application, recommend the type of material should be used on various surfaces, and recommend rates of application based on the climate and average daily traffic to provide a pavement marking program that is consistent through the state and based on best practices.

For the most part, there are no systematic procedures in place for performing this on non-interstate roads. Records are kept of when and where pavement markings are placed but these are hardcopy notes used for information purposes only. The lack of a systematic methodology to quantitatively evaluate pavement marking materials used on South Carolina's primary and secondary roads has made it difficult for the SCDOT to track the performance and lifecycle of pavement markings from when they are first installed to the time of their replacement.

Longitudinal pavement markings can reach the end of service life either because of bead loss, which results in poor retroreflectivity, loss of the base material due to chipping and abrasion, or color change and loss of contrast of the markings' base material. Daytime and nighttime visibility are closely related because as a marking is chipped or abraded by traffic action there typically is not only loss of marking material, which decreases the daytime visibility of the marking, but also loss of beads, which reduces the nighttime retroreflectivity of the marking.

In most cases, pavement marking retroreflectivity is the primary determinant of the service life of a pavement marking because it usually degrades faster than the other factors or as a direct result of these factors. Further, pavement marking retroreflectivity is quantifiable and its degradation is easier to track over time because it doesn't rely on subjective ratings. Thus, an efficient and economical method for determining a regular replacement schedule based on the retroreflectivity values for non-interstate highways is desired. Another desirable capability would be a method for determining the maximum service life for different types of markings placed on different types of pavement surfaces. Existing shortcomings in the evaluation of pavement markings as well as impending federal minimum retroreflectivity requirements for pavement markings makes it apparent that systematic guidelines for pavement marking application are needed.

Specifically, SCDOT intended that this project provide:

- an efficient and economical means for SCDOT to quantitatively evaluate the performance of pavement marking materials used on South Carolina's primary and secondary roads
- a means to predict the general performance of various types of pavement markings
- a set of guidelines for pavement marking applications that will take advantage of the entire lifecycle of pavement markings

Research focused on developing standardized guidelines for pavement marking applications that can be used throughout the state. Our approach included several work elements. Current and historical practices related to pavement marking applications and relevant legislation were researched, and a survey was conducted to identify guidelines and standard operating procedures used by other transportation agencies with regard to pavement markings. A field evaluation of the retroreflectivity of pavement markings at selected sites was also performed, the data from which was used to develop lifecycle models that can be incorporated into standardized pavement marking application guidelines.

1.2 Research Objectives

The overall goal of this project was to develop standardized guidelines for pavement marking applications for South Carolina. The research objectives identified for use in meeting the overall research goal include:

1. Conduct a literature search of current practices for pavement marking applications as well review available pavement marking lifecycle data collected in other states. The researchers also took advantage of the literature search and state agency survey information that was gathered in the previous Clemson/Citadel/SCDOT research project that focused on interstate markings.
2. Conduct an inventory of pavement marking retroreflectivity on selected primary and secondary roads using handheld retroreflectometers. A number of sites were required to provide an adequate sample to develop pavement marking lifecycle models.
3. Use the data collected to draw conclusions on the general performance of various types of pavement markings and develop look-up tables that can be included in the guidelines. The look-up tables will give an indication of frequency of pavement marking application depending on marking material, pavement surface, and traffic volume.
4. Document all findings in a set of standardized guidelines, and develop a plan for implementation of results.
5. Determine if there is any significant difference in performance between marking brands included in the study.
6. Use average marking installation costs in an effort to perform a lifecycle cost analysis for comparing high-build, waterborne and thermoplastic pavement markings.

1.3 Research Scope

This research focuses on white, and yellow longitudinal pavement markings on non-interstate primary and secondary roads throughout South Carolina. South Carolina currently uses waterborne and thermoplastic pavement markings on these roads. The survey of states conducted as part of this research as well as the literature review indicated that the vast majority of markings on non-interstate primary and secondary roads throughout the United States are waterborne and thermoplastic.

The data for this research was collected at sites throughout the state of South Carolina. For safety reasons, all of the sites were established on straight roadway segments where good sight distance exists. As such, curved road segments were not included. This is noteworthy because faster retroreflectivity degradation rates may be evident on curved segments where lane wandering of vehicles is most common.

Readers should note that the direct results of this research (such as the retroreflectivity degradation models) are based on data from South Carolina and may not be directly applicable to other geographic regions in the US and other countries. While the methodologies and procedures presented here may be applicable to other regions, the models should be only used if the results are field verified. Factors such as extensive snowplowing (which is not common in South Carolina) will likely impact pavement markings in a way that will not be reflected in the models presented in this report.

1.4 Benefits of this Research

The results of this research should have considerable benefits for SCDOT and users of the state's highways. These benefits fall into several categories. One significant benefit is with regard to safety. The use of recommended guidelines presented in Chapter 6 can help ensure that pavement markings are replaced before their useful lifetime has elapsed. Further, this research should allow the department to increase pavement marking life on average by using the right material on the right surface at a suitable application rate. This, in-turn, will reduce costs where pavement markings may historically have been reapplied too frequently. The guidelines in Chapter 6 make recommendations with regard to maintenance and rehabilitation activities to better coincide with pavement marking applications to minimize the impact of the activity on the lifecycle of pavement markings.

1.5 Report Organization

This report is organized into seven chapters. Chapter 2 provides a review of relevant literature and the results of a survey of states. Chapter 3 discusses data collection procedures and presents summary statistics and other data. Chapter 4 describes the analysis and model development. Chapter 5 gives a comparison of the various marking materials. Chapter 6 provides recommended guidelines based on the results of the research and Chapter 7 gives recommendations and conclusions as well as discusses future research possibilities.

2.0 LITERATURE REVIEW AND SURVEY OF STATES

2.1 Literature Review

2.1.1 Overview

A literature review was completed in order to gain knowledge on the subject of retroreflective pavement markings. The review was based off the literature of the earlier project, *Evaluation of Interstate Pavement Marking Retroreflectivity* [Sarasua et. al, 2003], with additional research completed in order to include new developments. The additional research was completed mostly using Transportation Research Board (TRB) journals and Transportation Research Information Services (TRIS).

2.1.2 Definition of Retroreflectivity

Given that longitudinal pavement markings provide visual guidance to drivers, the key issue is to understand what constitutes an effective visible pavement marking. The visibility of pavement markings at night is dependent on their retroreflectivity, which represents the portion of light from a vehicle's headlight reflected back toward the eye of the driver of that same vehicle, as discussed in a paper by [Migletz et al,1999]. According to McGee and Mace [McGee and Mace, 1987], retroreflection is an event that occurs when "light rays strike a surface and are redirected directly back to the source of light." The MUTCD [Federal Highway Administration, 2009] defines retroreflectivity as "a property of a surface that allows a large portion of light coming from a point source to be returned directly back to a point near its origin." Omar et al. [Omar et al, 2008] define retroreflectivity as "an engineering measure of the efficiency of the marking optics to reflect headlamp illumination incident on the pavement marking back to the driver."

A typical pavement marking material consists of binders, pigments, fillers, and glass beads. Binders are responsible for the thickness of marking material and adhere to the road surface, pigments distribute color throughout the mix, and fillers impart durability to the mix. The retroreflective effect of pavement markings is made possible with the help of small glass beads which are added by dropping them on the marking during the application of material in liquid form.

The retroreflection process in a glass bead occurs in three steps. As the light ray enters a bead, it gets refracted or bent. Once inside, it gets reflected in the material in which the bead is embedded, and then gets refracted a second time while leaving the bead surface [Delta Electronics, 2009]. Figure 2.1 illustrates this event.

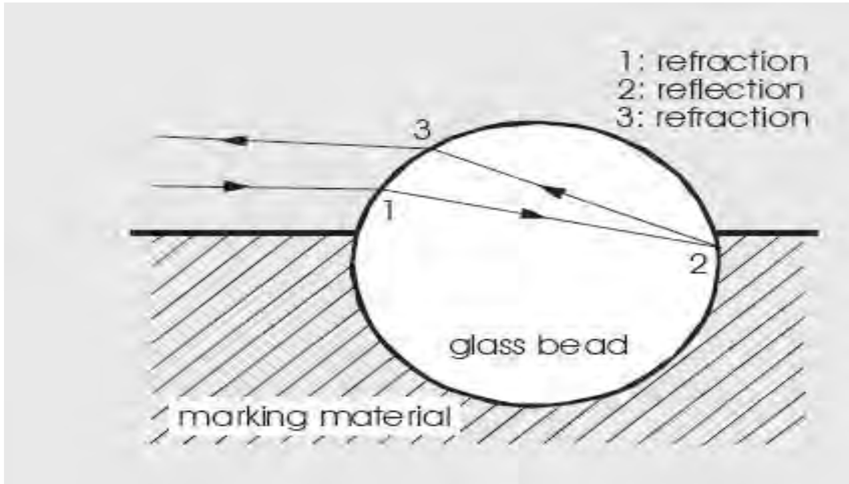


Figure 2.1: Three Step Process of Retroreflection in a Glass Bead [Delta Electronics, 2009]

The retroreflectivity of a pavement marking depends on several factors, such as bead size, bead type, quantity of beads, angle of bead embedment, and application method, among others. It should be noted that various marking types use different glass beads. For example, besides marking thickness, a primary difference between waterborne and high-build markings is glass bead size. According to SCDOT specifications [South Carolina Department of Transportation, 2007], bead types range in size from smallest to largest as Type I to Type IV, respectively. High-build marking specifications [South Carolina Department of Transportation, 2008] require an initial application of the larger Type III or IV beads, followed by an application of Type I beads, while waterborne specifications require Type I beads only. As a result, high-build markings tend to have higher initial retroreflectivity values than those of waterborne markings, primarily due to these larger beads. However, retroreflectivity degrades over time as beads become dislodged from the marking or are worn down. This degradation can be due to weather, traffic, snowplowing, and other adverse conditions for the roadway.

2.1.3 Retroreflectivity Measurement

The most common measure of pavement marking retroreflectivity is the coefficient of retroreflected luminance (R_L). ASTM defines R_L as the ratio of luminance in the direction of observation to normal illuminance, at the surface on a plane normal to incident light, expressed in millicandelas per square meter per lux ($mcd/m^2/lux$) in the standard *E 808-01 (re-approved 2009) - Standard Practice for Describing Retroreflection* [ASTM Standard E-808-01, 2009].

The current accepted standard for measurement of retroreflectivity of pavement marking materials using a portable retroreflectometer is *ASTM E 1710-05* [ASTM Standard E-1710-05, 2009]. It is adapted from standards originally set by the European Committee for Normalization (CEN). The standard clearly defines the requirements of a portable retroreflectometer to simulate nighttime visibility for an average driver in a passenger car. The measurement geometry of the instrument should be based on a viewing distance of 30 meters (98.43 ft), a headlight mounting height of 0.65 meters (2.13 ft) directly above the stripe, and an eye height of 1.2 meters (3.94 ft) directly over the stripe. These measurements create a co-entrance angle between the headlamp beam and pavement surface of 1.24 degrees and an observation angle of 1.05 degrees. The key parameters of the standard are shown in Figure 2.2.

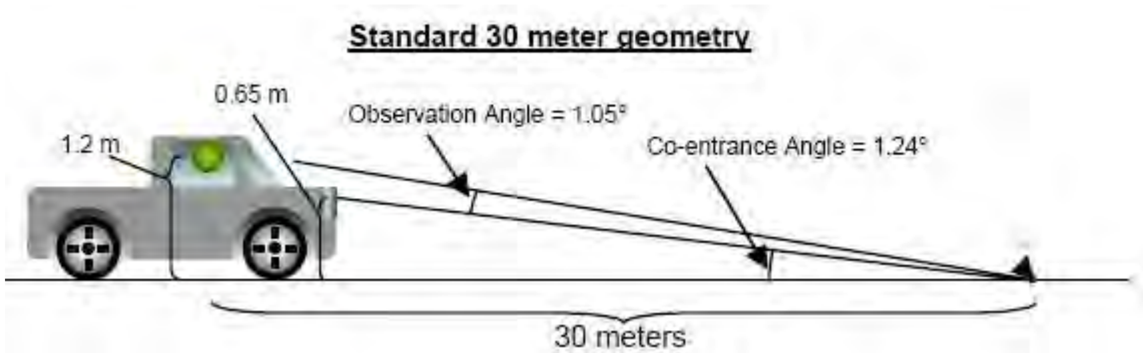


Figure 2.2: Standard 30-Meter Geometry Replicated by Retroreflectometers [Holzschuher and Simmons, 2005]

ASTM E 1710-05 also requires that the surface of marking be clean and dry, the reading direction of retroreflectometer be placed in the direction of traffic and the retroreflectometer be calibrated every hour.

Another ASTM Standard of relevance to the study is *ASTM E 2177-01,* which is the *Standard Test Method for Measuring Coefficient of Retroreflected Luminance of Pavement Markings in a Standard Condition of Wetness* [ASTM Standard E-2177-01, 2009] This test method is also referred to as the “recovery method” or “bucket method.” The procedure is for the intent of measuring retroreflectivity of pavement marking materials after rain has stopped and the marking is still wet. The test condition is created by liberally wetting the road marking and waiting a certain time period after wetting for water to runoff. Wetness can be achieved either with the help of a hand sprayer or a bucket of water. If a hand sprayer is used, the marking should be sprayed with water for 30 seconds. Otherwise, two to five liters of water in a bucket is poured slowly over the marking. The marking retroreflectivity is then measured after 45 ± 5 seconds after pouring is completed. Two to three readings are obtained by simply triggering the instrument a second or third time without any movement.

2.1.4 Minimum Acceptable Retroreflectivity Values

According to section 406(a) of the 1993 U.S. Department of Transportation Appropriations Act, the secretary of transportation is required to revise the MUTCD to include a standard for a minimum level of retroreflectivity to be maintained for pavement markings and signs which shall apply to all roads open to public travel [Federal Highway Administration MUTCD, 2009]. Accordingly, the FHWA did develop candidate MUTCD criteria, but it was never approved and implemented as a policy [Migletz and Graham, 2002].

Paniati and Schwab [Paniati and Schwab, 1991] discussed the development of a model to address the required reflectivity of traffic control devices to meet driver visibility requirements. Their paper recognized that determination of minimum retroreflectivity is a complex process involving the interaction of driver characteristics, vehicle headlight characteristics, roadway geometry, size and location of markings, and glare from oncoming vehicles.

A study in 1996 focusing specifically on retroreflectivity requirements for older drivers by Graham and Harold [Graham and Harold, 1996] used retroreflectivity measurements of existing roadway markers and subjective evaluations of their adequacy to determine a threshold. The authors reported that 85 percent of subjects aged 60 years and older rated a marking retroreflectivity of 100 mcd/m^2/lux adequate or more than adequate for nighttime conditions.

In the fall of 1999, the FHWA sponsored three workshops to discuss their efforts to establish minimum levels of retroreflectivity for pavement markings . Representatives from 67 state, county, and city agencies gave their inputs at the workshop. Based on FHWA guidelines, state and local agencies made recommendations for pavement marking retroreflectivity for roads without Retroreflective Raised Pavement Markers (RRPMs) or roadway lighting. For white markings, they recommended a retroreflectivity of 100 mcd/m^2/lux on freeways and 80 mcd/m^2/lux on collector and arterial roads. Unfortunately, participants of the workshop could not reach an agreement to adopt these minimum values as standards without further research.

The Minnesota Department of Transportation (MnDOT) [Loetterle et al, 2000] undertook a research project in 2000 to determine a threshold for acceptable retroreflectivity values for the state. Members of the general public were asked to drive state and county roads after dark and grade the visibility of edge lines and centerlines. The project results pointed to a threshold level between 80 and 120 mcd/m^2/lux. As a result of the project, MnDOT uses 120 mcd/m^2/lux as a minimum retroreflectivity threshold for its pavement marking management program.

Parker and Meja [Parker and Meja, 2003] performed a study in New Jersey in 2003 using a Laserlux retroreflectometer and a survey of the New Jersey driving public to determine visibility of markings on a 32-mile circuit. They concluded that the minimum acceptable level of retroreflectivity appeared to be between 80 and 130 mcd/m^2/lux for drivers under 55 and between 120 and 165 mcd/m^2/lux for drivers older than 55.

During the summer of 2007, the FHWA held two conferences with the primary goal of finalizing the wording and content of new minimum pavement marking and traffic sign retroreflectivity levels. The new traffic sign minimum levels were put into effect as of January 2008 [Katherine and Paul, 2008], while pavement marking minimums are still pending.

An additional report by Debaillon, et al. in October 2007 [Debaillon et al, 2007]did recommend minimum values for retroreflectivity to the FHWA. This research took into account pavement type, vehicle type, RRPM presence, marking configuration, and speed. The recommendations made in this report are shown in Table 2.1.

Table 2.1: Recommended Minimum Retroreflectivity Values (20)

Roadway Marking Configuration	**Without RRPMs**			**With RRPMs**
	≤ 50 mph	55 – 65 mph	≥ 70 mph	-
Fully-Marked Roadway (centerline, lane lines and/or edge line)	40	60	90	40
Roadways with Centerlines Only	90	250	575	50

In anticipation of the forthcoming minimum standards, many states have set initial reflectance requirements as a quality control measure. For example, SCDOT specifications [South Carolina Department of Transportation, 2008] require that white high-build markings must maintain a minimum reflectance value of 350 mcd/lux/m^2 , and white thermoplastic markings 450 mcd/lux/m^2 for a minimum of 30 days from the time of placement, as obtained with a Delta LTL 2000 Retroreflectometer or equal. Similarly, NCDOT has initial retroreflectivity requirements for paint markings, requiring white edge line paint markings to have a minimum retroreflectivity value of 225 mcd/m^2/lux after installation, as described in a report by Rasdorf et. al. [Rasdorf et al, 2009]

While there are currently no minimum threshold standards for marking retroreflectivity, proposed standards have been created and are expected to be implemented in the near future. Section 3A.03 of the 2009 MUTCD, which is titled *Maintaining Minimum Retroreflectivity of Longitudinal Pavement Markings,* is reserved for when the minimum criteria is established. In April 2010, a Notice of Proposed Amendments was published in the Federal Register, proposing to revise the 2009 MUTCD by adding Standards, Guidance, Options, and Support information regarding maintaining minimum retroreflectivity of longitudinal pavement markings. The proposed revisions would establish a uniform minimum level of nighttime pavement marking performance based on visibility needs of nighttime drivers, to promote safety, enhance traffic operations, and facilitate comfort and convenience for all drivers, including older drivers. The proposed standard, 2009 MUTCD, Section 3A.03, states public agencies or officials having jurisdiction shall use methods designed to maintain retroreflectivity values at or above minimum levels shown in Table 2.2. [Federal Highway Administration Proposed Revision, 2011]

Table 2.2: MUTCD Proposed Minimum Maintained Retroreflectivity Levels for Longitudinal Pavement Markings [Federal Highway Administration Proposed Revision, 2011]

	Posted Speed (mph)		
	≤30	**35–50**	**≥55**
Two-lane roads with center line markings only**	n/a	100	250
All other roads**	n/a	50	100

**Exceptions:

A. When RRPMs supplement or substitute for a longitudinal line, minimum pavement marking retroreflectivity levels are not applicable as long as the RRPMs are maintained so that at least 3 are visible from any position along that line during nighttime conditions.

B. When continuous roadway lighting assures that the markings are visible, minimum pavement marking retroreflectivity levels are not applicable.

Once the standards proposed in Table 2.2 are implemented, agencies such as SCDOT must meet the standards by compliance dates established by FHWA. The compliance dates are as follows:

a) Four years from date of Final Rule for implementation and continued use of a maintenance method that is designed to maintain pavement marking retroreflectivity at or above the established minimum levels.

b) Six years from date of Final Rule for replacement of pavement markings that are identified using the maintenance method as failing to meet established minimum levels.

2.1.5 Retroreflectivity Degradation Predictive Models

In 1997, Perrin, Martin, and Hansen [Perrin et al, 1998] evaluated marking materials on Utah highways using a Laserlux mobile unit. Three marking materials were compared: paint, epoxy, and tape. Pavements included both Portland Cement Concrete (PCC) and Asphalt Concrete (AC) types. Researchers employed the resulting data to investigate relationships between material age, Average Annual Daily Traffic (AADT), and pavement type on marking retroreflectivity or useful lifetime. They found that each of these variables was significant, and that the general relationship between the independent and dependent variables was hyperbolic.

Also in 1997, Andrady et al. [Andrady et al, 1997] developed the following equation which relates retroreflectivity of pavement marking materials to time.

$$T_{100} = 10^{(R_0 - 100)/b}$$

where

T_{100} = Duration in months for retroreflectivity to reach a value of 100 mcd/m^2/lux

R_0 = Estimate of initial retroreflectivity value

b = Gradient of semi-logarithmic plot of retroreflectivity

Using the equation, Andrady was able to predict the lifetime of epoxy markings as 18.8 months and the lifetime of thermoplastic markings in the range of 7.8 to 40.6 months.

In 1999, Migletz et al. [Migletz et al, 1999] reported on the results of a study of pavement marking retroreflectivity performed on behalf of FHWA. This study was performed during the fall of 1994 and spring of 1995, where retroreflectivity of selected sections of pavement markings in 32 states were measured. Although based upon a limited amount of data, statistical procedures for evaluating replacement needs of markings were developed. These were developed not to predict the life of the markings, but to determine when, based upon collected data, markings should be replaced. Two basic approaches were evaluated. In one approach, markings were considered for replacement when the mean retroreflectivity for 15 sample points fell below some threshold value. The other approach recommended replacement when the median of 15 sample points fell below the threshold.

Lee, Maleck, and Taylor of Michigan State University completed a study in 1999 for the Michigan Department of Transportation to determine a degradation model for waterbased pavement markings [Lee et al, 1999]. They reported results from their four-year project, which evaluated pavement marking materials to develop guidelines for their most cost-effective use. The results of this study were based on data collected with a handheld retroreflectometer using 15-meter geometry. From this study, a number of interesting results were obtained. First, retroreflectivity degradation was found to average 0.14 percent per day, with a service life of 445 days for waterbased markings. The research examined the relationships between retroreflectivity degradation and average daily traffic (ADT), speed limit, and commercial traffic on the measured sections. These factors were found to have no statistically significant correlation with retroreflectivity deterioration. Measured sections in colder locations where winter maintenance activities occurred were found to correlate with retroreflectivity loss. The linear regression model developed by Maleck and Taylor for waterbased markings was as follows:

$$Y = -0.4035X + 279.42, \quad R^2 = 0.17 \quad \text{(Waterbased Paints)}$$

$$Y = -0.3622X + 254.82, \quad R^2 = 0.14 \quad \textit{(Thermoplastic Paints)}$$

where

Y=Retroreflectivity of pavement markings in $mcd/m^2/lux$

X=Age of markings in days

Many recent studies use Cumulative number of Traffic Passages (CTP) as a variable in their models, which is the product of ADT and time, measured as millions of vehicle passages per lane. It is the cumulative exposure of a marking to vehicles since it was first installed. In 2001, Migletz et al. [Migletz et al, 2001] published a research paper in which they summarized the findings of their four-year study spread through 19 states to evaluate the durability of a variety of marking materials. They used CTP as the primary variable and quantified the relationship between the coefficient of retroreflectivity (R_L) and CTP using different model forms such as linear, quadratic, and exponential regressions. The general forms of the models are shown below, where a is initial retroreflectivity and b is the numerical coefficient of CTP:

Linear Model: Mean $R_L = a + (b*CTP)$

Quadratic Model: Mean $R_L = a + (b*CTP) + c * (CTP)^2$

Exponential Model: Mean $R_L = a * e^{(b*CTP)}$

In the study, the minimum threshold values were set to range between 85 – 150 $mcd/m^2/lux$ for white lines. Using these thresholds, the study found the service life for white waterbased markings on freeways in the range of 4.1 – 18.4 months.

A 2003 study by Lindly and Wijesundera [Lindly and Wijesundera, 2001] tested different regression model forms and found that CTP had a better correlation with retroreflectivity than marking age alone. Other secondary variables such as speed limit, marking width, geographic location, road type, etc. were considered but none were found to be statistically significant. The linear model that was developed from this study is

$$R_L = a + b * CTP$$

where

R_L = Pavement Marking Retroreflectivity in $mcd/m^2/lux$

a , b = model coefficients

CTP = Cumulative Traffic Passages in million vehicles

In 2002, Abboud and Bowman [Abboud and Bowman, 2001, 2002] conducted a study of the cost and longevity of waterbased markings to determine a useful lifetime. The authors used a minimum retroreflectivity threshold of 150 $mcd/m^2/lux$, determined from their previous study of crash data and traffic exposure on Alabama state highways. The researchers developed a logarithmic model relating retroreflectivity to exposure of markings to vehicular traffic. The equations they developed are as follows:

$$R_L = -19.457 \text{ Ln (VE)} + 267, \quad R^2 = 0.31 \quad \text{(Waterbased)}$$

$$R_L = -70.806 \text{ Ln (VE)} + 640, \quad R^2 = 0.58 \quad \text{(Thermoplastic)}$$

where

R_L = Pavement Marking Retroreflectivity in mcd/m^2/lux

Ln = Natural Logarithm

VE = Vehicle Exposure in thousands of vehicles

Thamizharasan, A., Sarasua, W. A., Clarke, D., and Davis, W. J. [Thamizharasan et al, 2003] presented a research paper at the TRB Annual meeting in 2003 in which they developed models to predict pavement marking degradation on interstate freeways. They first developed a nonlinear model based on time. They found out that when markings are newly applied the retroreflectivity initially increases until glass beads become exposed and then retroreflectivity decreases linearly to a minimum value due to various factors such as traffic exposure and environmental conditions. The other important variables considered while developing the model were marking color, surface type, marking material, and traffic volume or AADT. The study found that traffic volumes were not statistically significant for retroreflectivity degradation along straight sections of road.

A 2009 study by Rasdorf et. al. [Rasdorf et al, 2009] developed models to predict life cycles for waterborne markings for various scenarios. The independent variables validated by the models included time, initial R_L reading, AADT, and lateral location. For waterborne white edge markings, they developed a linear model to predict marking retroreflectivity if initial retroreflectivity measurements are available. The model is as follows:

$$R_L = \text{Initial } R_L - 0.205 \times \text{Days (waterborne white edge)}$$

From these models, it was determined that the fixed slope (degradation rate) of waterborne white markings is -75 mcd/m^2/lux annually, with an average lifecycle of 34.2 months if a minimum threshold of 100 mcd/m^2/lux is used and an average initial value of 310 mcd/m^2/lux are used. Models for thermoplastic white edge markings were also developed, which determined that for an AADT of 10,000 veh/day, the expected service life for thermoplastic on asphalt was 8.5 years if an initial value of 375 mcd/m^2/lux and a minimum standard of 150 mcd/m^2/lux are assumed. Their research also conducted a correlation study between pavement marking retroreflectivity and glass bead density, which determined that higher bead densities resulted in higher retroreflectivity values throughout pavement marking life.

2.1.6 Effect of Marking Placement Direction on Waterbased Markings

Researchers Rasdorf, Zhang, and Hummer from North Carolina State University [Rasdorf et al, 2009] performed a unique study in 2007-2008 addressing the impact of directionality of paint laying on pavement marking retroreflectivity for two-lane highway centerlines. Objectives of the study were to ascertain whether there is a relationship between retroreflectivity values and paint installation direction and whether retroreflectivity directionality would impact the minimum standards for retroreflectivity levels required by the FHWA, which are still pending.

The data collection effort mainly consisted of measuring the retroreflectivity of centerline pavement markings in both directions of traffic flow. The conclusions of the study were: (a) Retroreflectivity values measured along the direction of striping were always higher than those measured in the opposite direction for two-lane highways. (b) The study was able to establish a clear relationship between retroreflectivity and age. The study results were compared to a previous work done by Sitzabee, a fellow researcher from NCSU in 2008, which said that pavement marking retroreflectivity degrades at an average rate of about 50 mcd/m^2/lux annually for thermoplastic and waterbased markings. Results of the study were similar to the results reported in the previous work. (c) When comparing retroreflectivity values of yellow centerline paint pavement markings to pending FHWA minimum standards, the value taken in the opposite direction to the direction of striping should be used.

2.1.7 Effect of Wetness on Pavement Marking Retroreflectivity

In 2004, Aktan and Schnell [Aktan and Schnell, 2004] conducted a study to evaluate the performance of three different pavement marking materials under dry, wet, and rainy conditions in the field. The pavement marking materials used were paint with large glass beads, thermoplastic with high index beads, and patterned tape with mixed high index beads. Under dry conditions, all materials exhibited acceptable retroreflectivity, measured using an LTL-X handheld retroreflectometer and complying with the *ASTM E 1710* standard. Under wet conditions, the retroreflectivity values measured were much lower than the dry measurements. The test procedure employed was in compliance with the standard *ASTM E 2177*. Under simulated rain conditions, retroreflectivity was the lowest for all three materials.

In a 2005 study, Gibbons et al. [Gibbons et al, 2005] evaluated the visibility of six pavement marking materials under simulated rain conditions with a rainfall rate of 0.8 in/hr. The study indicated that visibility distance is highly correlated to luminance of the pavement marking material and moderately correlated to the measured retroreflectivity. Factors affecting visibility distance are wetness of pavement markings, material type, and vehicle type. The recovery time for visibility distance depends on the pavement marking material type. The average time of recovery was six minutes for visibility to reach normal conditions after rain.

2.1.8 Effect of Lane and Shoulder Width on Vehicle Lateral Placement

Though there are no studies which relate retroreflectivity degradation with lane or shoulder width, it can be concluded that these variables can potentially affect retroreflectivity. This is based on the concept of vehicular traffic driving over the markings causing glass beads to become dislodged and thus decreasing the retroreflectivity. Studies have been conducted that relate vehicle lateral placement to lane and shoulder width. With an increased probability of drivers driving closer to the edge lines or centerlines comes the possibility that drivers venture onto the lines themselves. Repeated occurrences of this results in more rapid marking degradation.

In 1969, the Missouri State Highway Department [Missouri State Highway Commission, 1969] undertook a project to study the effect of white edge lines on lateral position of vehicles on two-lane highways having a width in the range of 20 – 24 feet. The main finding of the study was that vehicles tend to move closer to the centerlines under free flow conditions. In 1971, Hassan [Hassan, 1971] conducted a similar study in Maryland with two two-lane roads, one having a width of 18 feet and the other a width of 24 feet. The results of the study were similar to the Missouri State Highway Department project. More recent studies have also been conducted, including a 2006 study by Tsyganov et al. [Tsyganov et al, 2006] in Texas where three two-lane roads with widths 9, 10, and 11 feet were selected to study the edge line effects on lateral placement of vehicles. The findings of the study were that as the width of the lane increases, drivers tend to be closer to the centerlines under all conditions of illumination.

In their research paper in 2003, Van Driel et al. [Van Driel et al, 2004] addressed the effect of shoulder width on the lateral placement of vehicles. The main findings of the study were that vehicles tend to move more towards the edge of the road when driving on roads with wide shoulders. As these vehicles move towards the edge of the road, they tend to drive on the edge marking, thus causing it to degrade faster. The effect of lateral marking placement on retroreflectivity was included in the paper by Rasdorf et. al. [Rasdorf et al, 2009], which determined that there is a significant difference in the rate of retroreflectivity degradation between edge lines and centerlines.

2.1.9 Environmental Effect on Pavement Markings

The Pavement Marking Handbook [Texas Department of Transportation, 2004] of the Texas Department of Transportation breaks down the effect of environment on performance of pavement markings into two broad categories:

- Weather conditions at the time of placement of markings
- Climate throughout the year

Quality control at the time of laying the markings is of utmost importance to ensure proper performance of pavement marking material. SCDOT specifications [South Carolina

Department of Transportation, 2007] require that marking specifications must be conducted during daylight hours with the air temperature at least 50º F before commencement of the laying operation for conventional waterbased, high-build, and thermoplastic markings to ensure proper drying and curing. A relative humidity of less than 85 percent is also required. Wind velocity is also important as it affects the dispersion of drop-on beads. If beads are dropped on the newly laid paint with strong winds blowing, they may not uniformly reach the binder material. Climatic conditions can also have adverse effects on long-term performance of pavement markings. Regions with heavy snowfall are susceptible to rapid marking retroreflectivity degradation due to frequent heavy abrasion from snowplowing. In hot and humid climates, exposure of the pavement to ultraviolet sunlight rays results in fading of color and cracking of pavement markings.

2.1.10 Cost Variability for Various Marking Types

When choosing a marking type, cost is always a major factor in determining which type of marking to install on a roadway. Over the years, many benefit-cost analyses have been performed for pavement markings. These analyses depend on many different factors including estimates for marking installation cost per linear foot, marking lifespan, traffic volume, pavement type, etc. A 2000 report by Montebello and Shroeder [Montebello and Shroeder, 2000] gave estimated costs and marking lifespans for various marking types. For this paper, approximate marking prices were obtained from SCDOT personnel who indicated that, in general, marking prices have nearly doubled since 2000 [Boozer, 2011]. Table 2.3 shows a comparison of marking types including approximate cost and estimated lifespan, assuming markings are applied to new pavement.

Table 2.3: Estimated Pavement Marking Costs and Lifespans (37, 38)

Marking Type	**Estimated Cost Per Linear Foot***	**Estimated Lifespan** **(From reference 41)**
Waterborne	$0.06 - $0.09	9 - 36 months
High Build	$0.12 - $0.18	3 years
Epoxy	$0.25 - $0.31	4 years
Thermoplastic	$0.25 - $0.30	3 - 6 years
Tape	$3.00 - $5.00	4 - 8 years

*Costs are given in 2011 dollars

It should be noted that the prices in Table 2.3 are general estimates for large contract projects and the lifespan estimates assume proper marking application practices. It should also be noted that markings on new or newly resurfaced roads generally last longer than markings that are restriped on existing pavement.

2.2 Survey of State Agencies

As a part of the research project, the research team created a survey and sent it to the DOT of each state in the United States. The survey was created using SurveyMonkey.com and was available online for six months for the state DOTs to complete. In this time, 20 states responded with full or partial completion of the survey. The main purpose of the survey was to learn of the pavement marking management systems in place in other states, if any. The survey also gave insight to other information such as the most commonly used marking material, replacement frequencies, and what factors DOTs felt were most important in retroreflectivity degradation.

From the survey, it was found that waterbased markings are by far the most commonly used material on primary and secondary roads in other states. Figures 2.3 and 2.4 show the breakdown of states that use one material for at least 50 percent of their markings on primary and secondary roads. Clearly, of the states that responded, waterbased markings are used the most, with a few states also using thermoplastic for the majority of their markings. None of the responding states reported using high-build as a major marking type on either primary or secondary roads.

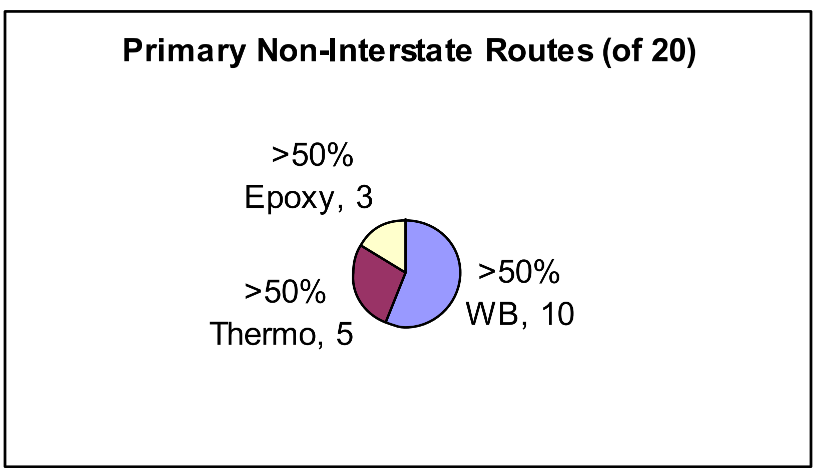


Figure 2.3: States Using One Material for 50% or More of Primary Routes

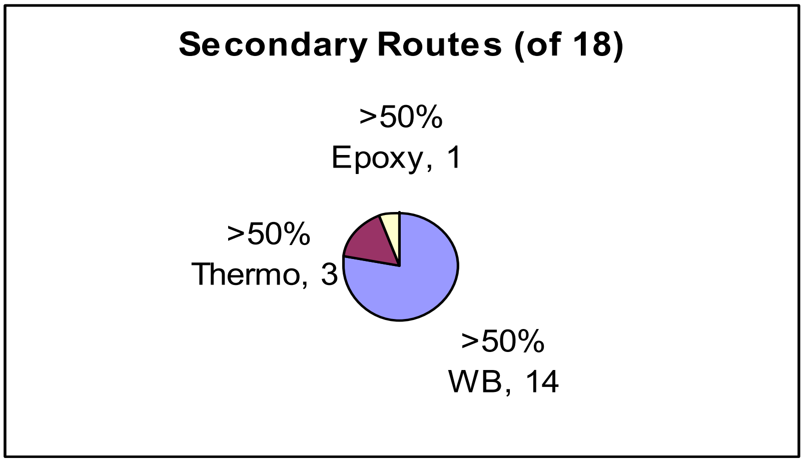


Figure 2.4: States Using One Material for 50% or More of Secondary Routes

Of these two materials, the states agree that waterbased markings should be replaced more frequently than thermoplastic markings. When ranking factors that contribute to marking deterioration, the states ranked all factors except history of road (marking material, application quality control, traffic volume, weather and climate, and road surface) as having similar importance. This is shown in Figure 2.5.

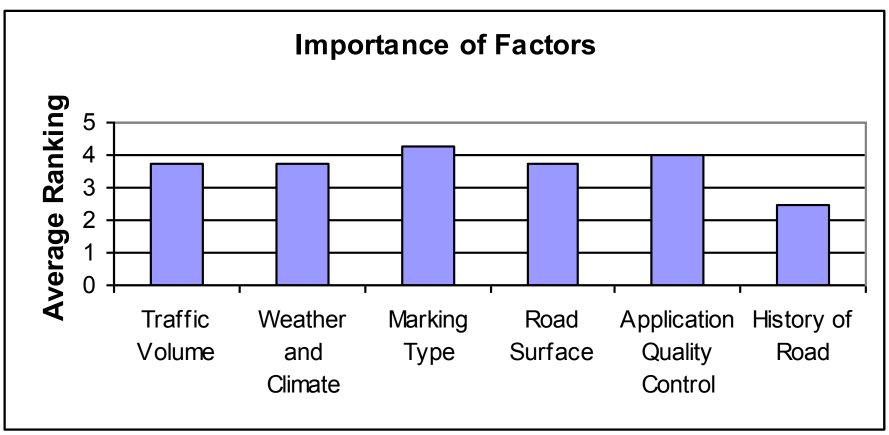


Figure 2.5: States' Ranking of Factors Contributing to Degradation

Of the states that responded, eight have developed a marking inventory system in which they inspect markings periodically. The inspections range from subjective nighttime inspections to retroreflectometer readings. A very important finding of the survey was that of the states that responded, no state's management system is able to predict pavement marking degradation.

2.3 Chapter Summary

There have been a large number of studies regarding pavement markings. These studies range from predicting degradation to determining minimum acceptable retroreflectivity values using various modeling techniques. It is apparent from the literature review that very little research has been conducted on high-build markings. Therefore, a major goal of this project was to develop reliable high-build models and compare their results to those of waterborne and thermoplastic models. Through this comparison, service lives and life cycle costs for each marking type can be determined, and the results and recommendations given to SCDOT.

From the literature regarding these studies, several things can be concluded. The first and most important conclusion is that there currently is no standard for the minimum acceptable retroreflectivity threshold, though such standards are pending and expected to be implemented soon. The lack of a federal standard makes creating an estimate of marking life difficult. However, the Pavement Marking Handbook of the Texas Department of Transportation [Texas Department of Transportation, 2004] has suggested that as a rule-of-thumb, average pavement marking retroreflectivity values of 80-100 mcd/m^2/lux should be considered for replacement. This estimate is consistent with the proposed FHWA minimum standards for most primary and secondary roads.

Another major conclusion derived from the literature is the lack of consistency in retroreflectivity degradation models. The significant variables determined by past research projects vary, though marking age and traffic volume seem to be the most common variables used. Some models deem only one of these variables significant, while others find both as major contributors to retroreflectivity degradation. Another major difference in predictive models is the initial retroreflectivity value. Most models assume a constant initial value for each material, but this presents a problem due to the variability in marking application. Accompanied with the variability in degradation models is variation in the predicted life spans of markings. Models from previous research give the life cycle of pavement markings as a very wide range, which is less than ideal when trying to create a pavement marking management system.

Though this research project did do extensive testing regarding the effects of wetness or directionality on pavement marking retroreflectivity, they are important factors, and thus are noted in the literature review. These aspects were taken into account in the project, and additional data collection was performed to test that the findings of this project coincide with the literature.

An important characteristic of this research is the approach of “leaving no stone unturned.” This research considers a large number of variables in the models including marking age, varying initial value, traffic volume, lane width, shoulder width, climate, marking thickness, and application rate for different markings. This research is explained in detail in Chapter 4.

3.0 DATA COLLECTION PROCEDURES AND DATA SUMMARY

3.1 Project Commencement

Through initial meetings with the SCDOT steering committee governing the project, it was determined that designated employees of each of the SCDOT districts would supply the research team with potential roadways to be included in the project. These roadways were to have had new markings laid up to 25 days prior to the research team being notified. The information included in the notification was road name, nearest crossing streets of new marking beginning and ending, marking material, pavement type, application rate, wet film thickness, bead type, and bead and paint manufacturers. These notifications were sent through e-mail, and often included multiple newly marked roadways.

From these lists of newly marked roadways, the research team selected certain roads for potential “sites.” The goal in selecting sites was to establish a distribution of sites from at least 100 test section locations spread across South Carolina. Note that a particular site location may have one or more test sites (white edge, white skip, yellow, etc.) As more sites were established, the research team became more selective in choosing potential site locations to ensure a good distribution. By the end of the site establishment period, a sufficient distribution was formed; however, the ideal distribution was not achieved, as there were many counties in South Carolina where no sites were established. Figure 3.1 shows the distribution of site locations established throughout South Carolina. Site locations with waterbased markings are represented by Palmetto trees, while sites with thermoplastic markings are represented by maple leaves.

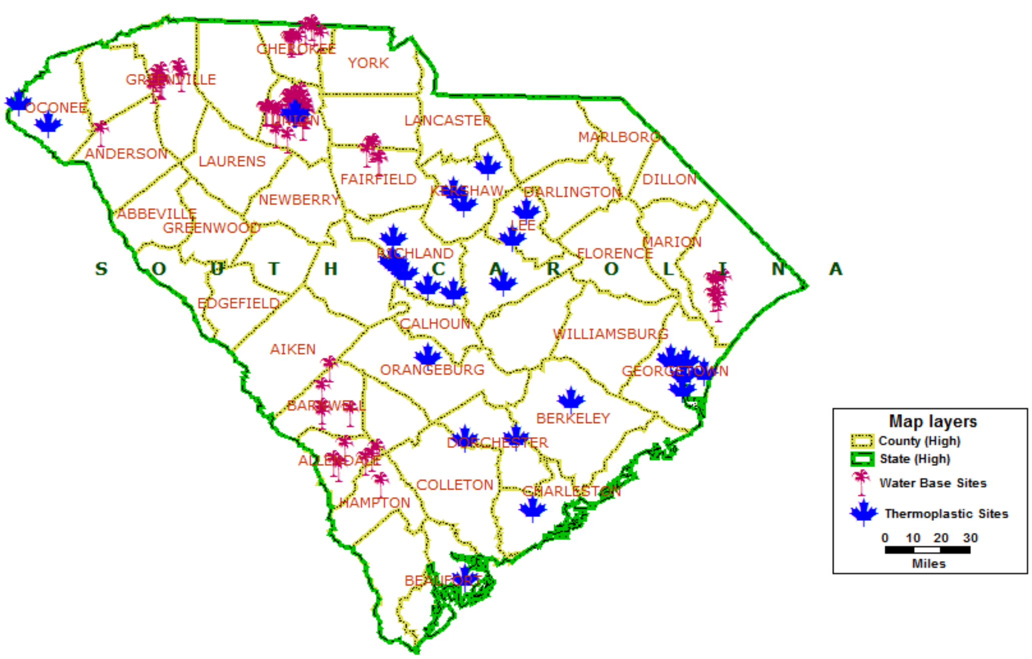


Figure 3.1: Site Locations Established in South Carolina

During the data collection, the research team was forced to abandon some sites. In many cases, this was caused by repaving, remarking, or the addition of a chip seal to the roadway. Some other sites were abandoned because of the concentration of sites in some areas. due to budget and time constraints, under the basis that there were many similar sites within the area. This also allowed the research team to establish additional sites in other areas that were not well represented. Waterborne sites in Horry County near Myrtle Beach were added during the second year of the project to help improve the distribution of data collection locations. Additionally, high-build sites were also added during the second year of the project in an attempt to develop lifecycle models for high-build markings. In comparison to conventional waterborne markings, high-build markings have shown promising results with respect to their retroreflectivity performance. However, there has been very little research done on high-build markings, which is why researching their performance was a primary objective of this project. Table 3.1 shows site statistics including marking color, configuration, and pavement types. Table 3.2 expands on Table 3.1 by giving statistics on sites based on pavement types. There were 213 sites established at 126 different locations from around the state.

Table 3.1: Established and Remaining Sites

Variable	Category	Established Sites	Sites Remaining After Latest Round
Marking Type	High-Build (HB)	21	10
	Waterbase (WB)	76	19
	Thermoplastic (T)	29	17
	Total	**126**	**46**
Marking Color by Material and Configuration	White Edge HB	21	10
	White Edge WB	51	8
	White Edge T	23	14
	Yellow Solid WB	67	18
	Yellow Skip WB	13	1
	Yellow Solid T	22	15
	Yellow Skip T	16	8
	Total	**213**	**74**
Pavement Type	New HMA	23	14
	Existing HMA	173	57
	Chip Seal	17	3
	Total	**213**	**74**

Table 3.2: Site Statistics by Pavement Type

Pavement Type	Marking	Initial Number of Sites	Avg.	Max	Min	Sites Remaining
Existing HMA	White HB	17	405	448	321	7
	White WB	46	315	467	116	7
	White T	16	444	501	400	9
	Yellow S WB	55	136	218	32	16
	Yellow S T	14	266	302	193	10
	Yellow Sk WB	13	150	182	102	1
	Yellow Sk T	12	290	446	258	7
	Total	**173**			**Total**	**57**
New HMA	White HB	4	370	462	312	3
	White TP	7	384	458	288	4
	Yellow S T	8	248	320	154	5
	Yellow Sk T	4	291	438	207	2
	Total	**23**			**Total**	**14**
Chip Seal	White WB	5	318	407	237	2
	Yellow S WB	12	164	204	108	1
	Total	**17**			**Total**	**3**
Overall Total		**213**		**Overall Total**		**74**

3.2 Site Establishment

The initial site establishment period began in May 2008 and lasted through the beginning of August 2008. During this time, 92 locations were established across the state. After one year, seven additional waterborne locations were added in Horry County, six thermoplastic locations in Georgetown County, and 21 high-build locations in Anderson, Greenville, and Spartanburg Counties. Therefore, there were 126 locations in the study. Most locations contained both yellow and white markings. If the locations are further sorted by colors and configurations, there are a total of 213 established sites in the study. The reason that high-build sites were only established in these three counties is because SCDOT wanted to use them as "trial" counties to observe the performance of high-build markings before installing them statewide. It should also be noted that there are no yellow high-build sites included in the research because at the time the sites were established, South Carolina limited the use of high-build markings to white edge lines.

Before roadway sections could be accepted as potential sites, it had to be verified that the new markings were placed within a 15-25 day window prior to site establishment. After determining roadways where potential sites would be placed and verifying the 15-25 day criteria, the research team traveled to the roadways to establish each individual research site. The first step of site establishment was to find a stretch of road with proper sight distance for oncoming traffic where the team of two could safely operate. This often meant finding a long, straight stretch of road with a large area (i.e. shoulder or parking lot) to park the vehicle. Once the road section was found on which to establish the site(s), additional safety measures were taken to protect the research team members. This included wearing reflective safety vests and placing cones and a "road work ahead" sign along the shoulder of the road in accordance with temporary traffic control protocols. Special care was also taken to have team members aware of traffic at all times and staying out of the road as much as possible.

Next, a 100-ft. tape measure was laid along the edge of the roadway, and templates were painted (Figure 3-2) using temporary marking paint every 25 feet along the white edge line, for a total of five templates. The templates corresponded to the shape of the bottom of the retroreflectometer to be used in data collection. The purpose of this was to ensure that data would be collected at these precise locations on every visit to the site. Finally, the site location was given an identification number, which was painted beside the first template markings (Figure 3-3). A long line was also painted across part of the travel lane to help with recognition when traveling back to the site for future data collection, as well as to easily identify if a site has been repainted.

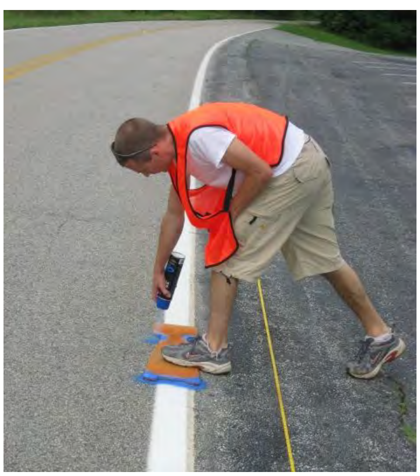


Figure 3.2: Marking with a Template

Figure 3.3: Site Location Numbering

3.3 Data Collection

After site establishment, the first of six rounds of data was collected at the site. This was accomplished using the retroreflectometer, following the retroreflectometer's procedures. This included calibration of the unit at the beginning of each day. An image of the retroreflectometer on a data collection point is shown in Figure 3.4.

Figure 3.4: Retroreflectometer Collecting Data

At the first data collection point, a printout of the GPS coordinates was created to aid in finding the site location for future data collection. For all of the data collection points, the retroreflectivity readings were recorded on data sheets that were kept in a notebook. Additionally, the site location information obtained from SCDOT, date, temperature, and humidity values were also recorded on the data sheets. An example of a data collection sheet is shown in Figure 3.5. Upon completion of the first round of data collection, all of the safety equipment was gathered and the research team moved on to the next potential site. Data collection was performed at each site approximately every three months, for a total of eleven data collection rounds for initial waterborne markings and nine complete rounds for high-build markings. The latest round of data collection was completed in October 2011. Table 3.3 provides summary data by round for the different marking materials.

3.4 Additional Data Collection

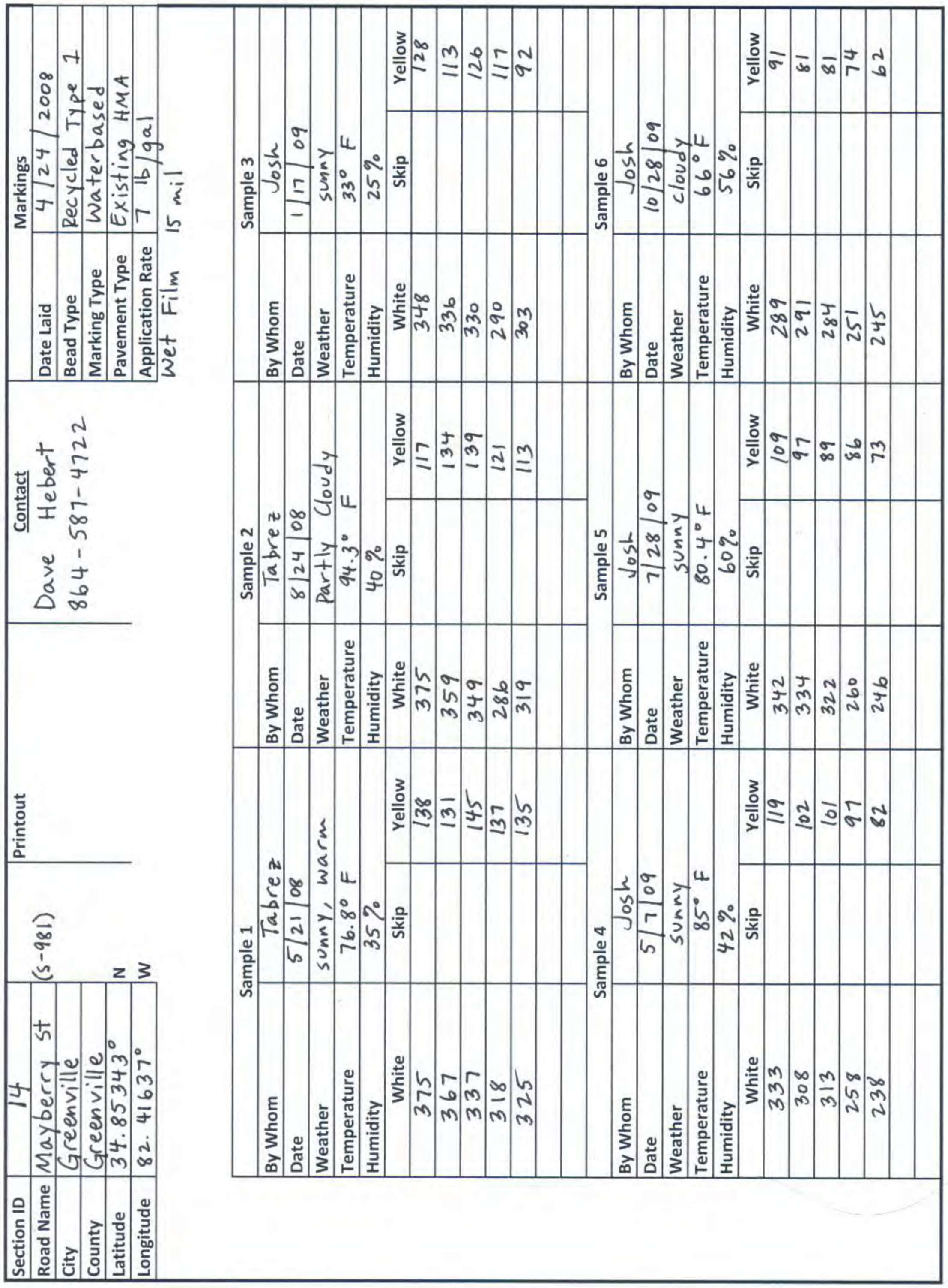
After a few rounds of data collection, it was determined that two additional variables needed to be included in the study. One of these is the effect of the paint-laying direction on retroreflectivity, and the other is the effect of wetness on retroreflectivity. In rounds four through six, additional steps were taken to study these effects. Additional qualitative information was observed and recorded as well. An example of a data collection sheet containing the additional information collected is shown in Figure 3.6.

Table 3.3: Summary Statistics By Round

	White Edge			**Yellow Solid**		**Yellow Skip**	
	Waterbase	Thermoplastic	High Build	Waterbase	Thermoplastic	Waterbase	Thermoplastic
Round 1	**226**	**422.6**	**394.6**	**115.0**	**255**	**169.0**	**290.7**
% Change	12.4	12.1	-0.5	7.1	9.4	12.1	4.9
Round 2	**208**	**473.9**	**396.8**	**107.3**	**278.9**	**149**	**305**
% Change	24.3	8.1	0.3	22.1	-4	2.7	-2.8
Round 3	**158**	**512.2**	**395.5**	**80.7**	**267.8**	**144.5**	**296.4**
% Change	-12.4	-3.4	2.2	0.6	-11.5	15.6	-21.3
Round 4	**161**	**494.9**	**386.7**	**80.1**	**236.9**	**122**	**233.3**
% Change	2.7	12.5	-0.2	6.1	-15.7	3.3	-14
Round 5	**155**	**556.6**	**387.5**	**74.8**	**199.7**	**118**	**200.6**
% Change	3.9	-6	1.4	13.0	-27.3	11.9	-31.5
Round 6	**147**	**523**	**381.9**	**64.0**	**145.1**	**104**	**137.4**
% Change	22.2	-6.4	-1.6	10.6	7.4	0.0	16.3
Round 7	**122**	**489.8**	**388.0**	**56.9**	**155.9**	**104**	**159.8**
% Change	0.1	-8.8	4.0	5.6	17	12.5	24.2
Round 8	**119**	**446.6**	**372.5**	**54.0**	**182.3**	**91**	**198.4**
% Change	-5.8	-9.2	2.8	-0.3	1.6	1.1	7.8
Round 9	**121**	**405.6**	**362.2**	**54.4**	**185.3**	**90**	**213.8**
% Change	13.8	-14.4	-	32.0	5.9	-	7.2
Round 10	**102**	**347.3**	-	**47.2**	**196.3**	-	**229.1**
% Change	1.7	6.9	-	32.0	7.2	-	23.7
Round 11	**100**	**371.3**	-	**49.6**	**210.4**	-	**283.3**

For the directional study, the retroreflectometer was faced backward on the fifth painted template on the yellow marking such that it would measure the retroreflectivity in the opposing direction of the site layout. From the literature, it is believed that the reading will always be less in the opposing direction of the paint laying. To attempt to verify this, these "backwards" readings were also taken on the white edge line for the sixth round. This was because the painting direction of the white edge line was known to be in the direction of travel, while the painting direction of the yellow centerline was unknown. The results of the yellow directional study is discussed in section 2.6 of Chapter 4.

In the wetness study, the fifth template on the white edge line was first swept clean and then soaked with water. Readings were taken at 30 seconds, one minute, and two minutes after the wetting ceased. The results of the wetness study is discussed in section 3.9 of Chapter 4.

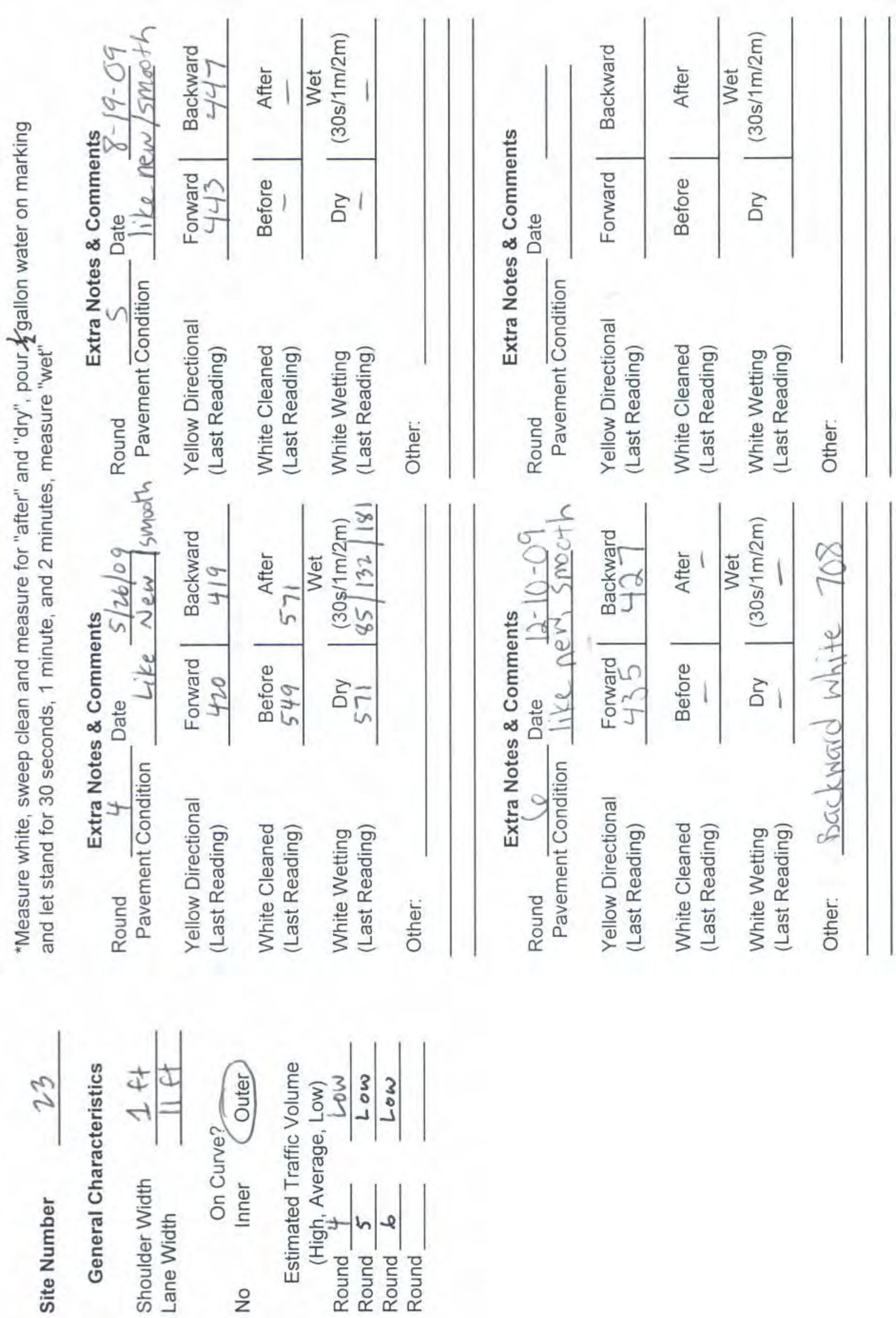


Section ID	14	Printout	Contact	Markings	
Road Name	Mayberry St (S-981)		Dave Hebert	Date Laid	4/24/2008
City	Greenville		864-587-4722	Bead Type	Recycled Type 1
County	Greenville			Marking Type	Waterbased
Latitude	34.85343° N			Pavement Type	Existing HMA
Longitude	82.41637° W			Application Rate	7 lb/gal
				Wet Film	15 mil

	Sample 1			Sample 2			Sample 3		
By Whom	Tabrez		By Whom	Tabrez		By Whom	Josh		
Date	5/21/08		Date	8/24/08		Date	1/17/09		
Weather	sunny, warm		Weather	Partly Cloudy		Weather	sunny		
Temperature	76.8° F		Temperature	94.3° F		Temperature	33° F		
Humidity	35%		Humidity	40%		Humidity	25%		
White	Skip	Yellow	White	Skip	Yellow	White	Skip	Yellow	
375		138	375		117	348		128	
367		131	359		134	336		113	
337		145	349		139	330		126	
318		137	286		121	290		117	
325		135	319		113	303		92	

	Sample 4			Sample 5			Sample 6		
By Whom	Josh		By Whom	Josh		By Whom	Josh		
Date	5/7/09		Date	7/28/09		Date	10/28/09		
Weather	sunny		Weather	sunny		Weather	cloudy		
Temperature	85° F		Temperature	80.4° F		Temperature	66° F		
Humidity	42%		Humidity	60%		Humidity	56%		
White	Skip	Yellow	White	Skip	Yellow	White	Skip	Yellow	
333		119	342		109	289		91	
308		102	334		97	291		81	
313		101	322		89	284		81	
258		97	260		86	251		74	
238		82	246		73	245		62	

Figure 3.5: Sample Data Collection Sheet



Site Number 23

General Characteristics

Shoulder Width 1 ft
Lane Width 11 ft

On Curve?
No Inner (Outer)

Estimated Traffic Volume
(High, Average, Low)
Round 4 Low
Round 5 Low
Round 6 Low
Round ____ ____

*Measure white, sweep clean and measure for "after" and "dry", pour ½ gallon water on marking and let stand for 30 seconds, 1 minute, and 2 minutes, measure "wet"

Extra Notes & Comments
Round 4 Date 5/26/09
Pavement Condition Like New /smooth

	Forward	Backward
Yellow Directional (Last Reading)	420	419

	Before	After
White Cleaned (Last Reading)	549	571

	Dry	Wet (30s/1m/2m)
White Wetting (Last Reading)	571	85 / 132 / 181

Other: ____

Extra Notes & Comments
Round 5 Date 8-19-09
Pavement Condition like new/smooth

	Forward	Backward
Yellow Directional (Last Reading)	443	447

	Before	After
White Cleaned (Last Reading)	–	–

	Dry	Wet (30s/1m/2m)
White Wetting (Last Reading)	–	–

Other: ____

Extra Notes & Comments
Round 6 Date 12-10-09
Pavement Condition like new, smooth

	Forward	Backward
Yellow Directional (Last Reading)	435	427

	Before	After
White Cleaned (Last Reading)	–	–

	Dry	Wet (30s/1m/2m)
White Wetting (Last Reading)	–	–

Other: Backward white 708

Extra Notes & Comments
Round ____ Date ____
Pavement Condition ____

	Forward	Backward
Yellow Directional (Last Reading)		

	Before	After
White Cleaned (Last Reading)		

	Dry	Wet (30s/1m/2m)
White Wetting (Last Reading)		

Other: ____

Figure 3.6: Sample Supplemental Data Collection Sheet

3.5 Discussion of Site Sample Sizes

Table 3.4 below shows the initial number of sites established for each marking material as compared to how many sites remain in the analysis. It is apparent from the table that many sites were lost throughout the study. The factors resulting in lost sites are obliteration (repaving, remarking, or adding a chip seal) and voluntary abandonment. The number of rounds collected for these lost sites varies from one to nine, with the majority having at least four rounds collected. Some of these lost sites were prematurely replaced and are discussed in further detail *3.6 Retroreflectivity Characteristics of Lost Sites*. Reasons for site abandonment are explained in *3.1 Project Commencement*. Figure 3.7 shows a graph of number of sites by round.

Table 3.4: Summary of Sites

Marking Material	**Initial Sites**	**Sites Lost to Restriping**	**Sites Lost to Repaving**	**Abandoned Sites**	**Total Lost Sites**	**Sites Remaining**
White Edge HB	21	5	0	6	11	10
White Edge WB	51	17	5	21	43	8
White Edge T	23	0	7	2	9	14
Yellow Solid WB	67	20	12	17	49	18
Yellow Skip WB	13	5	2	5	12	1
Yellow Solid T	22	1	5	1	7	15
Yellow Skip T	16	0	6	2	8	8
Total Sites	**213**	**48**	**37**	**54**	**139**	**74**

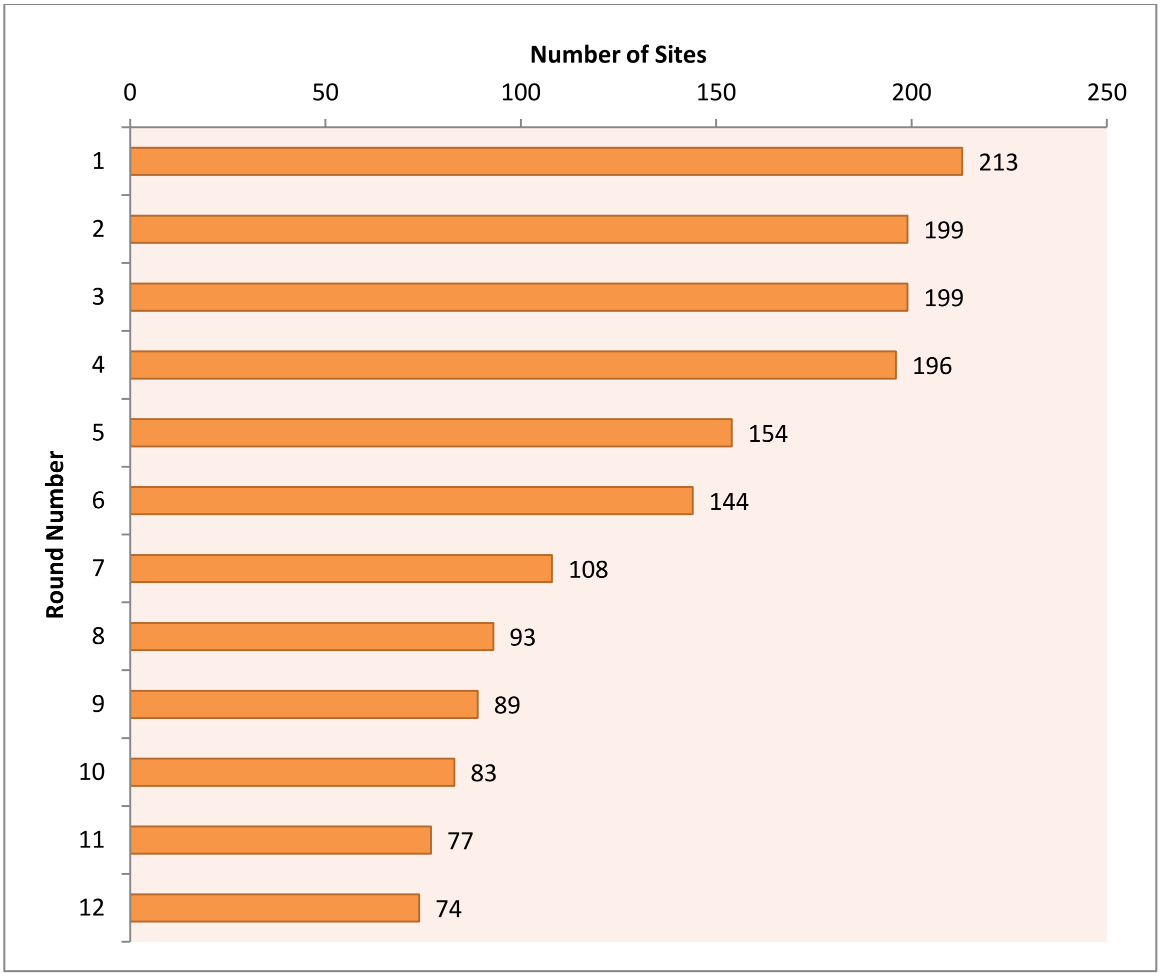


Figure 3.7: Number of Total Sites By Round

3.6 Retroreflectivity Characteristics of Lost Sites

As mentioned earlier, a number of sites were obliterated for various reasons during the study period. Of the sites that were restriped many of these sites had retreflectivity values significantly greater than the commonly accepted minimum threshold of 100 mc/m^2/lux. Statistics about these lost sites in this research are shown in Table 3.5.

As Table 3.4 shows, many sites that were repainted during the study occurred while their retroreflectivity values were greater than 100 mcd/m^2/lux. For all marking types and configurations, a total of 75% of all sites that were restriped occurred while they still had retroreflectivity values greater than 100 mcd/m^2/lux. The average values of these repainted sites were significantly higher than the previously described minimum threshold. While there may have been other reasons for these sites to be restriped, from a retroreflectivity standpoint, these markings had not yet reached the end of their functional lives and the resources used to replace them may have been more effectively used elsewhere.

Table 3.5: Statistics for Sites Restriped while $R_L > 100$

Marking Material	Total # of Lost Sites Due to Restriping	# of Restriped Sites with RL > 100	% of Lost Sites with RL > 100	Avg. RL of Lost Sites with RL > 100
White Edge HB	**5**	**5**	**100%**	**388**
White Edge WB	**17**	**14**	**82%**	**261**
White Edge T	**0**	**0**	**0%**	**-**
Yellow Solid WB	**20**	**12**	**60%**	**133**
Yellow Skip WB	**5**	**4**	**80%**	**147**
Yellow Solid T	**1**	**0**	**0%**	**-**
Yellow Skip T	**0**	**0**	**0%**	**-**
Total Sites	**48**	**36**	**75%**	

Also, there were four sites in the study that were repaved soon after marking installation. This problem is most likely attributed to a lack of coordination between entities within SCDOT. For these four sites, two were repaved after only one round of data, and the other two were repaved after three rounds of data. Essentially this means that all four of these sites were repaved less than a year after the markings were installed.

3.7 Sites with Low Retroreflectivity Values

On the other hand, there are sites still in service with retroreflectivity values below the 100 $mc/m^2/lux$ threshold. The low nighttime visibility of these sites could be potentially dangerous for drivers. Table 3.6 displays statistics about these sites.

As shown in Table 3.6, there are 23 sites in the study that have retroreflectivity values less than 100 $mc/m^2/lux$. All but one of these sites are waterborne sites and they make up 31% of the total remaining sites (all marking types and configurations). The low nighttime visibility of these sites poses a potential safety issue for drivers, and would not meet forthcoming MUTCD minimum retroreflectivity standards when they are implemented.

Table 3.6: Statistics for Sites with Low Retroreflectivity Values

Material	Total # of Sites Remaining	# of Sites with $R_L < 100$	% of Remaining Sites with $R_L < 100$	Avg. R_L of Sites with $R_L < 100$
White Edge HB	10	0	0%	-
White Edge WB	8	5	63%	65
White Edge T	14	0	0%	-
Yellow Solid WB	18	16	89%	46
Yellow Skip WB	1	1	100%	90
Yellow Solid T	15	1	7%	96
Yellow Skip T	8	0	0%	-
Total Sites	**74**	**23**	**31%**	

3.8 Data Editing and Management Prior to Preliminary Analysis

Field collected data was entered into a comprehensive database and checked for logical consistency. Anomalous readings typically attributed to tire marks, scraping, excess moisture, physical abrasion and ground in dirt, debris, etc. were identified and removed from the analysis. To best preserve sample sizes within the pavement marking types, only individual anomalous sample points, of the five per site, were removed from the analysis, and not the entire site. Furthermore, in processing specific sample points, retroreflectivity values greater than twice the standard deviation of the five site readings were considered anomalous and were omitted in the determination of a mean site value in any given round of data. Median values of measured retroreflectivity were determined along with average values for every data collection site. The average difference observed between means and medians was 4 mcd/m^2/lux for high-build markings and 3 mcd/m^2/lux for waterborne markings. These negligible differences provide a reliable indication that site collected data was not skewed. For use in the pavement marking degradation and retroreflectivity analysis, median values for each site were used because these values are less sensitive to outliers. Appendices A-G contain tables showing data points for all marking types (minus the omitted points) and their associated variables.

Additional variables were also recorded in the study. These variables are marking application rate, bead type, and wet film thickness. These variables were not considered in analysis due to the reasons shown in Table 3.7.

Table 3.7: Variables Eliminated from Analysis

Variable	**Reason for Exclusion**
Bead Type	Difficult to obtain accurate bead application rates for all sites, and all beads were the same for sites of the same marking material.
Wet Film Thickness	SCDOT reported values were uniform with a few exceptions. Without much variance in thickness between markings of the same type, this variable becomes insignificant.
Application Rate	Specific application rates per site were not reported, therefore, standard values were provided.

Considering all collected variables, a final list of variables to be used in the analysis was determined. These selected variables were: initial retroreflectivity, days since initial reading, traffic volume, temperature, humidity, lane width, and shoulder width. These variables were used in stepwise regression analyses for all marking types and configurations.

4.0 PAVEMENT MARKING MODELING AND ANALYSIS

4.1 Stepwise Regression Analysis

The purpose of stepwise regression analysis was to determine which variables were significant in predicting retroreflectivity of pavement markings. This was completed using the StatPro add-in for Microsoft Excel 2003. This program allows you to specify the dependent variable, independent variables, and maximum acceptable p-value for the variables to enter the model (thus making them statistically significant). If any included variable was missing for a given data point in stepwise regression, the entire data point was left out of the analysis. In a few cases, the data points were missing temperature, humidity, lane width, or shoulder width, causing the entire data point to be left out. The produced output lists the significant variables, their coefficients and p-values, and R-squared values. The R-squared values given begin with the most significant variable and then show the increase in R-squared if other significant variables are added to the model.

4.1.1 Consideration of Initial Retroreflectivity Values in Stepwise Regression

Our initial approach was to consider a stepwise regression analysis using median retroreflectivity values as the dependent variable and all other variables as independent variables. The literature indicated that some previous modeling efforts included a constant in their models. This constant reflected the influence of initial retroreflectivity on the model. These models would then predict the degradation of retroreflectivity over time considering whatever independent variables used. One problem with this approach is that it is based on the assumption that initial retroreflectivity is uniform for all sites. However, from viewing the first round of data, it was apparent that assuming a uniform initial retroreflectivity value for South Carolina would be a mistake, because the data showed that the initial values were highly variable as shown in Figure 4.1. This figure shows a graph of waterborne white edge retroreflectivity over time. The linear regression trend line includes retroreflectivity as the dependent variable and time as the independent variable. The constant of 315.56 represents the initial value created from the regression model. The variability of the initial retroreflectivity values (round 1 data closed to 0 days) is apparent.

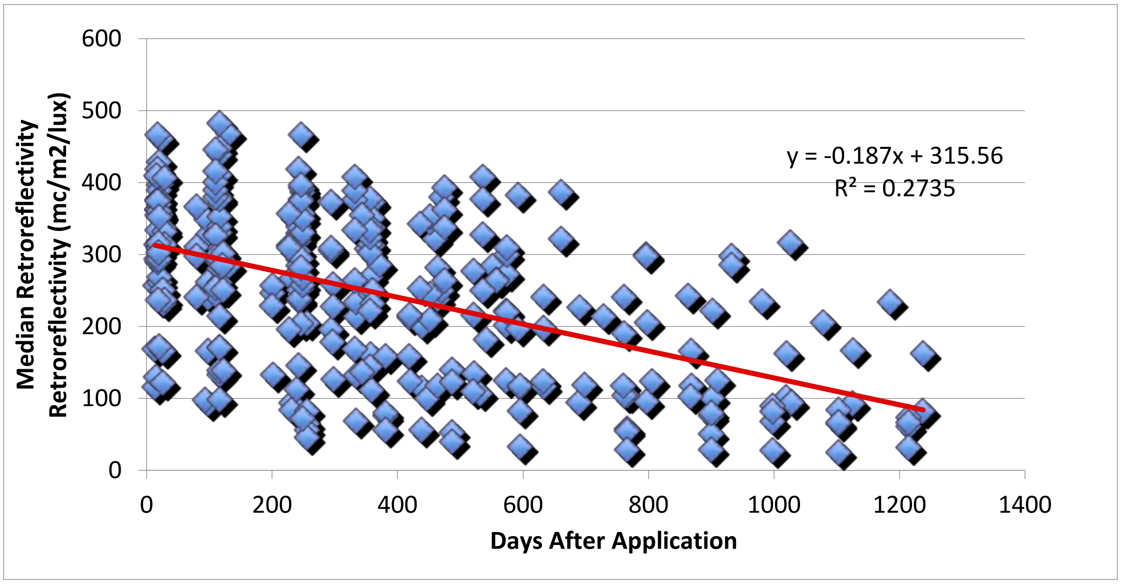


Figure 4.1: Waterborne White Edge Line Marking Performance

As an alternative to producing models that incorporate initial values as a constant, the researchers decided to produce models that predict actual degradation rather than predict retroreflectivity. Applying these models would require subtracting the modeled difference in degradation from an initial value to determine a predicted retroreflectivity value after a period of time or total amount of traffic passages.

Another alternate modeling approach to using initial values as a constant is to modelpercent difference from initial values. Absolute retroreflectivity difference models would be most accurate if marking degradation was uniform and similar for all sites of each material, no matter the initial value. Percent difference models would be most accurate for markings with a higher initial retroreflectivity that degrade at a faster uniform rate than those with lower initial values. Because this relationship was unknown, stepwise regression analyses were completed for both. For the percent difference analysis, a new variable was created for percent difference from initial retroreflectivity using the following formula:

$$\%Difference = {(Median - Initial)}\big/{Initial} \times 100$$

This percent difference then became the dependent variable in the stepwise regression analysis. In general, the significant variables selected by this stepwise regression were the same as the regression using absolute differences, but with slightly higher R-squared values.

4.2 Yellow Marking Degradation Models

4.2.1 Retroreflectivity Difference Stepwise Regression for Yellow Markings

For yellow centerline and skip markings, the first stepwise regression analysis used absolute differences from initial retroreflectivity as the dependent variable and all other variables as independent. The variables found significant for each marking type in these analyses are shown in Table 4.1.

Table 4.1: Stepwise Regression for Retroreflectivity Difference of Yellow Markings

Material	**Days Since Initial Reading**	**Traffic Volume**	**Humidity**	**Temp**	**Lane Width**	**Shoulder Width**
Waterborne Centerline	X	X				
Waterborne Skip	X	X				
Thermoplastic Centerline						X
Thermoplastic Skip	X				X	X

Table 4.1 shows that *days since initial reading* and *traffic volume* were found to be significant for waterborne yellow solid and skip markings. For thermoplastic markings, *shoulder width* was found to be significant for yellow centerline and skip markings, with *lane width* and *days since initial reading* also significant for skip markings. The decisions on the use of these and other variables in the models are discussed in greater detail in *4.2.1 Discussion of Possible White Edge Line Models*.

4.2.2 Retroreflectivity Percent Difference Stepwise Regression for Yellow Markings

The next stepwise regression analyses performed on the yellow markings used *percent difference from initial values* as the dependent variable, with all other variables as independent. The variables found to be significant in the percent difference stepwise regression analyses for waterborne and thermoplastic yellow centerline and skip markings are shown in Table 4.2.

Table 4.2: Stepwise Regression for Retroreflectivity Percent Difference of Yellow Markings

Material	Days Since Initial Reading	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
Waterborne Centerline	X	X				
Waterborne Skip	X					
Thermoplastic Centerline						X
Thermoplastic Skip	X				X	X

As shown in Table 4.2, the significant variables selected by this stepwise regression were almost the same as the results from the stepwise regression using absolute differences. The only difference was that *traffic volume* was not found to be significant for waterborne yellow skip markings. Once all of the significant variables were determined from absolute and percent difference stepwise regression analyses, variables to be included in the models were analyzed and selected.

4.2.3 Waterborne Solid Yellow Centerlines

For both difference and percent difference stepwise regression, *days since initial reading* and *traffic volume* were found to be significant for waterborne solid yellow centerlines. The coefficient associated with this variable was found to be negative in both cases. The negative correlation implies that retroreflectivity decreases over time with higher traffic volumes, which is expected. Also, simple regression was completed using only *days since initial reading* as the dependent variable with the constant set equal to zero, which was compared to multiple regression using *days since initial reading* and *traffic volume* as dependent variables. For both absolute and percent difference from initial value regressions, the R-squared values were only slightly higher when *traffic volume* was added. The slight improvement in the R-squared value achieved by adding *traffic volume* does not warrant the increase in data collection and model complexity associated with using it as a variable. The availability of accurate traffic volume data is limited to selected road segments throughout South Carolina. It is possible to interpolate estimated volumes in many cases from nearby counts however the accuracy would not be as good as actual counts. Therefore, it was decided that traffic volume could be eliminated for from waterborne yellow centerlines models, leaving *days since initial reading* as the only independent variable. The results from the waterborne yellow centerline regression scenarios are shown in Table 4.3.

Table 4.3: Waterborne Yellow Centerline Regression Scenarios

Regression Type	Variables Included	Abs. Diff. R-squared	% Diff. R-squared
Single	Days since initial reading	0.37	0.47
Multiple	Days since initial reading, Traffic Volume	0.39	0.48

4.2.4 Waterborne Yellow Skip Lines

The largest hindrance in creating a model for waterborne yellow skip lines was the small sample size for this particular marking configuration. Only 13 sites were established with waterborne yellow skip lines, and only one of these sites was remaining at the end of the study. With such a small sample size, any variability in the data could have a detrimental effect on the model. However, before developing a model, the significant variables were determined. For absolute difference stepwise regression, days and traffic volume were found significant, while only days was significant for the percent difference regression. Since the sample size was small and some data points were excluded in stepwise regression, these models should be used with caution. The regression scenarios developed are shown in Table 4.4

Table 4.4: Waterborne Yellow Skip Regression Scenarios

Regression Type	Variables Included	Abs. Diff. R-squared	% Diff. R-squared
Single	Days since initial reading	0.34	0.33
Multiple	Days since initial reading, Traffic Volume	0.40	-

In the multiple regression scenario for *absolute difference from initial value*, adding *traffic volume* improved the R-squared value, but it was decided not to be included in the final model because of the availability of accurate traffic volume data on many roads as well as it was not significant for the percent difference regression .

4.2.5 Thermoplastic Yellow Solid Centerlines and Skip Lines

For this research, it was determined that yellow thermoplastic markings could be modeled linearly. However, the only variable found to be significant for yellow centerlines was shoulder width. The use of polynomial models was considered, but for comparative purposes, models were created using *days since initial reading* as the independent variable. The first possible model analyzed was the thermoplastic yellow centerline linear model created from simple linear regression. This model was linear with the y-intercept set equal to zero to replicate initial conditions. Though these models produced the lowest R-squared values (0.05 for solid centerlines difference model and 0.09 for skip difference model), the slopes of the degradation trend lines seemed to be the most realistic. While the yellow skip models including shoulder width had higher R-squared values, shoulder width as single variable is not a good choice because it may not be known for all sites and was most likely found significant only because of the small sample size. Hence, the days since initial models were selected and used for the remainder of the analysis. The results from the regression scenarios are shown in Table 4.5.

Table 4.5: Thermoplastic Yellow Solid Centerline and Skip Line Regression Scenarios

Thermoplastic Marking Type	**Regression Type**	**Variables Included**	**Abs. Diff. R-squared**	**% Diff. R-squared**
Yellow Centerline	Single	Days	0.05	0.04
	Single	Shoulder Width	0.07	0.07
Yellow Skip	Single	Days	0.09	0.06
	Multiple	Days, Shoulder Width	0.33	0.33

4.2.6 Summary of Possible Models for Yellow Markings

After careful analysis of each marking type, the variables to be used in the final models were determined. These variables were determined based on their contribution to the model, data availability, and ease of use in statewide models. A summary of these results is shown in Table 4.6. The final models created using these variables are discussed in *4.2.7 Yellow Marking Final Degradation Models*.

Table 4.6: Summary of Yellow Centerline and Skip Modeled Variables

Material	**Variables Included**	**Notes**
Waterborne Yellow Centerline	Days (Difference and Percent Difference Models)	For agency application
Waterborne Yellow Skip	Days (Difference and Percent Difference Models)	For agency application
Thermoplastic Yellow Centerline	Days (Difference and Percent Difference Models)	For agency application
Thermoplastic Yellow Skip	Days (Difference and Percent Difference Models)	For agency application

4.2.7 Yellow Marking Final Degradation Models

The next step included the development of models for waterborne and thermoplastic yellow center and skip lines. All of the models created for these marking types were linear with a single independent variable. In each case, the equations' constant was set to zero. This was done to replicate real conditions where retroreflectivity is equal to the initial retroreflectivity value at zero days. For the waterborne models, R-squared values ranged from 0.33-0.47. For the yellow thermoplastic models, the decrease in retroreflectivity over time is very small. As a result, the model lines for the data are nearly horizontal and have low R-squared values, a characteristic that is typical of models with near horizontal trend lines. Table 4.7 lists the models created and their corresponding R-squared values.

Table 4.7: Yellow Marking Final Degradation Models

Material	Variables Used	Model	R^2
Yellow Solid WB	Days Since Initial Reading	DIFF = -0.0721 (D)	0.37
		% DIFF = -0.0569 (D)	0.47
Yellow Skip WB		DIFF = -0.0594 (D)	0.34
		% DIFF = -0.0366 (D)	0.33
Yellow Solid T		DIFF = -0.0764 (D)	0.05
		% DIFF = -0.0270 (D)	0.04
Yellow Skip T		DIFF = -0.1123(D)	0.09
		% DIFF = -0.0364(D)	0.06
Identification for model variables: D – Days since initial reading. Units are in Days.			

As a visual aid, graphs of the yellow marking final degradation models were developed. Graphs of these models are shown in Figures 4.2-4.5. It should be noted that the model graphs have been set to the same horizontal and vertical scales for ease of comparison

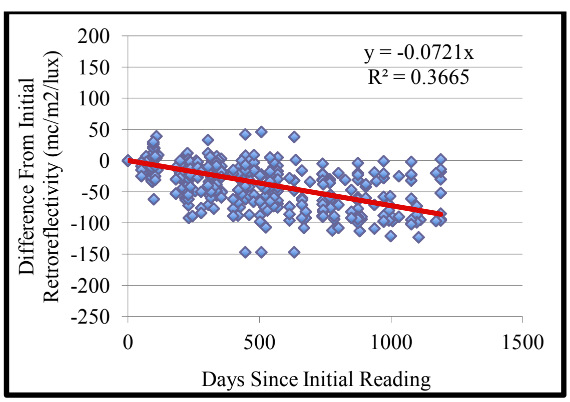


Figure 4.2A: WB YS Diff. vs. Days

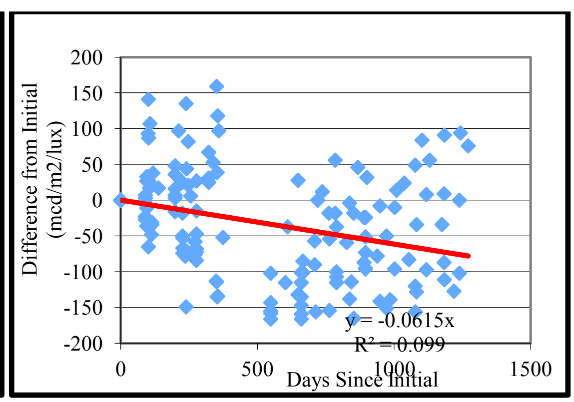


Figure 4.2B: TP YS Diff vs. Days

Figure 4.2: Yellow Solid Absolute Difference vs. Days Graphs

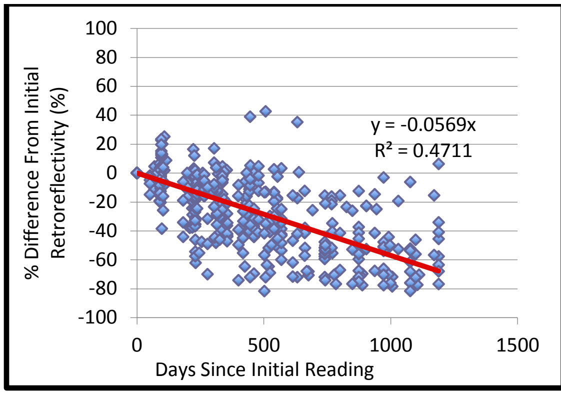


Figure 4.3A: WB YS % Diff vs. Days

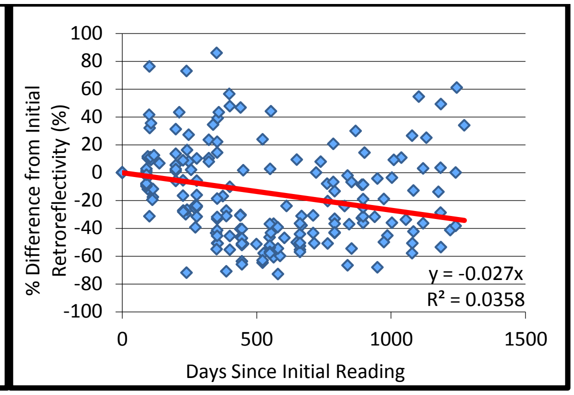


Figure 4.3B: TP YS % Diff vs. Days

Figure 4.3: Yellow Solid Percent Difference vs. Days Graphs

As shown in Figures 4.2 (Difference from Initial) and 4.3 (% Difference from Initial), waterborne yellow solid marking performance is much less variable over time than thermoplastic markings of the same type. However, both marking materials have similar negative trends over time, which is an expected characteristic of pavement markings. These figures also show that on average, waterborne yellow solid markings degrade at more than twice the rate of thermoplastic yellow solid markings.

Figures 4.4 and 4.5 show absolute difference and percent difference models, respectively, for waterborne and thermoplastic yellow skip markings.

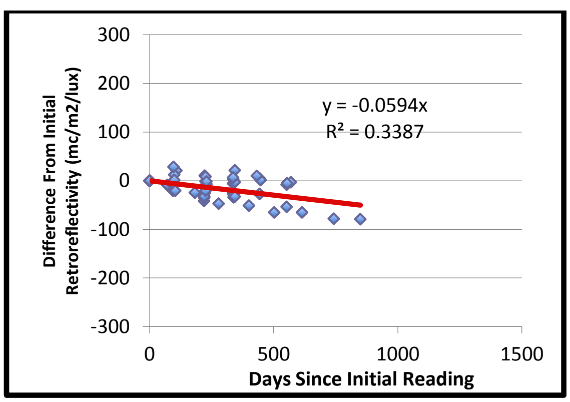


Figure 4.4A: WB YSk Diff. vs. Days

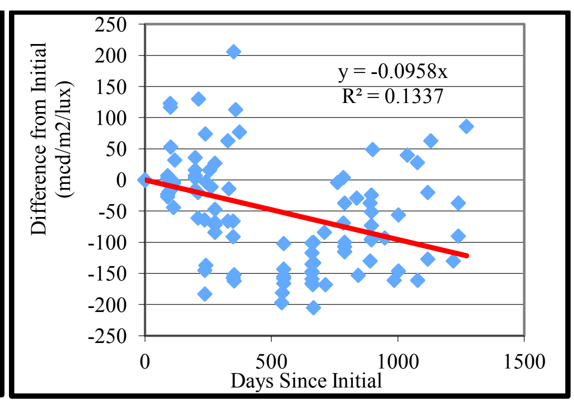


Figure 4.4B: TP YSk Diff vs. Days

Figure 4.4: Yellow Skip Absolute Difference vs. Days Graphs

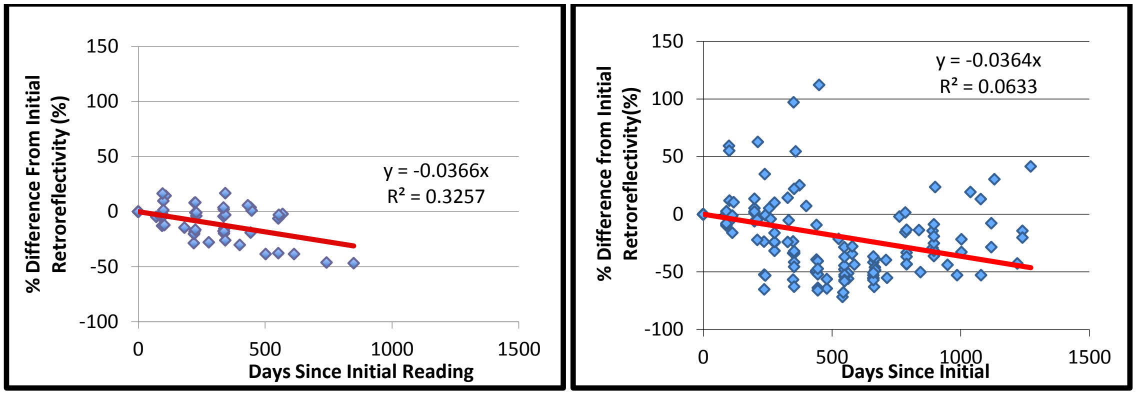


Figure 4.5A: WB YSk % Diff. vs. Days

Figure 4.5B: TP YSk %Diff vs. Days

Figure 4.5: Yellow Skip Percent Difference vs. Days Graphs

Figures 4.4 and 4.5 show that waterborne and thermoplastic yellow skip markings have similar degradation rates over time. It should be noted that the yellow skip thermo initial values are, on average, nearly twice as high as yellow skip waterborne initial values. Further the sample size of the waterborne yellow skip is much lower than thermoplastic.

4.2.8 Yellow Directional Study

One aspect of research not considered initially was the retroreflectivity difference depending on which direction the retroreflectometer was facing. Because of the tendency of the glass beads to roll or become embedded in the paint, it is possible that retroreflectivity is higher in one direction than the other. In particular, retroreflectivity could possibly be higher in the direction that the paint-laying truck traveled. To check this phenomena, yellow centerline markings were measured in both directions during the fourth round of data collection. It was determined that on average, waterborne markings were 29.8 percent higher and thermoplastic markings were 9.6 percent higher in one direction than the other.

After realizing this, the question became whether or not this affected the degradation model for yellow markings. To determine this, the solid yellow markings for both waterborne and thermoplastic marking materials were split into high and low direction data sets. The data sets were modeled using the difference models. A comparison indicated that the models were similar which indicated that the yellow markings deteriate in a similar manner in both directions.

One important piece of information that was concluded from this study was that direction of paint-laying should be taken into account when predicting marking degradation. This is because the initial retroreflectivity will be lower in one direction than the other. Following the theory that markings deteriorate at the same rate no matter the initial value means that the marking will reach the minimum retroreflectivity threshold in one direction before the other. If the retroreflectivity is not predicted properly, this could become a safety issue.

4.3 White Degradation Models

4.3.1 Retroreflectivity Difference Stepwise Regression for White Edge Line Markings

For white edge line markings, the first stepwise regression analyses used absolute differences from initial retroreflectivity as the dependent variable and all other variables as independent. The variables found significant for each marking type in these analyses are shown in Table 4.8.

Table 4.8: Stepwise Regression for Retroreflectivity Difference

Material	Days Since Initial Reading	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
High-Build	X	X			X	
Waterborne	X					
Thermoplastic		X				

As Table 4.8 shows, *lane width*, *traffic volume*, and *days since initial reading* were found to be significant for high-build white edge markings in the stepwise regression using absolute differences. However, for waterborne white edge markings, only *days since initial reading* was found significant, and only traffic volume for thermoplastics. Decisions on the use of these and other variables in the models are discussed in greater detail in *4.3.3 Discussion of Possible White Edge Line Models*.

4.3.2 Retroreflectivity Percent Difference Stepwise Regression for White Edge Line Markings

Percent difference stepwise regression analyses were the next analyses performed on the white edge line markings. The variables found to be significant in the percent difference stepwise regression analyses for white edge line markings are displayed in Table 4.9.

Table 4.9: Stepwise Regression for Retroreflectivity Percent Difference

Material	Days Since Initial Reading	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
High-Build	X	X			X	
Waterborne	X					
Thermoplastic	X	X				X

As shown in Table 4.9, the significant variables selected by this stepwise regression were the same as the regression using absolute differences for waterborne and high-build markings, but different for thermoplastic, with the addition of days and shoulder width. In comparison to the absolute difference analysis, the R-squared values increased for all marking types, but much more so for waterborne and thermoplastic (0.35 for waterborne, 0.24 for high-build, 0.15 thermoplastic). The waterborne R-squared value most likely had a greater increase because the retroreflectivity values for waterborne tend to degrade more rapidly than high-build, resulting in a greater percent change over time. The increase in R-squared for thermoplastic can most likely be attributed to the addition of days and shoulder width as significant variables.

Table 4.9 also shows that days since initial reading and traffic volume are significant for high-build and thermoplastic white edge marking percent differences. As stated in *2.0 Literature Review and Survey of States*, other research found cumulative traffic passages to be more significant than days and traffic volume combined. In order to see if this was also true for this research, days since initial reading was multiplied by traffic volume to calculate a new variable, cumulative traffic passages (CTP). CTP represents the cumulative exposure of the marking to vehicle travel since its initial reading. Both the difference and percent difference analyses found CTP alone to be more statistically significant than traffic volume and days when used together in both the absolute and percent difference high-build models. CTP was also significant in the waterborne models, but not more so than using days alone with the constant set to zero. CTP was not found to be significant for thermoplastic white edge models.

4.3.3 Discussion of Possible Waterborne White Edge Line Models

For waterborne markings, both absolute and percent difference stepwise regression analyses found days since initial reading and traffic volume to be significant. To determine whether these variables were truly significant and useful to the model, further investigation was required.

A variable was deemed useful if its contribution to the model outweighed the additional cost and complications created when adding the variable. Of the significant independent variables, days since initial reading is the easiest to use in a model. However, traffic volume can be particularly difficult to include in a model because accurate data is not always available, and the values fluctuate from year to year. To try and create a model that was most useful, multiple scenarios were examined using simple and multiple linear regression analyses for both absolute and percent differences. A summary of these results is shown in Table 4.10.

Table 4.10: Waterborne White Edge Line Regression Scenarios

Regression Type	Variables Included	Abs. Diff. R-squared	% Diff. R-squared
Single	Days Since Initial Reading	0.21	0.33
Single	Cumulative Traffic Passages	0.11	0.11

The first model was created using days since initial and setting the constant equal to zero, which produced the highest simple regression R-squared values for both absolute and percent differences. CTP was also modeled alone, but was less significant. Because the days since initial model had the best R-squared value as well as being the easiest to use by an agency such as SCDOT, it was selected as the model to be used for comparison to high-build.

4.3.4 Discussion of Possible High-Build White Edge Line Models

Both the difference and percent difference analyses found traffic volume, lane width, and days to be significant for predicting variance in the high-build white edge line model. However, the best R-squared values were achieved from the stepwise regression analysis using CTP only and setting the constant equal to zero. A summary of these results is shown in Table 4.11.

Table 4.11: High-Build White Edge Line Regression Scenarios

Regression Type	Variables Included	Abs. Diff. R-squared	% Diff. R-squared
Single	Cumulative Traffic Passages	0.32	0.35
Multiple	Cumulative Traffic Passages, Lane Width	0.26	0.29
Multiple	Days Since Initial Reading, Volume, Lane Width	0.23	0.26
Single	Days Since Initial Reading	0.06	0.06

4.3.5 Thermoplastic White Edge Lines

Traffic volume was the only variable found significant in both the difference and percent difference from initial value stepwise regression for thermoplastic white edge lines. However, days since initial reading and shoulder width were also found to be significant for the percent difference stepwise regression analysis. Examination of the coefficients associated with these variables revealed that there was a positive correlation between difference in retroreflectivity and days after application for the data. This meant that on average, retroreflectivity values increased over time for the majority of the data. Though this is desirable from a maintenance standpoint it is unrealistic. Upon further inspection of the data, it is clear that many of the thermoplastic white edge line marking retroreflectivity values had a strong tendency to rise significantly in the early rounds before beginning to degrade. To take this rise into account, the model was rerun allowing for a constant. This in turn shifts the y intercept which significantly improved the model.

4.3.6 Summary of Possible Models for White Edge Line Markings

After careful analysis of each marking type, the variables used in the final models were determined. A summary of these results is shown in Table 4.12. The final models created using these variables are discussed in *4.3.8 White Edge Line Final Degradation Models*.

Table 4.12: Summary of White Edge Line Modeled Variables

Material	**Variables Used**	**Notes**
High-Build	Cumulative Traffic Passages (Difference and Percent Difference Models)	For agency application.
	Days Since Initial Reading (Difference and Percent Difference Models)	Can be used if AADT data is greater than 3,500 veh/day or not available to calculate CTP
Waterborne	Days Since Initial Reading (Difference and Percent Difference Models)	For agency application
Thermoplastic	Days Since Initial Reading (Difference and Percent Difference Models)-	For agency application

4.3.7 White Edge Line Final Degradation Models

Once variables were selected, final models were created for high build, waterborne, and thermoplastic white edge line markings. The models created for all three marking types were linear. Note that only the high build and thermoplastic equations' constants were set to zero. The thermoplastic model had a positive constant as discussed in 4.3.6. It should also be noted that though the R-squared values are low for the high-build models vs. days, the p-value for days was 0.0007, thus making it a significant variable. Therefore these models were included as an alternative to the CTP models. The R-squared values are low for these models because the decrease in retroreflectivity over time is very small and models that are near horizontal typically have low R-squared values. Table 4.13 lists the models created and their R-squared values.

Table 4.13: White Edge Line Final Degradation Models

Material	**Variables Used**	**Model**	R^2
High Build	CTP	DIFF = -57.8900 (C)	0.20
		% DIFF = -15.6744 (C)	0.24
	Days Since Initial Reading	DIFF = -0.0436(D)	0.06
		% DIFF = -0.0112(D)	0.06
Waterborne	Days Since Initial Reading	DIFF = -0.1317(D)	0.22
		% DIFF = -0.0532(D)	0.34
Thermoplastic	Days Since Initial Reading	DIFF = 54.142 - 0.0403(D)	0.01
		% DIFF = 13.699 -0.0079(D)	0.01

Identification for model variables:

D – Days since initial reading. Units are in Days.

C – Cumulative Traffic Passages. Units are in Million Vehicles.

The modeled trends for retroreflectivity values for absolute differences are shown in Figures 4.6 and 4.7.

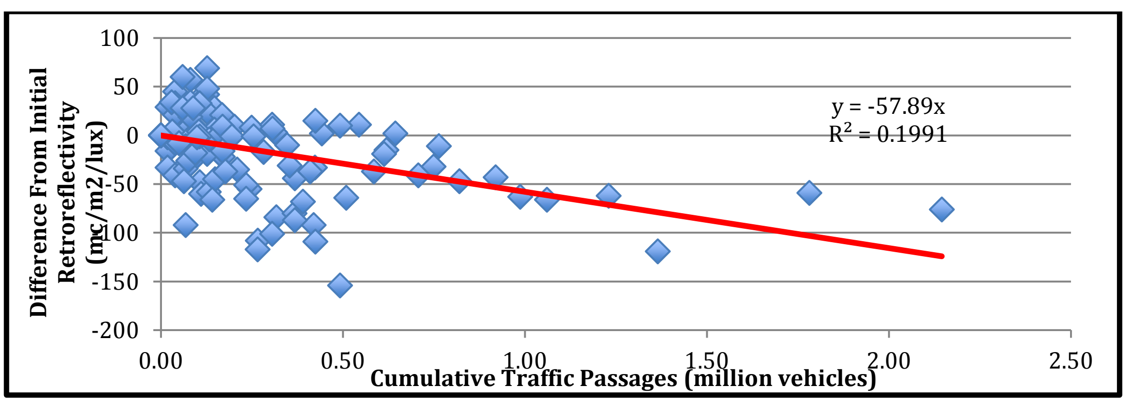
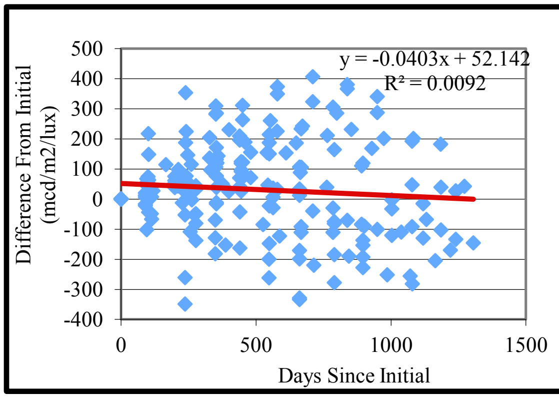


Figure 4.6: High-Build Differences vs. CTP



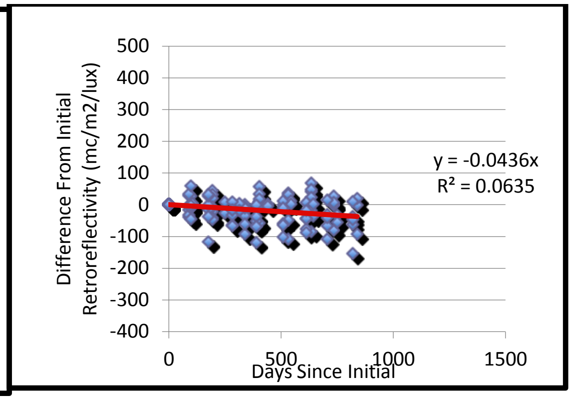


Figure 4.7A: Thermoplastic Differences vs. Days   Figure 4.7B High-Build Differences vs. Days

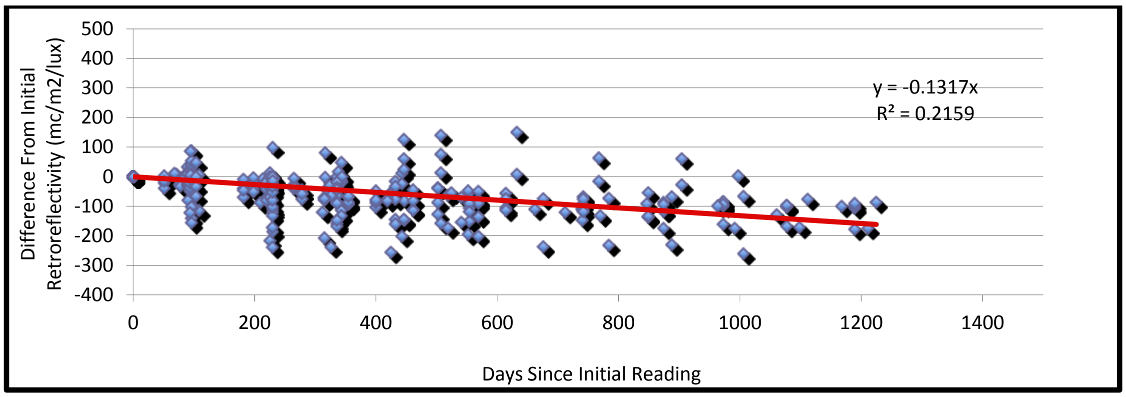


Figure 4.7C: Waterborne Differences vs. Days

Figure 4.7: Descriptive Graphs of Absolute Differences

As shown in Figures 4.8 and 4.9, the percent difference models had higher R-squared values for high-build CTP and waterborne *days since initial* models than the absolute difference models with the same variables shown in Figures 4.6 and 4.7.

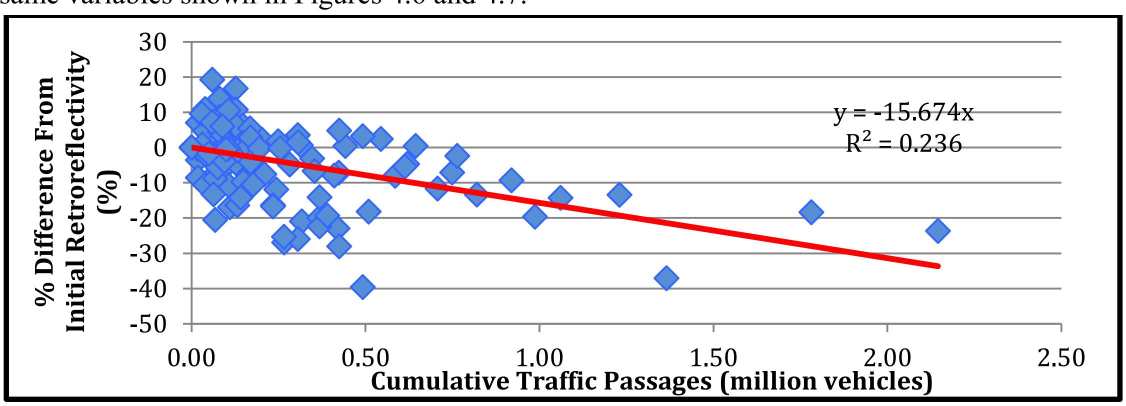
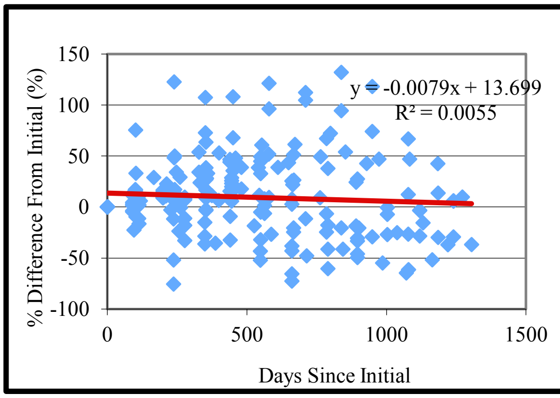


Figure 4.8: High-Build Percent Differences vs. CTP



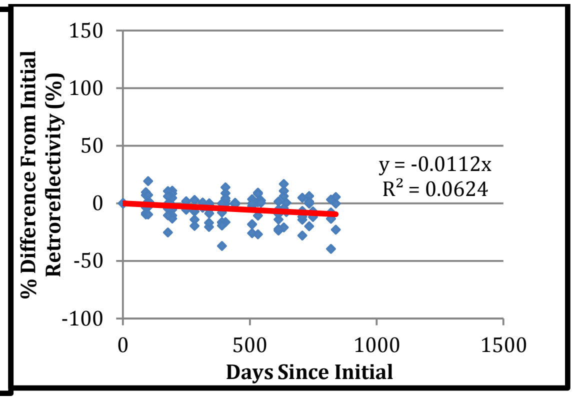


Figure 4.9A: TP WE % Differences vs. Days

Figure 4.9B: HB WE % Differences vs. Days

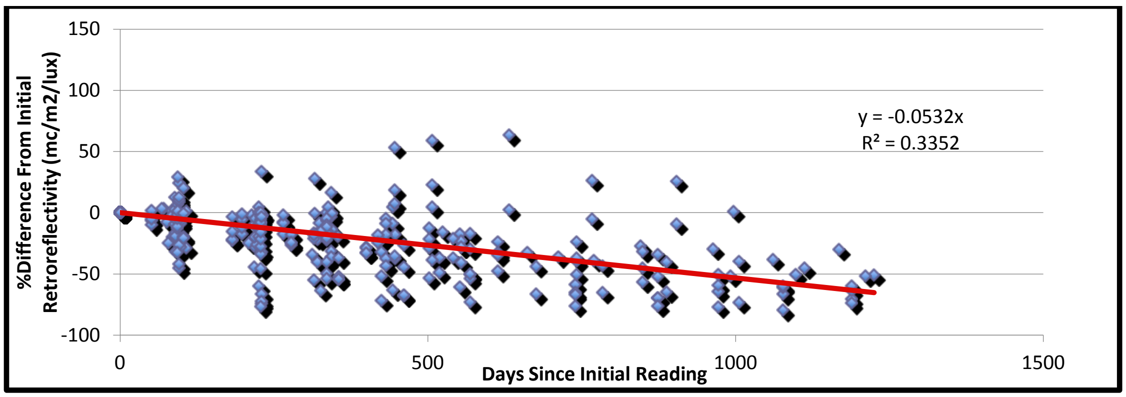


Figure 4.9C: WB WE % Differences vs. Days

Figure 4.9: Descriptive Graphs of Percent Differences for White Edge Markings

4.3.8 White Wetting Study

During the data collection, it was observed that marking wetness greatly affected retroreflectivity. The literature review confirmed this finding. Poor retroreflectivity of wet markings occurs due to a film of water covering the glass beads that causes light to scatter before it can enter the bead. Even minor amounts of water not obvious at first glance had an effect on the data in this research. In one early morning instance, dew on the marking lowered the retroreflectivity significantly. These observations led to added data collection for the effect of water on white pavement markings. The procedures used in this study are outlined in *3.4 Additional Data Collection.* A resulting graph of the study is shown in Figure 4.10.

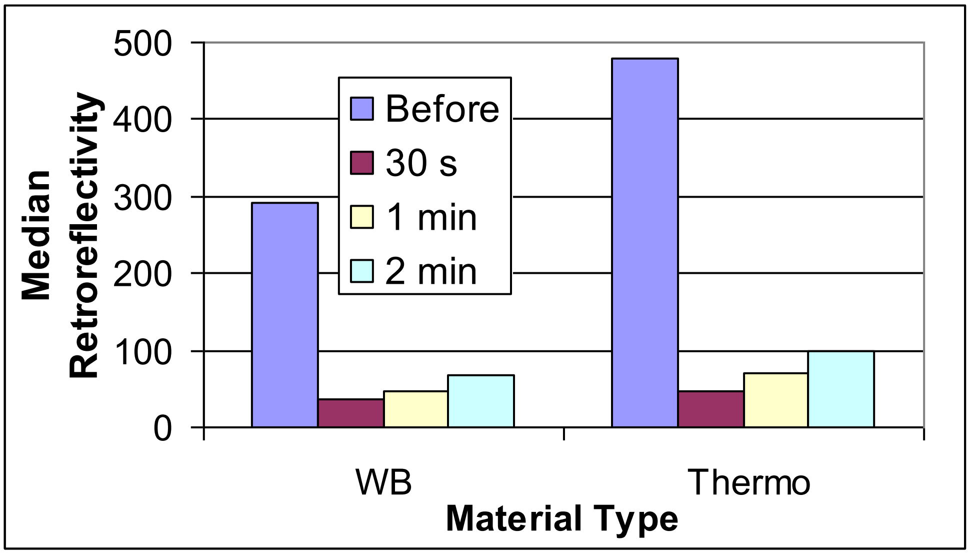


Figure 4.10: White Wetting Study by Material

Figure 4.10 shows the median retroreflectivity observed for waterborne and thermoplastic markings before wetting and 30 seconds, one minute, and two minutes after wetting. This shows the detrimental effect of water on the markings. Several observations were made about the ability of the markings to recover from the initial wetting. One observation pertained to the uniformity of the marking. In some instances, water would puddle on top of the marking, decreasing the recovery of the marking within the two-minute time frame. Another more obvious observation was that sunny weather enabled faster recovery due to the sun drying the water at a faster rate. Because this study was not the focal point of the research, only this minor work was completed.

4.4 Model Application

To use any of these models, the date of application, marking material, and initial retroreflectivity should be known, as well as traffic volume for high-build sites. These equations can then be used to predict present retroreflectivity values or marking life, assuming a minimum threshold for retroreflectivity. As an illustrative example, suppose the marking type is a waterborne white edge and we would like to predict the retroreflectivity reading 400 days from when the marking was placed. If the initial retroreflectivity value is 300 mcd/m^2/lux, the models can be used to determine current retroreflectivity as follows:

$$DIFF = -0.1328\ (D) = -0.1328\ (400) \approx -53$$

Therefore, Retroreflectivity = 300 – 53 = 247 mcd/m^2/lux

$$\%\ DIFF = -0.0551\ (D) = -0.0537\ (400) \approx -21\%$$

Therefore, Retroreflectivity = 300 – (0.21)(300) = 237 mcd/m^2/lux

Now suppose the minimum threshold for retroreflectivity of this marking is set to be 100 mcd/m^2/lux. In this case, the difference is known to be -200 mcd/m^2/lux, and the percent difference is known to be -67 percent. The number of days until the marking reaches the minimum threshold can be determined as follows:

$$DIFF = -200 = -0.1328\ (D)$$

Solving for Days, Marking Life ≈ 1506 days ≈ 4.13 years

$$\%\ DIFF = -67\% = -0.0537\ (D)$$

Solving for Days, Marking Life ≈ 1248 days ≈ 3.42 years

Further discussion of model performance is contained in *5.0 Comparison of Marking Types.*

5.0 COMPARISON OF MARKING TYPES

5.1 Graphs of White Edge Line Markings

Graphs of white edge line high-build, waterborne, and thermoplastic marking retroreflectivity values over time are shown in Figures 5.1-5.3, respectively. Figure 5.1 shows that the initial median retroreflectivity values for high-build markings (N=122) range from 300 to 500 mcd/m^2/lux with relatively small changes in retroreflectivity levels more than 2 years after placement. Figure 5.2 shows that initial retroreflectivity values vary greatly from 100 to 500 mcd/m^2/lux for waterborne markings (N=301) and they appear to degrade much faster than high-build. For thermoplastic white edge line markings (N = 212), initial retroreflectivity varies from 300 to 500 mcd/m^2/lux and degrades slightly faster than high-build markings of the same type.

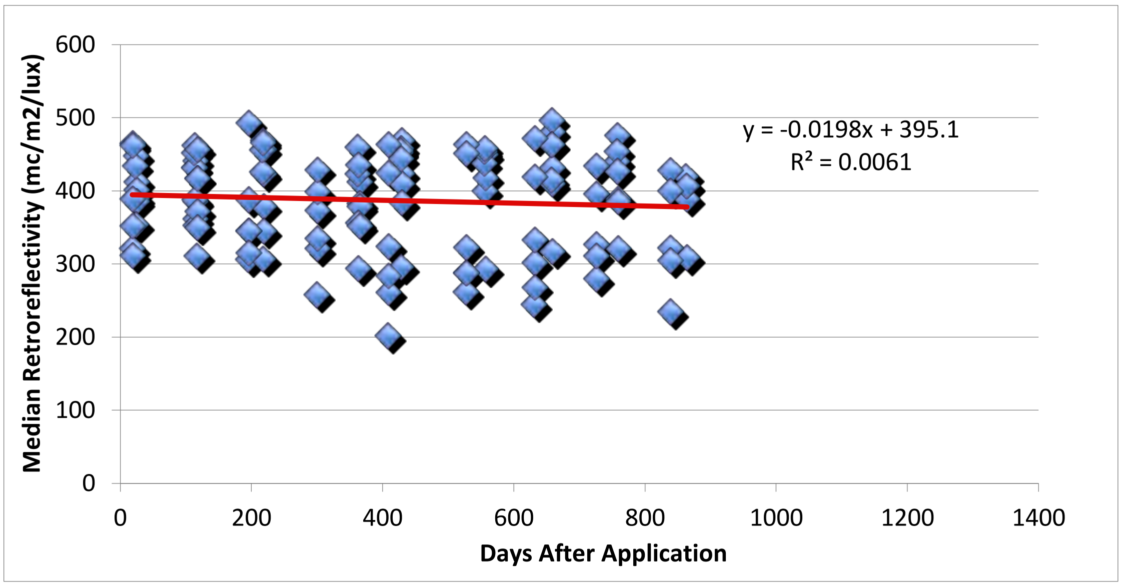


Figure 5.1: High-Build White Edge Line Marking Performance

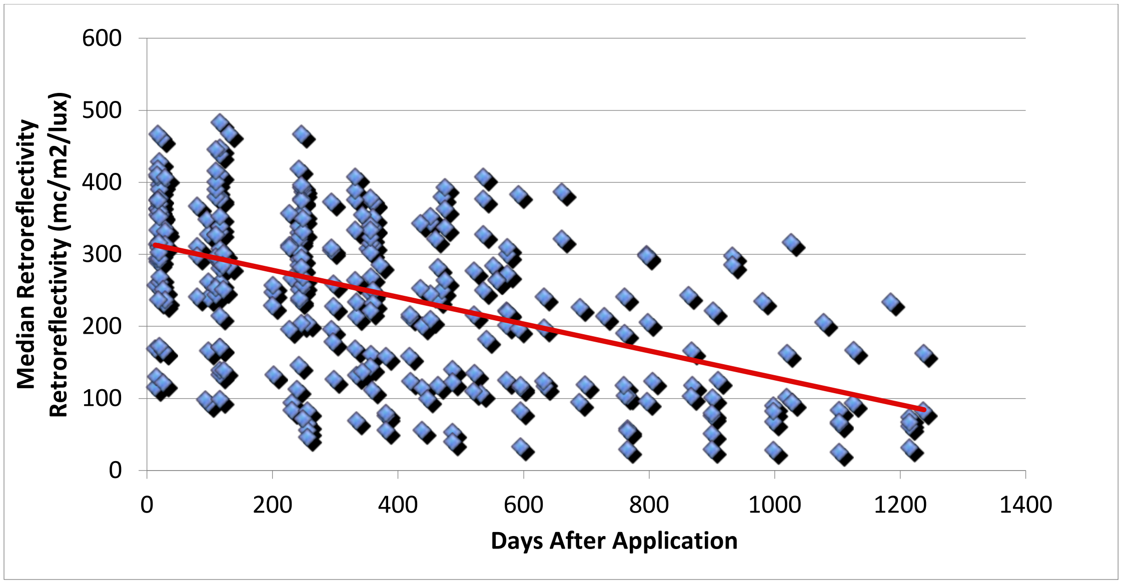


Figure 5.2: Waterborne White Edge Line Marking Performance

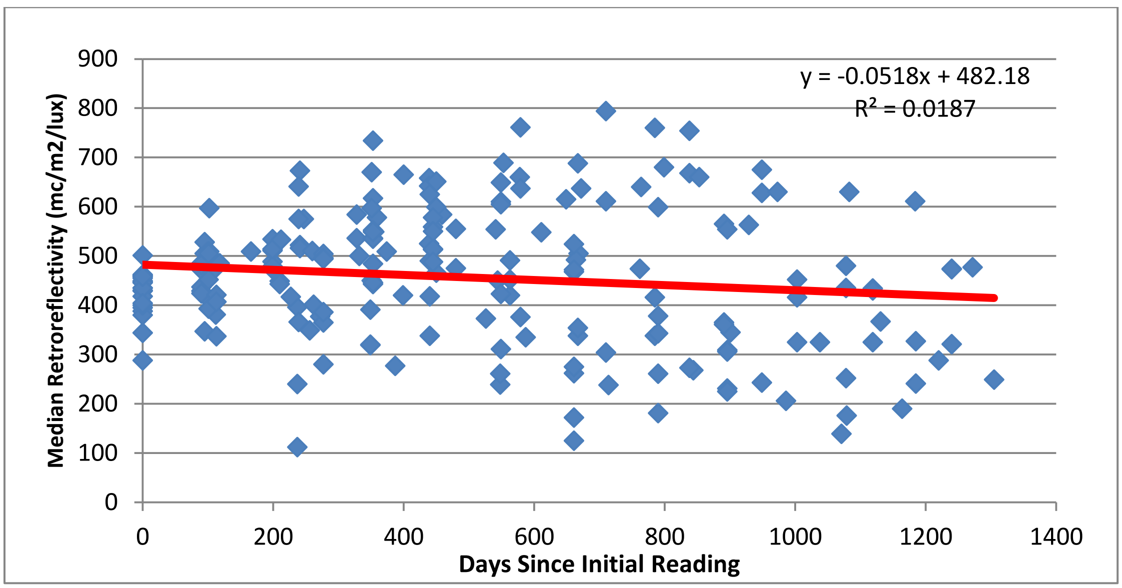


Figure 5.3: Thermoplastic White Edge Line Marking Performance

5.2 Graphs of Yellow Centerline and Skip Markings

Graphs of waterborne and thermoplastic yellow centerline and skip marking retroreflectivity values over time are shown in Figures 5.4-5.7, respectively. Figure 5.4 shows that the initial median retroreflectivity values for waterborne yellow centerline markings (N=456) range from less than 50 to over 200 mcd/m^2/lux with a downward trend for retroreflectivity for more than 2 years after placement. Figure 5.4 shows that initial retroreflectivity values vary greatly from 150 to 350 mcd/m^2/lux for thermoplastic markings (N=207) and they appear to degrade much slower than waterborne. For waterborne yellow skip markings, initial retroreflectivity varies from 100 to 200 mcd/m^2/lux , while thermoplastic yellow skip markings have initial values ranging from 200 to 500 mcd/m^2/lux.

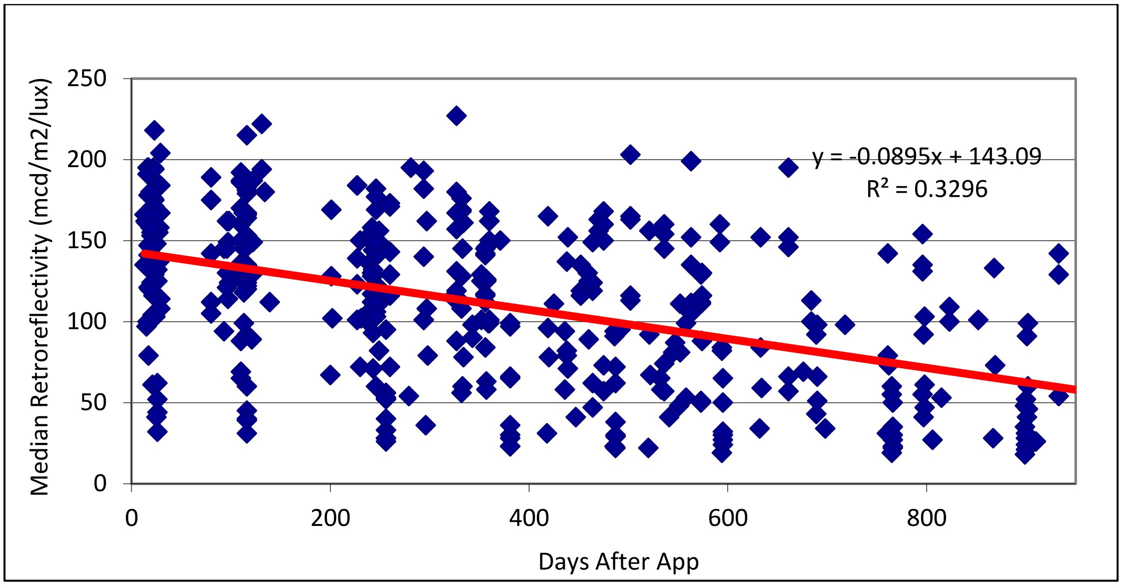


Figure 5.4: Waterborne Yellow Centerline Performance

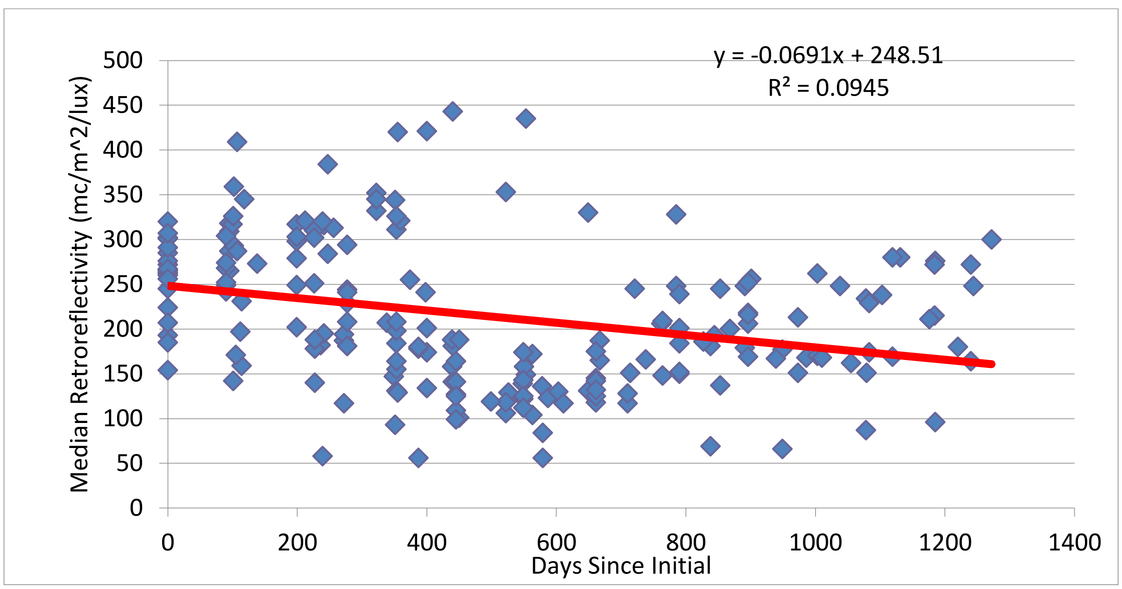


Figure 5.5: Thermoplastic Yellow Centerline Performance

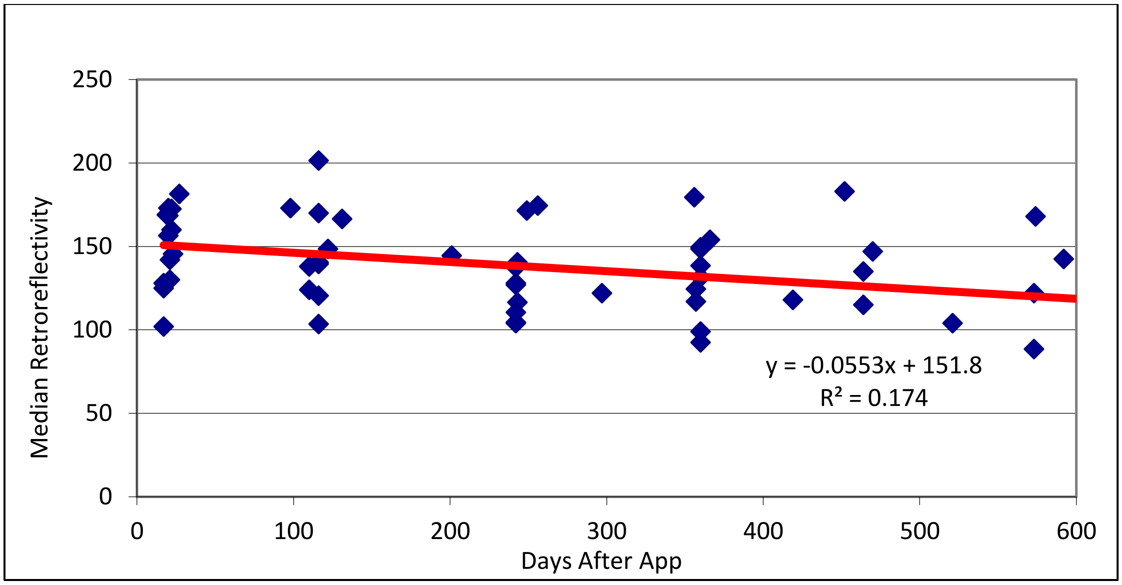


Figure 5.6: Waterborne Yellow Skip Performance

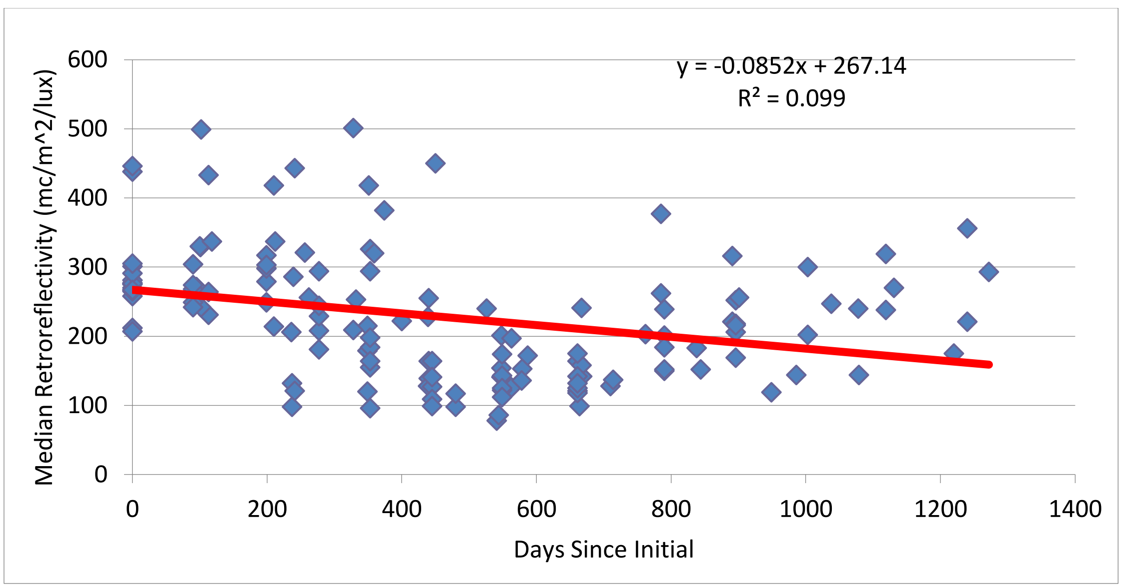


Figure 5.7: Thermoplastic Yellow Skip Performance

5.3 Discussion of Marking Brands

Across the state, various brands of materials are used for pavement markings. As stated in *1.0 Introduction*, one of the objectives of this research was to compare the performance of marking brands included in the study. For the high-build sites, all of the markings were of the same brand, however, there were seven brands of thermoplastic markings, and two brands of waterborne markings. Upon development of the marking performance graphs, it was determined that for waterborne markings, one brand performed better on average than the other. For thermoplastic markings, it was difficult to compare brand performance due to the large variety of brands and the variability of the degradation data. Further, many of the thermoplastic brands were only used at just a few sites thus their performance may not be representative. A comparison of these brands is shown in Table 5.1 for all marking types and configurations. Note that some of the brands were only used on just a few sites

Table 5.1: Pavement Marking Performance By Brand

Marking Material	Brand	Initial # of Sites	Avg. Initial R_L	Avg. Annual Degradation (mcd/m^2/lux)
White Edge HB	Brand A	21	404	-23
White Edge WB	Brand A	40	335	-56
	Brand B	11	244	-48
	Overall	**51**	**307**	**-48**
White Edge T	Brand A	10	452	-35
	Brand C	4	403	84
	Brand D	5	383	22
	Brand E	3	450	3
	Brand F	1	395	4
	Overall	**23**	**426**	**11**
Yellow Solid WB	Brand A	50	151	-29
	Brand B	17	112	-23
	Overall	**67**	**141**	**-27**
Yellow Solid T	Brand A	13	271	-52
	Brand D	4	231	-21
	Brand E	3	267	-23
	Brand F	3	154	19
	Brand G	1	302	-26
	Overall	**24**	**260**	**-28**
Yellow Skip WB	Brand A	10	146	-11
	Brand B	3	164	-39
	Overall	**13**	**150**	**-22**
Yellow Skip T	Brand A	8	279	-63
	Brand C	3	327	-89
	Brand D	3	241	-11
	Brand E	2	352	-41
	Overall	**16**	**290**	**-41**

To give a visual example of comparisons between marking brands, graphs of high-build, waterborne, and thermoplastic white edge line marking performances by brand are shown in Figures 5.8-5.10, respectively. For waterborne and high-build markings, Brand A is shown with solid lines and Brand B is shown with dashed lines. The graph of thermoplastic white edge brand performance is shown in Figure 5.10.

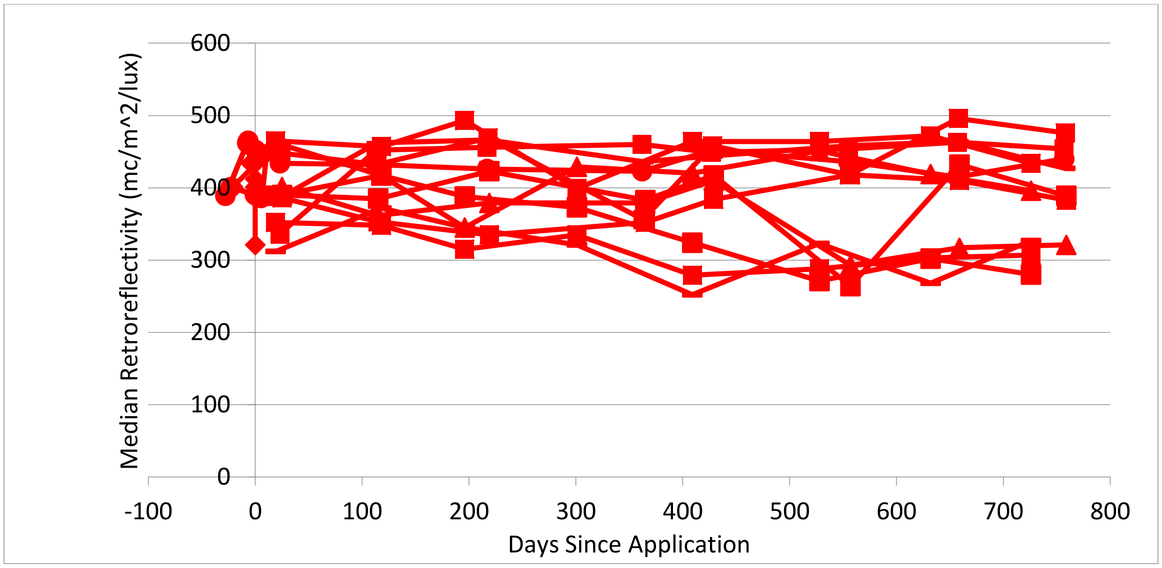


Figure 5.8: High-Build Marking Performance

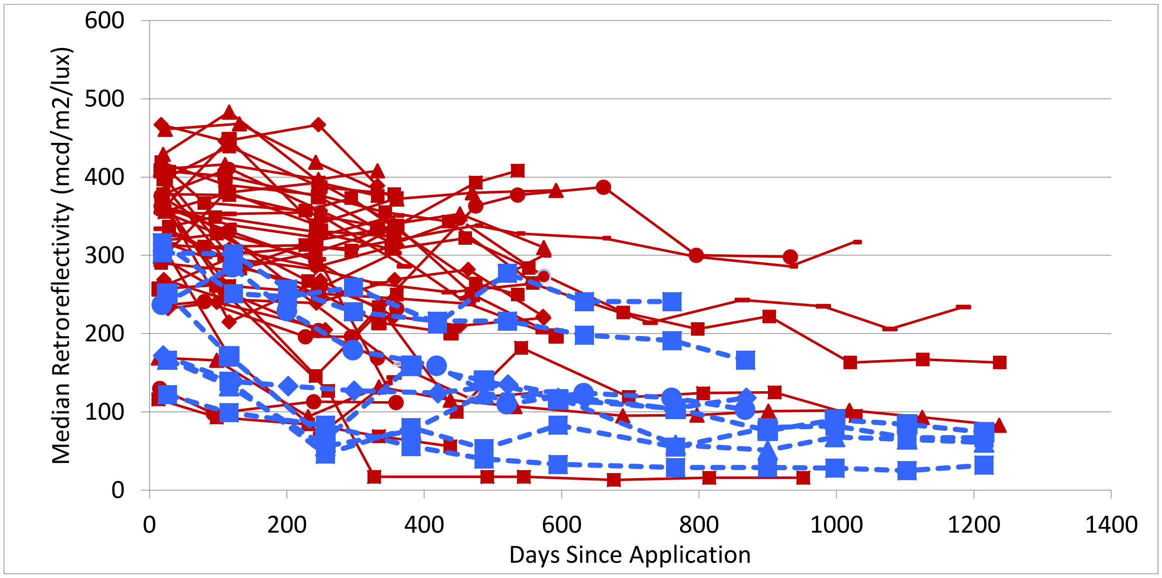


Figure 5.9: Waterborne White Edge Marking Performance By Brand

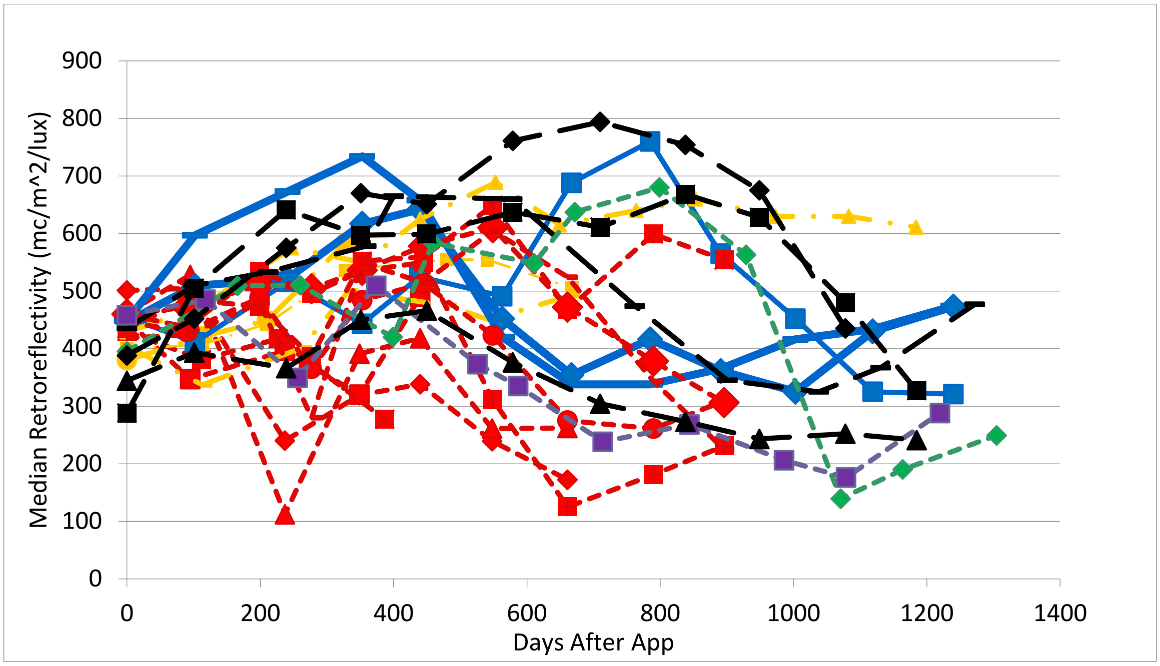


Figure 5.10: Thermoplastic White Edge Line Performance By Brand

As shown in Table 5.1 and Figures 5.8-5.10, the performances of various marking brands are significantly different. For waterborne markings, Brand B has an average initial retroreflectivity value of 244 mcd/m^2/lux. This is much lower than the average initial value for Brand A, which is 335 mcd/m^2/lux. While Brand B does have a lower annual degradation rate than Brand A, because its initial retroreflectivity value is much lower, Brand B would most likely have a much shorter lifespan than Brand A for waterborne white edge markings. It should also be noted that of the 5 waterborne white edge sites mentioned earlier in the chapter with R_L values less than 100, 4 of those sites were Brand B markings. As stated earlier, a ranking of brand performance was not developed for thermoplastic markings, but the statistics for each brand are shown in Table 5.1.

From this research, it is apparent that there are performance differences amongst various pavement marking brands. Knowledge of brand performance could prove useful for agencies such as SCDOT when selecting pavement marking brands to meet their specific needs.

5.4 Retroreflectivity Degradation Model Performance

Testing using field collected values of retroreflectivity is necessary to determine the anticipated performance of each model. Data from sites were compared to model predicted values using initial recorded retroreflective values and number of days since application for waterborne and thermoplastic markings and CTP for high-build markings. The magnitudes of the residuals are pretty consistent as time progresses, which is a desirable characteristic from a modeling standpoint.

Performance of the models is shown in Table 5.2 through indication of the percentage of measured values that would fall within identified error ranges. The upper far right column shows the percentage of sites with less than ± 20 percent error, which is equal to the sum of the first two error columns. Generally speaking, degradation models developed from this research predict retroreflectivity values within a 20 percent error for approximately 65 percent of the measured pavement marking values for waterborne white edge lines, 90 percent for high-build white edge line markings, 71 percent for waterborne yellow solid, and so on. It should be noted that the low performance percentages for thermoplastic yellow models are most likely attributed to the variability over time of thermoplastic markings.

Model error can result from either under-predicting or over-predicting actual measured values of retroreflectivity. Under-predicted values could lead to premature pavement marking replacement, but is not a safety issue. However, over-predicted values are a safety issue in that pavement markings could exhibit low levels of retroreflectivity before the model identifies the need for replacement using threshold minimums. Taking these factors into consideration, the lower portion of Table 5.2 provides a tabulation of the percentage of sites that were classified as over-predicted in various error ranges as determined from the models created for pavement markings evaluated in this research.

Note that the columns labeled "<10% Over" and "<20% Over" include all under predicted values. Upon further examination, difference models were more accurate predictors of retroreflectivity, and in both cases difference models produced a higher percentage of sites predicted at less than 20 percent over actual retroreflectivity values. This observation serves to support the assumption that all similar type pavement markings deteriorate at the same rate, regardless of the initial retroreflectivity value. Based on this analytical insight, difference models are recommended as the most suitable means for predicting retroreflectivity degradation of pavement markings.

As indicated in Table 5.2, there is a likelihood that the degradation models will over-predict actual retroreflectivity in some cases. To account for this concern, a margin of safety should be considered to decrease the chance of this occurring, particularly as pavement markings begin to reach minimum threshold values of retroreflectivity. It should be noted that the performance statistics in Table 5.2 are for high-build models vs. CTP, while all other marking configurations are vs. days.

Table 5.2: Overall Model Performance and Over-Prediction of Retroreflectivity

Model Performance--proportion of predicted values with specified error margin						
Material	Sample Size	Model	<±10% Error	±10-20% Error	>±20% Error	<±20% Error
White Edge HB	N=122	DIFF	72%	20%	7%	93%
		% DIFF	69%	21%	10%	90%
White Edge WB	N=303	DIFF	49%	16%	35%	65%
		% DIFF	49%	16%	35%	65%
White Edge T	N=212	DIFF	26%	27%	47%	53%
		% DIFF	32%	16%	52%	48%
Yellow Solid WB	N = 456	DIFF	48%	23%	29%	71%
		% DIFF	47%	20%	32%	68%
Yellow Skip WB	N = 59	DIFF	56%	32%	12%	88%
		% DIFF	53%	32%	15%	85%
Yellow Solid T	N = 207	DIFF	30%	19%	50%	50%
		% DIFF	26%	14%	60%	40%
Yellow Skip T	N = 144	DIFF	38%	19%	43%	57%
		% DIFF	31%	10%	59%	41%
Model Performance--proportion of values over predicted specified margin.						
Material	Sample Size	Model	<10% Over	10-20% Over	>20% Over	<20% Over
White Edge HB	N=122	DIFF	66%	11%	7%	93%
		% DIFF	63%	16%	10%	90%
White Edge WB	N=303	DIFF	69%	10%	21%	79%
		% DIFF	71%	13%	40%	60%
White Edge T	N=212	DIFF	90%	15%	24%	76%
		% DIFF	84%	2%	22%	78%
Yellow Solid WB	N = 456	DIFF	69%	13%	14%	86%
		% DIFF	70%	13%	21%	79%
Yellow Skip WB	N = 59	DIFF	56%	14%	3%	97%
		% DIFF	63%	14%	14%	86%
Yellow Solid T	N = 207	DIFF	78%	7%	28%	72%
		% DIFF	84%	6%	45%	55%
Yellow Skip T	N = 144	DIFF	77%	10%	24%	76%
		% DIFF	78%	4%	49%	51%

5.5 Estimate of Marking Service Lives

The principal goal of this research was to develop degradation models of pavement markings in order to compare and predict marking life for high-build, waterborne, and thermoplastic markings. In this section, the service lives of pavement markings are estimated from a retroreflectivity standpoint using the models developed in the research. Because of high variability in initial retroreflectivity and the lack of set standards for minimum allowable retroreflectivity, predicting an all-encompassing marking life was not possible. However, it was possible to obtain an estimate of pavement marking life based on certain assumptions. For comparative purposes, the average initial values of all sites determined for each marking type and configuration were used. Based on literature, a minimum threshold of 100 mcd/m^2/lux was used as the lowest acceptable retroreflectivity value. Estimates of marking life for high-build, waterborne, and thermoplastic markings were calculated using the difference and percent difference models. Once again, these models should be used with caution if used for periods greater than those specified in this report. The results are shown in Table 5.3.

Table 5.3: Prediction of Marking Life

Material	**Model**	**R-Squared**	**Average Initial Value**	**Estimated Marking Lives**	
White Edge HB	DIFF = -57.8900 (C)	0.32	390	5.01 CTP	
	% DIFF = -15.6744 (C)	0.35		4.74 CTP	
White Edge WB	DIFF = -0.1317(D)	0.22	315	1632 Days	4.47 Years
	% DIFF = -0.0537(D)	0.34		1271 Days	3.48 Years
White Edge T	DIFF = 54.142 – 0.0403 (D)	0.01	426	6745 Days	18 Years
	% DIFF = 13.699 – 0.0079 (D)	0.01		9279 Days	25 Years
Yellow Solid WB	DIFF = -0.0721 (D)	0.37	141	569 Days	1.56 Years
	% DIFF = -0.0569 (D)	0.47		511 Days	1.40 Years
Yellow Skip WB	DIFF = -0.0594 (D)	0.34	150	879 Days	2.41 Years
	% DIFF = -0.0366 (D)	0.33		911 Days	2.50 Years
Yellow Solid T	DIFF = -0.0764 (D)	0.05	260	2094 Days	5.74 Years
	% DIFF = -0.0270 (D)	0.04		2279 Days	6.24 Years
Yellow Skip T	DIFF = -0.1123(D)	0.09	290	1691 Days	4.64 Years
	% DIFF = -0.0364(D)	0.06		1800 Days	4.93 Years

For comparative purposes, the waterborne white edge difference model using days only was compared to the high-build white edge difference model using days, which is shown in Figure 4.5B. The results show that when only marking age is considered, high-build white edge markings last considerably longer than waterborne markings of the same type and have a much lower annual degradation rate. The results are shown in Table 5.4. While it is unrealistic to believe that high-build markings can last 20 years and thermoplastic markings 26 years, the data shows that there is very little drop in retroreflectivity even after 3 years of data collection.

Table 5.4: Waterborne and High-Build White Edge Lifecycle Estimates Using Marking Age

Marking Type	Avg. Initial Value	Time (Years) 1	2	3	4	5	20	26	Annual Degradation (mcd/m2/lux)	Initial Cost ($/LF)	Cost ($/LF/year)
WB	**315**	259	211	163	115	67			-48	0.09	0.018
HB	**390**	388	372	356	340	324	86		-16	0.18	0.009
TP	**426**	465	451	436	421	407		97	-14	0.30	0.011

Because retroreflectivity for white edge waterborne markings is dependent on marking age only and CTP only for high-build white edge markings using the final models, a sensitivity analysis was conducted using the models to compare the lifespans of the two marking types while varying time and volume. It was determined that the average 2-way AADT for the waterborne sites in this analysis was around 2000 veh/day, so AADTs up to 2000 were used for the high-build calculations. The analysis was conducted using the average initial values. Retroreflectivity values were then calculated at one year increments until they were less than or equal to the proposed minimum threshold value of 100 mc/m^2/lux. Once the estimated service lives were determined, the installation costs per linear foot were divided by the number of years in the service life to calculate normalized costs for comparative purposes. The results are shown in Table 5.5.

Table 5.5: Model Predicted White Edge Marking Lifespans

Marking Type	Avg. Initial Value		Time (Years) 1	2	3	4	5	6	7	8	15	26	Est. Cost ($/LF)	Cost ($/LF/yr.)
WB	307		259	210	162	113	65						0.09	0.018
TP	426		451	436	421	407	407					97	0.30	.011
		AADT												
HB	404	1000	383	362	341	319	298	277	256	235	87		0.18	0.012
		2000	362	319	277	235	193	150	108	66			0.18	0.023

As shown in Table 5.5, high-build white edge markings are predicted to outlast waterborne markings of the same type and are also more cost-effective for lower rural AADT volumes. For high-build markings with an AADT of 1000 veh/day, the model predicts that the marking could last up to 15 years. While not replacing a high-build pavement marking for 15 years may be non-realistic, it shows the potential performance of high-build as compared to waterborne markings when only retroreflectivity is considered. Because the waterborne and high-build models created were based on 37 and 28 months of data collection, respectively, it is recommended that these models be used with caution for time periods greater than these specified periods after marking placement. It should also be noted that the volumes at all of the high-build sites range between 200 and 3,500 veh/day, which is similar to the range of waterborne sites, which had an average AADT of 2000 veh/day. Because traffic volume has such a significant impact on the degradation of high-build markings, it would be beneficial to conduct this analysis on high-build markings with higher volumes and compare the results. Also, because the predicted lifespans are greater than the research periods, additional data collection would be necessary to verify these models for the remainder of pavement marking life.

Similarly, estimated lifespans and lifecycle costs were calculated for yellow pavement markings. The results are shown in Table 5.6

Table 5.6: Model Predicted Yellow Marking Lifespans

		Time (Years)								
Marking Type	**Avg. Initial Value**	**1**	**2**	**3**	**4**	**5**	**6**		**Initial Cost ($/LF)**	**Cost ($/LF/year)**
WB Y Solid	141	115	88						0.09	0.045
T Y Solid	260	232	204	176	148	121	93		0.30	0.050
WB Y Skip	150	128	107	85					0.09	0.030
T Y Skip	290	249	208	167	126	85			0.30	0.060

The results shown in Table 5.6 were calculated the same way as for the white markings shown in Table 5.5. The table shows that the estimated lifespans for yellow markings are considerably lower than those of white markings. For yellow pavement markings, waterborne materials were calculated to be more cost effective per linear foot per year for both yellow centerlines and skip markings. However, in both cases, thermoplastic markings were calculated to have longer estimated lifespans.

6.0 RECOMMENDED GUIDELINES FOR SELECTION AND APPLICATION OF PAVEMENT MARKINGS

6.1 Overview

An objective of this research project was to develop recommended pavement marking guidelines based on findings and results from the research. This chapter identifies recommended pavement marking guidelines that should be considered by SCDOT to optimize benefits of pavement markings in the most cost efficient manner possible. Recommended guidelines are based on evaluation of field-collected data as well an extensive literature review of best practices from other states. Recommendations are intended to assist engineers and designers in selection of the most appropriate pavement marking material to apply for given roadway conditions and to identify possible improved specifications for pavement marking contractors. It is important to note that adoption and use of these recommended guidelines will not replace the need for engineering judgment in selecting and applying optimal pavement marking materials.

6.2 Selection of Pavement Marking Material

This section provides guidance for selection of waterborne, high build, or thermoplastic pavement markings for a variety of roadway conditions. A variety of factors should be considered when choosing and specifying pavement marking materials. Ideally all marking materials should be selected to ensure desired performance requirements are met at the lowest possible cost. Primary factors for consideration in selecting optimal pavement marking materials include traffic volumes, roadway functional class, roadway surface type, expected remaining service life of pavement, and whether marking materials will be provided by in-house crews or by external pavement marking contractors. Table 6.2 provides estimated marking life spans.

After estimating life spans based on marking age and traffic volumes, conclusions were used to identify which marking materials to be used for various conditions. These recommendations are shown in Table 6.1 for white edge markings. The average life span for yellow markings would be roughly half of the white edge markings but this is greatly dependent on the initial retroreflectivity of the markings. Yellow markings tend to have much lower initial values and higher degradation rates than white markings. The use of raised pavement markings in conjunction with yellow markings will allow longer life spans. Note that the data collection did not include any high-build yellow markings.

Table 6.1: Criteria for Selection of White Edge Pavement Markings

Traffic Volume (veh/day)	Recommended Marking	Avg. Estimated Lifespan (Years)	Cost/LF/year ($)
< 1000	Waterborne	3.5 - 4.5	0.026 - 0.020
500 – 2000 +	High-Build	5 +	< 0.036
> 2000	Thermoplastic	5 +	< 0.060

Table 6.2: Estimated Life Spans and Costs for Pavement Markings

Marking Type		Avg. Initial Value	Time (Years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	26	Annual Degradation (mcd/m2/lux)	Initial Cost ($/LF)	Cost ($/LF/year)
WB Y Solid		**141**	115	88															-26	0.09	0.045
T Y Solid		**260**	232	204	176	148	121	93											-28	0.30	0.050
WB Y Skip		**150**	128	107	85														-22	0.09	0.030
T Y Skip		**290**	249	208	167	126	85												-41	0.30	0.060
WB WE		**315**	259	211	163	115	67												-48	0.09	0.018
T WE		426	465	451	436	421	407											97	-14	0.30	0.011
	ADT																				
	1000		383	362	341	319	298	277	256	235	214	193	172	150	129	108	87		-21		0.012
	1100		381	358	334	311	288	265	241	218	195	172	148	125	102	79			-23		0.013
	1200		379	353	328	303	277	252	227	201	176	150	125	100	74				-25		0.014
	1300		377	349	322	294	267	239	212	184	157	129	102	74					-27		0.015
	1400		374	345	315	286	256	227	197	167	138	108	79						-30		0.016
HB WE	**1500**	**390**	372	341	309	277	246	214	182	150	119	87							-32	0.18	0.018
	1600		370	336	303	269	235	201	167	134	100	66							-34		0.018
	1700		368	332	296	260	224	188	153	117	81								-36		0.020
	1800		366	328	290	252	214	176	138	100	62								-38		0.020
	1900		364	324	284	243	203	163	123	83									-40		0.023
	2000		362	319	277	235	193	150	108	66									-42		0.023

As shown in Table 6.1, waterborne markings are recommended for low volume roads. Higher volume roads would degrade the markings even faster, shortening their life spans. High-build markings have proven to be cost effective for roads with volumes from 500 to 2,000 vehicles per day due to their durability and performance. However, as traffic volumes increase, high-build marking life spans begin to drop rapidly. For primary and secondary roads with volumes greater than 2,000 vehicles per day, thermoplastic markings are recommended due to their increased durability and performance. Many thermoplastic sites included in the study were actually shown to increase in retroreflectivity over time. However, in no case should high performance markings be placed if the pavement is scheduled to be resurfaced within one year for high volume roads with ADT greater than 10,000 or two years for other roads.

6.3 Surface Preparation

Effective application of any pavement marking material absolutely relies on a clean and dry pavement surface prior to marking placement to accomplish proper bonding, desired pavement marking performance, and acceptable service life. Performance of thermoplastic pavement markings is particularly dependent on proper pavement surface preparation. Waterborne and high build markings are less sensitive to changes in temperature, moisture, and other environmental characteristics than thermoplastic materials, however surface preparation remains essential to pavement marking performance. To achieve proper bonding, the following conditions must exist for waterborne, high build, and thermoplastic markings:

- The pavement surface must be free of dirt, dust, and other contaminants. (Accomplishing this pre-application condition may require brooming.)
- The pavement surface must be free of poorly adhered existing markings, and loose glass beads. (Removal methods for existing markings include, flailing, waterblasting and sandblasting)
- Existing tape markings should be removed prior to placement of new water borne, high build, or thermoplastic markings.
- Loose aggregate should be removed if markings are placed on roadway surface treatments.
- The pavement surface must be free of moisture.

Optimal performance of pavement markings is influenced by the condition of the underlying pavement surface and underlying existing pavement markings, if present. Retroreflectivity values and service life are commonly lower on rough pavements because glass beads can become lodged between the aggregates or fall into surface voids. In addition, when pavement markings are reapplied along roadways with existing markings, assuming proper adherence, it is beneficial to align new marking materials directly with existing markings, as the presence of existing markings functions as a primer base and improves retroreflectivity

6.4 Environmental Considerations

Pavement and air temperatures at the time of installation are important considerations to maximize marking performance. Sprayed on thermoplastic relies on thermal bonding to asphalt pavements to ensure good adhesion. Thermal bonding is adversely affected if pavements are too cold. Pavement temperature influences the curing rate of waterborne markings. Thus thermoplastic, waterborne and high build markings should only be installed if pavement temperature is greater than the minimum specified by the material manufacturer. This is typically 50 degrees for thermoplastic and 40 degrees for waterborne and high build. Other important environmental factors include humidity, wind velocity and surface moisture at time of application. Humidity is important to pavement marking drying and curing times. Wind velocity is important to drop-on glass bead dispersion. Pavement surface moisture can adversely affect bonding capabilities of the marking material.

6.5 Glass Beads

Glass beads used for pavement marking applications in South Carolina are typically produced from recycled glass because of their attractive cost when compared to virgin beads. Properties of glass beads that effect retroreflectivity include clarity, shape, and refractive index. The higher the refractive index of a glass bead, the more light is retroreflected. Recycled glass beads have a lower refractive index than virgin glass beads. The literature review indicated that some agencies use a mixture of recycled and virgin beads. SCDOT might consider conducting some field tests using virgin beads. Round beads have the best retroreflective characteristics.

As described earlier, various marking types use different bead sizes and densities. According to SCDOT specifications [South Carolina Department of Transportation, 2007], bead types range in size from smallest to largest as Type I to Type IV, respectively. High-build marking specifications [South Carolina Department of Transportation, 2008] require an initial application of the larger Type III or IV beads, followed by an application of Type I beads, while waterborne specifications require Type I beads only. As a result, high-build markings tend to have higher initial retroreflectivity values than those of waterborne markings, primarily due to these larger beads. Similarly, because thermoplastic markings have high bead densities, they tend to have higher retroreflectivity values. However, retroreflectivity degrades over time as beads become dislodged from the marking or are worn down. This degradation can be due to weather, traffic, snowplowing, and other adverse conditions for the roadway.

Field-collected data from this research project indicate that wet markings have very low retroreflective properties. The literature review confirmed this finding. Poor retroreflectivity of wet markings occurs due to a film of water covering the glass beads that causes light to scatter before it can enter the bead. The literature indicated that larger beads are generally more effective when roads are slightly wet because there size allows them to disperse water quicker.

6.6 Performance-Based Contracts

Field-collected data from sites included in this research project indicates that pavement marking retroreflectivity values varied considerably from site to site when measured approximately 15 to 30 days after initial placement. This large range of variability was particularly evident for waterborne markings. The high variability in initial readings for pavement markings indicates that increased quality control measures are needed to provide more consistently applied marking material. A recommended guideline of this research is that SCDOT consider implementation of performance-based pavement markings contracts. Performance-based retroreflectivity pavement marking contracts have been used successfully by other states in recent years to establish final acceptance standards. Such contracts are proving effective through specification of an objective means for inspection of pavement marking installation prior to final acceptance.

Requiring minimum values for pavement marking retroreflectivity compliance will help to ensure acceptable levels of quality control are met by contractors as well as manufacturers. In addition, retroreflectivity measurement provides a numeric measure of how efficiently a marking returns light to the driver’s eyes, thereby reducing the subjectivity that exists when relying on visual inspections. Measures of performance for pavement markings commonly focus on retroreflectivity, durability, and color. Performance measures can result in maintaining a brighter line through the warranty period leading to higher driver ratings of visibility or contribute to a longer life of the warranted marking (NCHRP Synthesis 408, 2010).

6.6.1 Minimum Retroreflectivity Readings

Recommended minimum retroreflectivity readings included in this section are based on empirical data collected during the research and information from the literature search, shown in Table 6.3. Recommended minimum readings for various pavement types were estimated based on average values observed in the field and are summarized in Table 6.4

Table 6.3: Recommended Minimum Initial Retroreflectivity Values

Material	Recommended Minimum Initial Value
White Edge HB	390
White Edge WB	315
White Edge T	430
Yellow Solid WB	140
Yellow Solid T	260
Yellow Skip WB	150
Yellow Skip T	290

Table 6.4: Summary of Retroreflectivity Values for Research Sites

Pavement Type	Marking	Initial Number of Sites	Avg.	Max	Min	Sites Remaining
Existing HMA	White HB	17	405	448	321	7
	White WB	46	315	467	116	7
	White T	16	444	501	400	9
	Yellow S WB	55	136	218	32	16
	Yellow S T	14	266	302	193	10
	Yellow Sk WB	13	150	182	102	1
	Yellow Sk T	12	290	446	258	7
	Total	**173**			**Total**	**57**
New HMA	White HB	4	370	462	312	3
	White TP	7	384	458	288	4
	Yellow S T	8	248	320	154	5
	Yellow Sk T	4	291	438	207	2
	Total	**23**			**Total**	**14**
Chip Seal	White WB	5	318	407	237	2
	Yellow S WB	12	164	204	108	1
	Total	**17**			**Total**	**3**
Overall Total		**213**		**Overall Total**		**74**

Initial retroreflectivity data for performance compliance and database tracking should be collected 15 to 30 days after placement of the pavement markings as follows:

- Readings should be collected in the same direction of travel at minimum intervals of one-mile along the entire length of the newly marked section of roadway. All of the readings along a particular pavement marking line should fall within 20% Additional readings should be collected in the vicinity of any anomalous readings and should include a minimum of three supplemental measurements within that mile segment for which an anomalous reading was detected. Spacing between supplemental readings should be at intervals of at least 1,000 feet.
- After an initial retroreflectivity reading is taken, the marking should be swept and another reading should be collected in the same location. A swept reading should be comparable to an unswept reading. This stipulation would serve to ensure that glass beads have adhered to the paint and are not easily dislodged.

- For yellow centerline markings, readings should be taken in both directions. These readings should not vary more than 20% by direction for waterborne markings and 10% for thermoplastic markings by direction.
- In determining appropriate minimum retroreflectivity values to specify in contract documents it should be noted that minimum values for thermoplastic edge line, lane line, and centerline markings from Texas DOT Special Specification 8975 are as follows:
    - White markings: 250 millicandelas per square meter per lux (mcd/m2lx)
    - Yellow markings: 175 mcd/m^2/lx

6.6.2 Basis for Specification Compliance

Upon collection of the initial retroreflectivity data obtained 15 to 30 days after placement of the pavement markings, compliance with the specification should be based on the following:

- The retroreflectivity average for a specified pavement marking section is greater than the specified minimum value.
- The percentage of measurements that are less than the specified minimum retroreflectivity value for a given pavement marking section is less than the specified minimum percentage.

Contractor penalties could be identified in the project bid documents specifying minimum values to be achieved and stipulating cost reimbursement amounts or corrective actions. Contract Agreement provisions could include a reduced basis of payment per linear foot for reimbursement of pavement marking lines applied. In very problematic cases, based on two of three supplemental readings along an identified mile long segment falling below minimum retroreflectivity requirements, contract provisions could deem the marking unacceptable and necessitating remarking at the contractor's expense.

6.7 Warranties for Pavement Marking Contracts

The practice of specifying pavement marking warranties should be considered for all external pavement marking contract projects. Warranty specifications (NCHRP Synthesis 408, 2010) for pavement marking projects typically include:

- Duration of the warranty period
- Contract bonding requirements
- Maintenance responsibilities
- Method of conflict resolution
- Contractor Responsibilities
- Agency responsibilities

- Performance indicators
- Requirements for corrective action
- Method of measurement
- Method of payment

The performance of a marking is not ensured even with careful inspections. For example, if glass beads do not adhere properly, the markings may reflect high initial retroreflectivity values that drop considerably after their exposure to traffic. Thus, periodic inspections should be made during the warranty period to ensure compliance. If roadway sections fall out of compliance, the contractor should be required to remark deficient sections. Frequency of periodic retroreflectivity performance inspections for warranties varies widely from agency to agency, however, some commonly used methods include:

- District offices have retroflectometers and use in-house personnel to test markings annually and compare to contract specified warranty values.
- District offices have retroflectometers and test markings on a random schedule and compare to contract specified warranty values.
- Inspections are performed at least once during the warranty period.
- Inspections are conducted as needed, based upon routine visual assessments, noticeable concerns or complaints by agency personnel or the public.

Pavement marking warranty periods typically cover one to two years after installation acceptance and occasionally extend to four years. Generally speaking, the impact of warranties on road construction costs commonly results in 10 to 20 percent higher initial costs but reduced life cycle costs over time.

6.8 Pavement Marking Inspection

From a broad perspective of pavement marking inspections, specific activities cover pre-installation inspections, and inspection during application. Issues and methods for each phase of inspection is summarized as follows:

- <u>Pre-installation Inspections:</u> Inspection activities ensure proper bonding between marking and the roadway surface. Inspection methods and procedures commonly include surface moisture, dirt and debris, air and pavement temperature, material temperature, placement guides for new surfaces, marking equipment and traffic control.
- <u>Inspection during application:</u> Inspection activities ensure durability and performance of pavement markings. Inspection methods and procedures commonly include thickness and width measurements, marking color, glass bead application (amount, dispersion, and embedment), nighttime brightness, and material disposal. With regard to thickness

measurement, duct tape or metal plates are placed on the pavement surface at maximum intervals of 2,000 feet. After pavement markings are applied, the tape or plate is removed and thickness is measured using a needlepoint micrometer and averaged over three measurement points (Texas DOT Pavement Marking Handbook, 2004). For thermoplastic markings the minimum thicknesses and application rates are as follows:

- 60 mils, 1500 micrometers for thermoplastic marking application rate of 1,000 lbs per mile
- 75 mils, 2250 micrometers for thermoplastic marking application rate of 1,300 lbs per mile
- 100 mils, 2500 micrometers for thermoplastic marking application rate of 1,800 lbs per mile

6.9 Monitoring Pavement Marking Performance

A critically important aspect of pavement marking management is performance monitoring through use of systematic database procedures. SCDOT staff should monitor both in-house and contractor-applied pavement marking projects. Upon completion of pavement marking installation projects, a series of descriptive data items should be recorded and tracked over the duration of the service life of the material. Data should include:

- Type of pavement marking material, including paint and glass bead manufacturer
- Pavement marking lines applied (with linear foot quantities)
- Type of pavement surface
- Pavement marking installation date(s)
- Contract cost (if applicable)
- Project location information including: County, Route Number, RIMS segment identification or GPS coordinates
- Identification of in-house SC DOT crew, or external pavement marking contractor and contract number
- Specified retroreflectivity warranty values (if applicable)
- Initial retroreflectivity readings collected 15 to 30 days after installation, along specified project intervals
- Initial swept retroreflectivity readings collected 15 to 30 days after installation, along specified project intervals
- Scheduled dates or intervals for performance monitoring inspections

- Results of performance monitoring, retroreflective inspection values, dates collected, and actions taken
- Calculated value for estimated project service life based on initial retroreflectivity readings entered into appropriate degradation models developed through this research
- Calculated value for predicted date that pavement marking service life will conclude

The predictive degradation models and lookup table for pavement marking retroreflectivity provided in this research report can be used to estimate project service life, predict service life conclusion and determine an optimal schedule for routine performance monitoring inspections. The lookup tables are included as Appendices H-T.

Creating and updating a comprehensive pavement marking database could be administered at the district level and used to developed useful summaries on a district-wide basis that could be helpful in planning and scheduling pavement marking projects. If consistent and uniform database formatting was adhered to, statewide tabulations of pavement marking activities could be created that would be useful from an administrative and management perspective. Lastly, it may be advantageous to include pavement marking information in the RIMS (Roadway Inventory Management System), which is already used extensively by SCDOT personnel on a statewide basis to track a large range of roadway conditions and facility infrastructure characteristics.

6.10 Coordination of SCDOT Maintenance, Resurfacing and Pavement Marking Restriping

Effective operation and maintenance of South Carolina's statewide primary and secondary roadway network relies upon accomplishing a complex list of transportation infrastructure tasks through simultaneous work activities that are addressed by personnel for a wide range of functional departments organized within the SCDOT. Coordination of critical and sometimes conflicting work activities is a challenging endeavor. With regard to scheduled primary and secondary road network maintenance, pavement resurfacing and pavement marking restriping, the following coordination recommendations were identified for enhanced efficiency:

- <u>Shoulder Blading:</u> This a common maintenance practice performed periodically to improve roadway surface storm water runoff that can be impeded by periodic buildup of debris and grass shoulders adjacent to the travelway. Shoulder blading is typically accomplished using a road motor grader with an angled blade to scrape off buildup, level shoulder areas, and restore positive drainage surfaces adjacent to paved roadways. When conducting this work white edge lines are often damaged, retroreflectivity values are frequently reduced, and subsequent pavement marking service lives shortened. For optimal sequencing, scheduled shoulder blading should be performed prior to HMA pavement resurfacing, surface course applications, and pavement marking installations.

- <u>HMA pavement resurfacing:</u> This is a periodic maintenance activity necessitated by traffic loading, oxidation of binder materials, and the need to preserve the stability of underlying pavement base layers. For optimal sequencing, scheduled HMA pavement resurfacing projects should be published and widely distributed within SCDOT districts so personnel scheduling other road maintenance activities can make informed decisions, in particular shoulder balding, surface course treatments, and pavement marking restriping.

- <u>Surface course treatments:</u> This is a frequent maintenance activity on low volume secondary roads necessitated by oxidation of binder materials and the need to provide desirable levels of surface friction. For optimal sequencing, scheduled surface course treatment applications should be published and distributed widely within SCDOT districts so personnel scheduling other road maintenance activities can make informed decisions, in particular shoulder balding, and pavement marking restriping.

- <u>Pavement marking restriping:</u> This is a frequent maintenance activity on the primary and secondary road network necessitated by the need to provide desirable levels of retroreflectivity for nighttime visibility. For optimal sequencing, pavement marking restriping projects should be planned and coordinated with other road maintenance activities in particular shoulder balding, HMA pavement resurfacing and application of surface course treatments.

It should be noted that field-collected data gathered during this research project identified four sites in resurfaced soon after restriping applications were completed. Each of these sites had considerable pavement marking life remaining. While instances may arise that necessitate pavement resurfacing soon after restriping applications, enhanced coordination could be helpful in minimizing this occurrence. At the very least, knowledge that pavement resurfacing may occur in the short-term would likely influence restriping material selection.

6.11 Implementation Plan

Implementation of the recommendations presented in this report will require adoption of new operating procedures, modification of contract specifications, capital expenditures for new equipment, namely retroreflectometers for each SCDOT district, personnel training, pavement marking contractor acceptance, and other related resources. Possible benefits include optimal performance of pavement markings on primary and secondary roads across the state, improved pavement marking performance, increased pavement marking service life, enhanced coordination of road maintenance activities, and creation of pavement marking database for improved tracking and better management. An implementation plan for recommendations and suggested tasks identified in this report should be further evaluated through the following tasks:

<u>Task 1:</u> Some states conduct pavement marking performance and durability testing prior to modifying practices and procedures for wide scale application. SCDOT should evaluate

installation of a test site where product materials can be analyzed to determine optimal suitability of pavement marking material performance for use on primary and secondary roads in the state.

Task 2: Review existing in-house operating procedures related to pavement marking restriping practices across all SCDOT districts, with specific emphasis on the following:

- Practices for selection of pavement marking materials
- Practices for surface preparation
- Practices for consideration of environmental factors
- Practices for ensuring quality of glass beads
- Practices for ensuring minimum retroreflective values
- Practices for ensuring appropriate inspection procedures

Task 3: Review existing specifications used to provide the contact basis for hiring all external pavement marking contractors, with specific emphasis on the following:

- Provisions for surface preparation
- Provisions for consideration of environmental factors
- Provisions for ensuring quality of glass beads
- Provisions to accommodate performance-based contracts
- Provisions for ensuring minimum retroreflective values
- Provisions for ensuring appropriate inspection procedures
- Provisions for specification compliance
- Provisions to accommodate warranties in pavement marking contracts

Task 4: Modify internal documents and formally adopt changes for in-house operating procedures for pavement marking restriping procedures.

Task 5: Modify specifications, update contract documents, and formally adopt changes for provisions to be used by pavement marking contractors.

Task 6: Evaluate creation of a pavement marking performance system and monitoring procedures to be instituted within each of the SCDOT district offices.

Task 7: Evaluate means and develop action plan to facilitate enhanced coordination of roadway maintenance practices through in-house stakeholder input and agency personnel buy-in.

Task 8: Assess capital cost impacts to purchase retroreflectometers for each SCDOT district

Task 9: Communicate recommended specification and contract changes with current list of approved pavement marking contractors and solicit feedback.

Task 10: Assess and develop plan for in-house personnel training to institute new procedures related to pavement marking restriping coordination and performance based monitoring.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Research goals and objectives focused on improving performance monitoring procedures and evidence-based understanding of life cycle duration for waterborne, high-build and thermoplastic pavement markings. A specific research objective was to examine methods for performance monitoring and to determine lifecycle duration of pavement markings from initial installation to eventual restriping applications. Research results focused on identifying systematic procedures and analytically based degradation models that would be useful in evaluating and improving performance of pavement marking materials used on South Carolina's primary and secondary roads. Findings were used to identify and recommend efficient and economical means for determining numeric-based periodic replacement schedules through use of retroreflectivity degradation models and acceptable minimum threshold values. A further objective of the research was to establish a method to analytically determine the maximum service life for different types of commonly used pavement marking materials. However, some areas remain where further improvement should be considered, as discussed in *7.2 Recommendations*.

7.1 Research Conclusions

The objective of this research was to develop, compare, and evaluate degradation models for high-build, waterborne, and thermoplastic pavement markings to determine how often to replace pavement markings on primary and secondary roads in South Carolina. The degradation models that were developed to predict pavement marking retroreflectivity, including service life estimates, are shown in Table 7.1.

Table 7.1: Retroreflectivity Degradation Models

Material	Model	R-Squared	Average Initial Value	Estimated Marking Lives	
White Edge HB	DIFF = -57.8900 (C)	0.32	390	5.01 CTP	
	% DIFF = -15.6744 (C)	0.35		4.74 CTP	
White Edge WB	DIFF = -0.1317(D)	0.22	315	1632 Days	4.47 Years
	% DIFF = -0.0537(D)	0.34		1271 Days	3.48 Years
White Edge T	DIFF = 54.142 – 0.0403 (D)	0.01	426	6745 Days	18 Years
	% DIFF = 13.699 – 0.0079 (D)	0.01		9279 Days	25 Years
Yellow Solid WB	DIFF = -0.0721 (D)	0.37	141	569 Days	1.56 Years
	% DIFF = -0.0569 (D)	0.47		511 Days	1.40 Years
Yellow Skip WB	DIFF = -0.0594 (D)	0.34	150	879 Days	2.41 Years
	% DIFF = -0.0366 (D)	0.33		911 Days	2.50 Years
Yellow Solid T	DIFF = -0.0764 (D)	0.05	260	2094 Days	5.74 Years
	% DIFF = -0.0270 (D)	0.04		2279 Days	6.24 Years
Yellow Skip T	DIFF = -0.1123(D)	0.09	290	1691 Days	4.64 Years
	% DIFF = -0.0364(D)	0.06		1800 Days	4.93 Years

Findings and conclusions from this research are summarized as follows:

- As described in *3.6 Retroreflectivity Characteristics of Lost Sites*, 36 sites, which make up 75% of the total repainted sites included in the study, were repainted while their retroreflectivity values were still greater than 100 mcd/m^2/lux. While there may have been other reasons for these sites to be restriped, from a retroreflectivity perspective, these markings had not yet reached the end of their functional lives. There were also four waterborne sites in the study that were repaved within a year of their installation. From these findings, it can only be assumed that there are other sites throughout the state that have been either restriped before the end of their functional lives, or repaved soon after they were striped, costing SCDOT large amounts of time and resources that may have been more effectively used elsewhere.

- There are 23 sites in the study mentioned in *3.7 Sites with Low Retroreflectivity Values* that have retroreflectivity values less than 100 mc/m^2/lux. These sites make up 31% of the total remaining sites in the study, so it can only be assumed that there are other sites throughout the state in similar poor condition. The low nighttime visibility of these sites poses a potential safety issue for drivers, and would most likely not meet MUTCD minimum retroreflectivity standards when they are established.

- As shown in Table 5.1, there is a significant difference in the performance of marking brands included in the study. It was concluded that for waterborne markings, Brand B. had an average initial retroreflectivity value of 244 mcd/m^2/lux, which is much lower than that of Brand A, 335 mcd/m^2/lux. While the degradation rates of both brands were fairly similar, this difference in initial values could create a large difference in marking lifespans. Four of the five waterborne sites in the study with $R_L < 100$ that are still in service are Brand B markings. For thermoplastic markings, a definitive ranking of brand performance was not created due to the high variability over time of thermoplastic marking retroreflectivity.

- As described in *4.1 Stepwise Regression Analysis*, pavement marking data shows a great deal of variability and thus using models that assume an initial value wouldn't be prudent. Instead, initial values should be used as the constant in the equations, and therefore applicable to markings with any initial value. Thus, we are proposing that SCDOT takes initial readings at each site to be used in the models, as well as for quality control of markings.

- As shown in Table 6.1, for white and yellow waterborne pavement markings, number of days since initial reading is the most significant variable in the retroreflectivity degradation model. If the initial retroreflectivity value and number of days since the initial value was recorded are known, retroreflectivity values can be predicted with reasonable accuracy, assuming the marking was properly installed and there are no extraordinary site conditions.

- As summarized in Table 7.1 for high-build pavement markings, Cumulative Traffic Passages (CTP) is the most significant variable in the retroreflectivity degradation model. CTP was found to be more significant than marking age alone, as well as volume alone. Implementing a model that relies upon CTP may pose some problems on a statewide basis, however if traffic volumes are known, a reliable model can be created and used to predict high-build pavement marking performance.

- As described in *4.0 Pavement Marking Analysis*, due to the high variability of thermoplastic markings, white edge line thermoplastic models were not created, but estimated average annual degradation values were calculated. For yellow thermoplastic markings, models were created with days since initial value as the independent variable.

- As depicted in Figures 4.5 and 4.7, and estimated in corresponding degradation models, high-build white edge line markings are predicted to last considerably longer than waterborne markings for comparable locations. While both marking types may have similar initial retroreflectivity values, predictive models indicate that high-build edge line markings degrade at a much lower rate than waterborne edge lines. While high-build white edge markings were not able to be directly compared to thermoplastic white edge markings, it is predicted that they offer comparable lifespans to thermoplastic markings on lower volume roads at a lower cost.

- As tabulated in Table 5.2, an evaluation of model performance indicated that the likelihood of pavement marking degradation models to produce over-predicted retroreflectivity values, as compared to actual measured values, was roughly 35 percent of the time for waterborne white edge markings, and less than 10 percent for high-build white edge markings. This concern could be effectively addressed through use of margin of safety factors.

- As summarized in Table 7.1, model estimated pavement-marking life was determined to be 3.48 years for waterborne white edge markings and 4.74 million vehicle passages for high build white edge markings, using percent difference retroreflectivity models, and 4.47 years and 5.01 million vehicle passages using absolute difference retroreflectivity models. Model estimated marking lives for yellow markings are: 1.40 years for waterborne yellow solid, 2.41 years for waterborne yellow skip, 5.74 years for thermoplastic yellow solid, and 4.64 years for thermoplastic yellow skip markings. These estimates assume the average initial values from the study and a minimum threshold value of 100 mcd/m²/lux.

- As summarized in Table 5.5, even though high-build marking installation costs are approximately double that of waterborne markings, observed durability and lifespan of high-build white edge line markings appear more desirable based on retroreflectivity degradation comparisons. Compared to waterborne white edge line markings, high-build markings are more cost-effective for volumes up to 1,600 veh/day.

7.2 Recommendations

- Because model-predicted estimates for service marking lives exceed the duration of many control sites included in this research study project, additional data collection would be necessary to verify these models are reliable over the remainder of pavement marking life. Also, because high-build sites in the study are only located along roads with AADTs up to 3,500 veh/day, it would be beneficial for SCDOT to conduct a similar study on high-build markings for roadways with higher daily traffic volumes.

- Agencies should have better coordination and communication between those in charge of striping and paving roadways. As shown in the study, four sites were repaved within a year of being striped. If it is known that a road is going to be repaved soon, it should not be restriped before, only to be restriped again after repaving.

- Additional research on the performance of various pavement marking brands would be beneficial in aiding SCDOT in selecting a marking brand to best suit their needs while still meeting safety requirements.

- Minimum initial retroreflectivity value standards should be established for contractors applying pavement markings. Use of minimum initial values would enable the models to reliably predict service life of markings, as well as permit extended marking lives in the event initial values are high enough. For more accurate results, initial values should be measured so degradation models can be applied. It is recommended acceptable initial values be relatively close in magnitude average initial values determined from control sites included this research study, which were around 400 mcd/m^2/lux for high-build markings and 300 mcd/m^2/lux for waterborne markings.

- When considering means to establish and adopt minimum retroreflectivity thresholds values, it is recommended target values be set above proposed federal minimum standards to allow for a margin of safety. Currently, a threshold value of 100 mcd/m^2/lux is commonly considered an acceptable minimum, under dry conditions, and this is still a relatively high value. Forcing DOT's to comply with minimum specified values that are too high will result in increased pavement marking maintenance expenses. Instead, retroreflectivity goals should be established for guidance on minimum preferred retroreflectivity levels. These minimum thresholds should be low enough that they are reasonable from a pavement marking management perspective, but high enough to ensure that the roadways are safe for the people that use them.

APPENDICES

Appendix A: Waterborne White Edge Data

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	1	1	232	232	0	4600	0.48	82.6	-	-
E HMA	Brand A	1	2	232	240	71	4600	0.32	95.9	-	-
E HMA	Brand A	1	3	232	205	229	4600	0.20	29.0	-	-
E HMA	Brand A	2	1	257	257	0	19200	0.28	82.9	-	0.2
E HMA	Brand A	2	2	257	262	84	19200	0.38	80.6	-	0.2
E HMA	Brand A	2	3	257	252	232	19200	0.33	59.0	-	0.2
E HMA	Brand A	2	4	257	214	320	19200	0.27	73.0	-	0.2
E HMA	Brand A	2	5	257	201	425	19200	0.62	79.3	-	0.2
E HMA	Brand A	3	1	169	169	0	6200	0.37	83.8	10	0.2
E HMA	Brand A	3	2	169	166	85	6200	0.33	89.8	10	0.2
E HMA	Brand A	3	3	169	94	218	6200	0.20	60.0	10	0.2
E HMA	Brand A	3	4	169	132	321	6200	0.20	73.0	10	0.2
E HMA	Brand A	3	5	169	115	425	6200	0.52	83.1	10	0.2
E HMA	Brand A	3	6	169	107	519	6200	0.53	73.4	10	0.2
E HMA	Brand A	3	7	169	95	676	6200	0.2	59.0	10	0.2
E HMA	Brand A	3	8	169	96	784	6200	0.53	78.0	10	0.2
E HMA	Brand A	3	9	169	101	888	6200	0.25	98.0	10	0.2
E HMA	Brand A	3	10	169	102	1006	6200	0.2	74.0	10	0.2
E HMA	Brand A	3	11	169	93	1112	6200	0.38	90.0	10	0.2
E HMA	Brand A	3	12	169	83	1225	6200	0.31	91.0	10	0.2
E HMA	Brand A	4	1	116	116	0	11300	0.58	79.0	10	1.5
E HMA	Brand A	4	2	116	93	85	11300	0.36	89.2	10	1.5
E HMA	Brand A	4	3	116	84	218	11300	0.20	60.0	10	1.5
E HMA	Brand A	4	4	116	69	321	11300	0.20	73.0	10	1.5
E HMA	Brand A	4	5	116	56	425	11300	0.52	84.6	10	1.5
E HMA	Brand A	5	1	355	355	0	7500	0.20	84.7	-	2.0
E HMA	Brand A	5	2	355	328	76	7500	0.31	90.5	-	2.0
E HMA	Brand A	5	3	355	267	209	7500	0.31	60.0	-	2.0
E HMA	Brand A	5	4	355	234	312	7500	0.25	90.0	-	2.0
E HMA	Brand A	5	5	355	100	425	7500	0.53	82.2	-	2.0
E HMA	Brand A	5	6	355	182	519	7500	0.53	75.0	-	2.0
E HMA	Brand A	5	7	355	119	676	7500	0.2	60.0	-	2.0
E HMA	Brand A	5	8	355	124	784	7500	0.51	83.0	-	2.0
E HMA	Brand A	5	9	355	125	888	7500	0.22	94.0	-	2.0
E HMA	Brand A	5	10	355	95	1006	7500	0.2	66.0	-	2.0
E HMA	Brand A	8	1	130	130	0	8200	0.47	78.8	11	0.0
E HMA	Brand A	8	2	130	98	78	8200	0.57	77.6	11	0.0
E HMA	Brand A	8	3	130	113	224	8200	0.22	59.0	11	0.0
E HMA	Brand A	8	4	130	112	344	8200	0.40	84.0	11	0.0
E HMA	Brand A	14	1	337	337	0	1000	0.35	76.8	11	6.0
E HMA	Brand A	14	2	337	349	68	1000	0.40	94.3	11	6.0
E HMA	Brand A	14	3	337	330	214	1000	0.25	33.0	11	6.0

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	14	4	337	308	324	1000	0.42	85.0	11	6.0
E HMA	Brand A	14	5	337	322	432	1000	0.60	80.4	11	6.0
E HMA	Brand A	14	6	337	284	524	1000	0.56	66.0	11	6.0
E HMA	Brand A	14	7	337	227	662	1000	0.2	58.0	11	6.0
E HMA	Brand A	14	8	337	206	770	1000	0.44	85.0	11	6.0
E HMA	Brand A	14	9	337	222	874	1000	0.33	90.0	11	6.0
E HMA	Brand A	14	10	337	163	992	1000	0.2	66.0	11	6.0
E HMA	Brand A	14	11	337	167	1098	1000	0.21	103.0	11	6.0
E HMA	Brand A	14	12	337	163	1211	1000	0.26	91.0	11	6.0
E HMA	Brand A	24	1	319	319	0	25	0.55	86.0	10	0.0
E HMA	Brand A	24	2	319	328	89	25	0.47	81.3	10	0.0
E HMA	Brand A	24	3	319	236	222	25	0.31	68.0	10	0.0
E HMA	Brand A	24	4	319	161	336	25	0.53	81.7	10	0.0
E HMA	Brand A	24	5	319	118	443	25	0.44	86.0	10	0.0
E HMA	Brand A	24	6	319	125	552	25	0.26	52.0	10	0.0
E HMA	Brand A	27	1	261	261	0	50	0.53	87.0	11	1.0
E HMA	Brand A	27	2	261	294	89	50	0.40	86.0	11	1.0
E HMA	Brand A	27	3	261	251	222	50	0.30	70.0	11	1.0
E HMA	Brand A	27	4	261	245	336	50	0.53	80.6	11	1.0
E HMA	Brand A	27	5	261	238	443	50	0.46	85.0	11	1.0
E HMA	Brand A	27	6	261	202	552	50	0.26	52.0	11	1.0
E HMA	Brand A	28	1	269	269	0	150	0.52	88.0	10	0.0
E HMA	Brand A	28	2	269	244	89	150	0.40	86.0	10	0.0
E HMA	Brand A	28	3	269	239	222	150	0.31	75.0	10	0.0
E HMA	Brand A	28	4	269	269	336	150	0.50	86.7	10	0.0
E HMA	Brand A	28	5	269	282	443	150	0.46	85.0	10	0.0
E HMA	Brand A	28	6	269	222	552	150	0.26	52.0	10	0.0
E HMA	Brand A	29	1	398	398	0	3700	-	-	10	0.3
E HMA	Brand A	29	2	398	284	108	3700	0.46	71.8	10	0.3
E HMA	Brand A	29	3	398	319	219	3700	0.27	60.0	10	0.3
E HMA	Brand A	29	4	398	337	337	3700	0.71	80.8	10	0.3
E HMA	Brand A	29	5	398	250	447	3700	0.49	76.3	10	0.3
E HMA	Brand A	29	6	398	197	569	3700	0.23	28.0	10	0.3
E HMA	Brand A	30	1	461	461	0	1850	-	-	10	0.5
E HMA	Brand A	30	2	461	468	108	1850	-	71.8	10	0.5
E HMA	Brand A	30	3	461	419	219	1850	-	60.0	10	0.5
E HMA	Brand A	30	4	461	372	337	1850	0.62	85.5	10	0.5
E HMA	Brand A	30	5	461	380	447	1850	0.49	76.8	10	0.5
E HMA	Brand A	30	6	461	383	569	1850	0.23	28.0	10	0.5
E HMA	Brand A	31	1	356	356	0	500	-	-	10	0.5
E HMA	Brand A	31	2	356	380	94	500	0.30	74.0	10	0.5
E HMA	Brand A	31	3	356	339	220	500	0.30	60.0	10	0.5
E HMA	Brand A	31	4	356	373	338	500	0.56	87.6	10	0.5
E HMA	Brand A	33	1	363	363	0	500	-	-	10	0.5

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	33	2	363	261	99	500	-	74.0	10	0.5
E HMA	Brand A	33	3	363	146	225	500	-	60.0	10	0.5
E HMA	Brand A	33	4	363	250	343	500	0.50	93.0	10	0.5
E HMA	Brand A	34	1	363	363	0	600	-	-	10	0.5
E HMA	Brand A	34	2	363	331	99	600	-	74.0	10	0.5
E HMA	Brand A	34	3	363	293	225	600	-	60.0	10	0.5
E HMA	Brand A	34	4	363	232	343	600	0.48	92.1	10	0.5
E HMA	Brand A	35	1	290	290	0	700	-	-	10	0.3
E HMA	Brand A	35	2	290	281	99	700	-	74.0	10	0.3
E HMA	Brand A	35	3	290	304	225	700	-	60.0	10	0.3
E HMA	Brand A	35	4	290	338	343	700	0.44	95.0	10	0.3
E HMA	Brand A	36	1	363	363	0	1150	-	-	10	0.3
E HMA	Brand A	36	2	363	339	99	1150	-	74.0	10	0.3
E HMA	Brand A	36	3	363	323	225	1150	-	60.0	10	0.3
E HMA	Brand A	36	4	363	351	343	1150	-	95.0	10	0.3
E HMA	Brand A	37	1	355	355	0	550	-	-	9	0.2
E HMA	Brand A	37	2	355	353	99	550	-	74.0	9	0.2
E HMA	Brand A	37	3	355	355	225	550	-	60.0	9	0.2
E HMA	Brand A	37	4	355	286	354	550	0.43	89.4	9	0.2
E HMA	Brand A	38	1	314	314	0	150	-	-	-	0.2
E HMA	Brand A	38	2	314	308	100	150	-	74.0	-	0.2
E HMA	Brand A	38	3	314	285	226	150	-	60.0	-	0.2
E HMA	Brand A	38	4	314	313	344	150	0.44	95.0	-	0.2
E HMA	Brand B	39	1	251	251	0	1450	-	-	10	0.3
E HMA	Brand B	39	2	251	171	90	1450	-	80.0	10	0.3
E HMA	Brand B	39	3	251	65	230	1450	-	72.5	10	0.3
E HMA	Brand B	39	4	251	159	355	1450	0.48	82.9	10	0.3
E HMA	Brand B	39	5	251	140	461	1450	0.42	68.0	10	0.3
E HMA	Brand B	39	6	251	116	569	1450	0.20	54.0	10	0.3
E HMA	Brand B	39	7	251	104	740	1450	0.55	79.0	10	0.3
E HMA	Brand B	39	8	251	76	874	1450	0.20	71.0	10	0.3
E HMA	Brand B	39	9	251	90	972	1450	0.2	67	10	0.3
E HMA	Brand B	39	10	251	84	1077	1450	0.37	102	10	0.3
E HMA	Brand B	39	11	251	74	1189	1450	0.79	66	10	0.3
E HMA	Brand B	40	1	167	167	0	500	-	-	9	-
E HMA	Brand B	40	2	167	133	90	500	0.35	80.0	9	-
E HMA	Brand B	40	3	167	56	230	500	0.30	76.6	9	-
E HMA	Brand B	40	4	167	76	355	500	0.45	87.4	9	-
E HMA	Brand B	40	5	167	123	461	500	0.41	73.4	9	-
E HMA	Brand B	40	6	167	118	569	500	0.20	54.0	9	-
E HMA	Brand B	40	7	167	58	740	500	0.48	87.0	9	-
E HMA	Brand B	40	8	167	51	874	500	0.22	82.0	9	-
E HMA	Brand B	40	9	167	68	972	500	0.2	76	9	-
E HMA	Brand B	40	10	167	65	1077	500	0.32	102	9	-

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand B	40	11	167	61	1189	500	0.74	67	9	-
E HMA	Brand B	41	1	166	166	0	500	-	-	9	0.0
E HMA	Brand B	41	2	166	139	90	500	0.31	84.0	9	0.0
E HMA	Brand B	41	3	166	46	230	500	0.30	80.2	9	0.0
E HMA	Brand B	41	4	166	80	355	500	0.47	85.5	9	0.0
E HMA	Brand B	41	5	166	53	461	500	0.39	73.4	9	0.0
E HMA	Brand B	41	6	166	83	569	500	0.20	55.0	9	0.0
E HMA	Brand B	41	7	166	55	740	500	0.45	94.0	9	0.0
E HMA	Brand B	41	8	166	80	874	500	0.20	77.0	9	0.0
E HMA	Brand B	41	9	166	82	972	500	0.2	78	9	0.0
E HMA	Brand B	41	10	166	67	1077	500	0.29	107	9	0.0
E HMA	Brand B	41	11	166	67	1189	500	0.79	66	9	0.0
E HMA	Brand B	42	1	122	122	0	500	-	-	10	5.0
E HMA	Brand B	42	2	122	99	90	500	0.33	83.0	10	5.0
E HMA	Brand B	42	3	122	83	230	500	0.30	85.3	10	5.0
E HMA	Brand B	42	4	122	56	355	500	0.44	87.3	10	5.0
E HMA	Brand B	42	5	122	40	461	500	0.39	72.0	10	5.0
E HMA	Brand B	42	6	122	33	569	500	0.20	55.0	10	5.0
E HMA	Brand B	42	7	122	29	740	500	0.36	97.0	10	5.0
E HMA	Brand B	42	8	122	29	874	500	0.21	78.0	10	5.0
E HMA	Brand B	42	9	122	28	972	500	0.2	81	10	5.0
E HMA	Brand B	42	10	122	25	1077	500	0.28	107	10	5.0
E HMA	Brand B	42	11	122	32	1189	500	0.74	68	10	5.0
E HMA	Brand A	49	1	378	378	0	1450	-	79.0	10	0.5
E HMA	Brand A	49	2	378	411	96	1450	0.35	81.0	10	0.5
E HMA	Brand A	49	3	378	357	229	1450	0.27	83.0	10	0.5
E HMA	Brand A	49	4	378	315	336	1450	0.45	88.0	10	0.5
E HMA	Brand A	49	5	378	345	432	1450	0.42	84.6	10	0.5
E HMA	Brand A	49	6	378	273	554	1450	0.21	33.0	10	0.5
E HMA	Brand A	50	1	397	397	0	650	-	79.0	10	1.0
E HMA	Brand A	50	2	397	439	96	650	0.37	83.0	10	1.0
E HMA	Brand A	50	3	397	387	229	650	0.37	88.0	10	1.0
E HMA	Brand A	50	4	397	378	336	650	0.46	86.0	10	1.0
E HMA	Brand A	51	1	390	390	0	375	-	79.0	10	0.2
E HMA	Brand A	51	2	390	288	96	375	-	83.0	10	0.2
E HMA	Brand A	51	3	390	258	229	375	-	88.0	10	0.2
E HMA	Brand A	51	4	390	303	336	375	0.48	85.5	10	0.2
E HMA	Brand A	51	5	390	245	432	375	0.39	84.0	10	0.2
E HMA	Brand A	51	6	390	300	554	375	0.23	32.0	10	0.2
E HMA	Brand A	52	1	311	311	0	225	-	79.0	10	10.0
E HMA	Brand A	52	2	311	171	96	225	0.30	80.0	10	10.0
E HMA	Brand A	52	3	311	72	229	225	0.30	88.0	10	10.0
E HMA	Brand A	52	4	311	144	336	225	0.30	86.0	10	10.0
E HMA	Brand A	53	1	370	370	0	100	-	79.0	9	0.0

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	53	2	370	215	96	100	-	80.0	9	0.0
E HMA	Brand A	53	3	370	268	229	100	-	88.0	9	0.0
E HMA	Brand A	53	4	370	222	336	100	-	86.0	9	0.0
E HMA	Brand A	53	5	370	210	432	100	0.39	84.2	9	0.0
E HMA	Brand A	53	6	370	220	554	100	0.24	32.0	9	0.0
E HMA	Brand A	54	1	360	360	0	100	-	79.0	9	0.0
E HMA	Brand A	54	2	360	448	96	100	0.27	83.0	9	0.0
E HMA	Brand A	54	3	360	331	229	100	0.26	88.0	9	0.0
E HMA	Brand A	54	4	360	324	336	100	0.46	86.0	9	0.0
E HMA	Brand A	55	1	429	429	0	600	-	79.0	10	2.0
E HMA	Brand A	55	2	429	483	96	600	0.46	83.0	10	2.0
E HMA	Brand A	55	3	429	392	229	600	0.46	88.0	10	2.0
E HMA	Brand A	55	4	429	340	336	600	0.46	84.7	10	2.0
E HMA	Brand A	55	5	429	353	432	600	0.39	84.4	10	2.0
E HMA	Brand A	55	6	429	310	554	600	0.24	31.0	10	2.0
E HMA	Brand A	56	1	378	378	0	275	-	79.0	9	0.3
E HMA	Brand A	56	2	378	377	96	275	0.24	83.0	9	0.3
E HMA	Brand A	56	3	378	350	229	275	0.24	88.0	9	0.3
E HMA	Brand A	56	4	378	334	336	275	0.43	83.7	9	0.3
E HMA	Brand A	57	1	294	294	0	350	-	78.0	10	0.0
E HMA	Brand A	57	2	294	380	94	350	0.38	83.0	10	0.0
E HMA	Brand A	57	3	294	393	230	350	0.29	82.0	10	0.0
E HMA	Brand A	57	4	294	376	316	350	0.49	94.0	10	0.0
E HMA	Brand A	58	1	376	376	0	1850	-	78.0	10	0.3
E HMA	Brand A	58	2	376	254	93	1850	0.38	74.0	10	0.3
E HMA	Brand A	58	3	376	204	229	1850	0.29	82.0	10	0.3
E HMA	Brand A	58	4	376	169	315	1850	0.50	95.0	10	0.3
E HMA	Brand A	59	1	419	419	0	3200	-	78.0	11	0.0
E HMA	Brand A	59	2	419	390	93	3200	0.35	85.0	11	0.0
E HMA	Brand A	59	3	419	377	229	3200	0.29	80.0	11	0.0
E HMA	Brand A	59	4	419	355	326	3200	0.45	87.8	11	0.0
E HMA	Brand A	59	5	419	343	419	3200	0.44	81.0	11	0.0
E HMA	Brand A	59	6	419	265	541	3200	0.23	32.0	11	0.0
E HMA	Brand A	60	1	375	375	0	500	-	78.0	10	0.0
E HMA	Brand A	60	2	375	327	93	500	-	85.0	10	0.0
E HMA	Brand A	60	3	375	295	229	500	-	80.0	10	0.0
E HMA	Brand A	60	4	375	137	326	500	0.44	88.3	10	0.0
E HMA	Brand A	61	1	334	334	0	75	-	78.0	10	0.5
E HMA	Brand A	61	2	334	297	93	75	0.38	84.0	10	0.5
E HMA	Brand A	61	3	334	282	229	75	0.27	80.0	10	0.5
E HMA	Brand A	61	4	334	264	315	75	0.56	87.1	10	0.5
E HMA	Brand A	61	5	334	253	419	75	0.43	76.8	10	0.5
E HMA	Brand A	61	6	334	264	541	75	0.23	32.0	10	0.5
E HMA	Brand A	61	7	334	214	712	75	0.57	82.0	10	0.5

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	61	8	334	243	846	75	0.22	77.0	10	0.5
E HMA	Brand A	61	9	334	235	964	75	0.2	75	10	0.5
E HMA	Brand A	61	10	334	206	1061	75	0.41	96	10	0.5
E HMA	Brand A	61	11	334	234	1168	75	0.75	65	10	0.5
E HMA	Brand A	62	1	467	467	0	175	-	78.0	10	0.5
E HMA	Brand A	62	2	467	446	93	175	0.35	85.0	10	0.5
E HMA	Brand A	62	3	467	467	229	175	0.28	83.0	10	0.5
E HMA	Brand A	62	4	467	389	315	175	0.28	91.0	10	0.5
E HMA	Brand A	63	1	408	408	0	175	-	78.0	9	0.5
E HMA	Brand A	63	2	408	401	93	175	0.26	89.0	9	0.5
E HMA	Brand A	63	3	408	375	229	175	0.27	86.0	9	0.5
E HMA	Brand A	63	4	408	334	315	175	0.49	93.0	9	0.5
E HMA	Brand A	64	1	410	410	0	550	-	78.0	10	0.3
E HMA	Brand A	64	2	410	416	94	550	0.38	84.0	10	0.3
E HMA	Brand A	64	3	410	397	230	550	0.28	86.0	10	0.3
E HMA	Brand A	64	4	410	408	316	550	0.49	93.0	10	0.3
Chip Seal	Brand A	115	1	298	298	0	5300	0.50	88.0	11	-
Chip Seal	Brand A	115	2	298	249	98	5300	0.54	88.0	11	-
Chip Seal	Brand A	115	3	298	127	245	5300	0.54	82.0	11	-
Chip Seal	Brand A	115	4	298	17	312	5300	0.55	86.0	11	-
Chip Seal	Brand A	115	5	298	17	477	5300	0.23	53.0	11	-
Chip Seal	Brand A	115	6	298	17	530	5300	0.23	60.0	11	-
Chip Seal	Brand A	115	7	298	13	661	5300	0.28	93.0	11	-
Chip Seal	Brand A	115	8	298	16	800	5300	-	51.0	11	-
Chip Seal	Brand A	115	9	298	16	937	5300	-	73	11	-
Chip Seal	Brand A	117	1	332	332	0	425	0.40	87.0	10	-
Chip Seal	Brand A	117	2	332	311	51	425	0.54	75.0	10	-
Chip Seal	Brand A	117	3	332	313	198	425	0.53	84.0	10	-
Chip Seal	Brand A	117	4	332	306	265	425	0.41	87.0	10	-
Chip Seal	Brand A	117	5	332	393	446	425	0.34	42.0	10	-
Chip Seal	Brand A	117	6	332	408	507	425	0.23	63.0	10	-
Chip Seal	Brand A	118	1	237	237	0	325	0.40	87.0	10	0.5
Chip Seal	Brand A	118	2	237	241	51	325	0.52	75.0	10	0.5
Chip Seal	Brand A	118	3	237	196	198	325	0.52	85.0	10	0.5
Chip Seal	Brand A	118	4	237	196	265	325	0.58	85.0	10	0.5
Chip Seal	Brand A	118	5	237	363	446	325	0.26	42.0	10	0.5
Chip Seal	Brand A	118	6	237	377	507	325	0.23	63.0	10	0.5
Chip Seal	Brand A	118	7	237	387	632	325	-	88.0	10	0.5
Chip Seal	Brand A	118	8	237	300	767	325	-	57.0	10	0.5
Chip Seal	Brand A	118	9	237	298	904	325	-	70	10	0.5
Chip Seal	Brand A	119	1	407	407	0	900	0.40	87.0	11	1.5
Chip Seal	Brand A	119	2	407	367	51	900	0.52	76.0	11	1.5
Chip Seal	Brand A	119	3	407	357	198	900	0.52	85.0	11	1.5
Chip Seal	Brand A	119	4	407	373	265	900	0.43	87.0	11	1.5

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
Chip Seal	Brand A	119	5	407	264	446	900	0.37	40.0	11	1.5
Chip Seal	Brand A	119	6	407	250	507	900	0.24	63.0	11	1.5
Chip Seal	Brand A	120	1	314	314	0	850	0.40	85.0	9	-
Chip Seal	Brand A	120	2	314	298	51	850	0.50	76.0	9	-
Chip Seal	Brand A	120	3	314	310	198	850	0.50	85.0	9	-
Chip Seal	Brand A	120	4	314	309	265	850	0.48	84.0	9	-
Chip Seal	Brand A	120	5	314	338	446	850	0.39	36.0	9	-
Chip Seal	Brand A	120	6	314	328	507	850	0.27	63.0	9	-
Chip Seal	Brand A	120	7	314	322	632	850	-	93.0	9	-
Chip Seal	Brand A	120	8	314	298	767	850	-	55.0	9	-
Chip Seal	Brand A	120	9	314	286	904	850	-	71	9	-
Chip Seal	Brand A	120	10	314	317	997	850	-	80	9	-
E HMA	Brand B	151	1	352	352	0	1000	0.53	89.2	-	0.5
E HMA	Brand B	152	1	172	172	0	1000	0.42	95.0	-	-
E HMA	Brand B	152	2	172	139	103	1000	0.55	83.0	-	-
E HMA	Brand B	152	3	172	133	182	1000	0.35	46.0	-	-
E HMA	Brand B	152	4	172	127	278	1000	0.27	80.0	-	-
E HMA	Brand B	152	5	172	124	400	1000	0.68	93.0	-	-
E HMA	Brand B	152	6	172	135	502	1000	0.2	81.0	-	-
E HMA	Brand B	152	7	172	116.5	614	1000	0.2	79.0	-	-
E HMA	Brand B	152	8	172	104	742	1000	0.33	98.0	-	-
E HMA	Brand B	152	9	172	118	849	1000	0.6	70.0	-	-
E HMA	Brand B	153	1	294	294	0	1000	0.43	90.3	-	-
E HMA	Brand B	154	1	309	309	0	1000	0.41	91.4	-	-
E HMA	Brand B	155	1	316	316	0	2700	0.38	95.0	-	-
E HMA	Brand B	155	2	316	251	103	2700	0.42	81.0	-	-
E HMA	Brand B	155	3	316	247	182	2700	0.35	47.0	-	-
E HMA	Brand B	155	4	316	259	278	2700	0.27	81.0	-	-
E HMA	Brand B	155	5	316	213	400	2700	0.67	89.0	-	-
E HMA	Brand B	155	6	316	277	502	2700	0.2	80.0	-	-
E HMA	Brand B	155	7	316	241	614	2700	0.29	80.0	-	-
E HMA	Brand B	155	8	316	241	742	2700	0.34	100.0	-	-
E HMA	Brand B	156	1	303	303	0	2600	0.4	92.0	-	-
E HMA	Brand B	156	2	303	302	103	2600	0.46	80.0	-	-
E HMA	Brand B	156	3	303	257	182	2600	0.35	47.0	-	-
E HMA	Brand B	156	4	303	228	278	2600	0.27	81.0	-	-
E HMA	Brand B	156	5	303	216	400	2600	0.6	90.0	-	-
E HMA	Brand B	156	6	303	216	502	2600	0.2	83.0	-	-
E HMA	Brand B	156	7	303	198	614	2600	0.3	77.0	-	-
E HMA	Brand B	156	8	303	191	742	2600	0.35	101.0	-	-
E HMA	Brand B	156	9	303	166	849	2600	0.6	70.0	-	-
E HMA	Brand B	157	1	237	237	0	1000	0.39	93.0	-	-
E HMA	Brand B	157	2	237	285	103	1000	0.51	86.0	-	-
E HMA	Brand B	157	3	237	229	182	1000	0.35	48.0	-	-

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand B	157	4	237	179	278	1000	0.27	81.0	-	-
E HMA	Brand B	157	5	237	159	400	1000	0.6	88.0	-	-
E HMA	Brand B	157	6	237	110	502	1000	0.2	84.0	-	-
E HMA	Brand B	157	7	237	124	614	1000	0.3	77.0	-	-
E HMA	Brand B	157	8	237	118	742	1000	0.32	102.0	-	-
E HMA	Brand B	157	9	237	103	849	1000	0.6	70.0	-	-

Appendix B: High-Build White Edge Data

Pavement Type	Brand	Site	Round	Initial	Median	Days Since Initial Reading	CTP (mv)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity	AADT
E HMA	Brand A	86	1	412	412	0	0.0000	10	0	79	0.52	200
E HMA	Brand A	86	2	412	441	90	0.0180	10	0	76	0.47	200
E HMA	Brand A	86	3	412	457	194	0.0388	10	0	50	0.24	200
E HMA	Brand A	86	4	412	412	340	0.0680	10	0	84	0.58	200
E HMA	Brand A	86	5	412	469	404	0.0808	10	0	93	0.51	200
E HMA	Brand A	86	6	412	450	532	0.1064	10	0	73	0.26	200
E HMA	Brand A	86	7	412	481	634	0.1268	10	0	89	0.2	200
E HMA	Brand A	87	1	390	390	0	0.0000	10	0	80	0.52	200
E HMA	Brand A	87	2	390	386	90	0.0180	10	0	80	0.46	200
E HMA	Brand A	87	3	390	423	194	0.0388	10	0	50	0.28	200
E HMA	Brand A	87	4	390	383	340	0.0680	10	0	84	0.58	200
E HMA	Brand A	87	5	390	424	404	0.0808	10	0	92	0.5	200
E HMA	Brand A	87	7	390	432	634	0.1268	10	0	85	0.2	200
E HMA	Brand A	87	8	390	389	734	0.1468	10	0	99	0.4	200
E HMA	Brand A	87	9	390	389	839	0.1678	10	0	79	0.88	200
E HMA	Brand A	88	1	401	401	0	0.0000	9	0.5	82	0.5	500
E HMA	Brand A	88	2	401	362	90	0.0450	9	0.5	80	0.44	500
E HMA	Brand A	88	3	401	379	194	0.0970	9	0.5	51	0.3	500
E HMA	Brand A	88	4	401	379	340	0.1700	9	0.5	84	0.58	500
E HMA	Brand A	88	5	401	410	404	0.2020	9	0.5	101	0.36	500
E HMA	Brand A	88	6	401	293	532	0.2660	9	0.5	73	0.27	500
E HMA	Brand A	88	7	401	317	634	0.3170	9	0.5	77	0.2	500
E HMA	Brand A	88	8	401	321	734	0.3670	9	0.5	99	0.33	500
E HMA	Brand A	88	9	401	309	839	0.4195	9	0.5	78	0.88	500
E HMA	Brand A	89	1	448	448	0	0.0000	10	0	82	0.52	200
E HMA	Brand A	89	2	448	432	90	0.0180	10	0	81	0.44	200
E HMA	Brand A	89	3	448	469	194	0.0388	10	0	53	0.3	200
E HMA	Brand A	89	4	448	356	339	0.0678	10	0	85	0.58	200
E HMA	Brand A	89	5	448	458	404	0.0808	10	0	100	0.32	200
E HMA	Brand A	89	6	448	400	532	0.1064	10	0	73	0.27	200
E HMA	Brand A	89	7	448	496	634	0.1268	10	0	75	0.2	200
E HMA	Brand A	89	8	448	476	734	0.1468	10	0	94	0.34	200
E HMA	Brand A	90	1	386	386	0	0.0000	10	0	86	0.48	200
E HMA	Brand A	90	2	386	353	90	0.0180	10	0	83	0.44	200
E HMA	Brand A	90	3	386	345	194	0.0388	10	0	53	0.3	200
E HMA	Brand A	90	4	386	352	340	0.0680	10	0	55	0.58	200
E HMA	Brand A	90	5	386	384	404	0.0808	10	0	99	0.36	200
E HMA	Brand A	90	6	386	418	532	0.1064	10	0	73	0.27	200
E HMA	Brand A	90	7	386	410	634	0.1268	10	0	78	0.2	200
E HMA	Brand A	90	8	386	386	734	0.1468	10	0	93	0.42	200
E HMA	Brand A	90	9	386	407	839	0.1678	10	0	73	0.88	200
E HMA	Brand A	91	1	434	434	0	0.0000	10	0	84	0.47	200
E HMA	Brand A	91	2	434	432	90	0.0180	10	0	83	0.44	200
E HMA	Brand A	91	3	434	426	194	0.0388	10	0	53	0.3	200
E HMA	Brand A	91	4	434	423	339	0.0678	10	0	85	0.58	200

Pavement Type	Brand	Site	Round	Initial	Median	Days Since Initial Reading	CTP (mv)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity	AADT
E HMA	Brand A	91	5	434	453	404	0.0808	10	0	97	0.41	200
E HMA	Brand A	91	6	434	438	532	0.1064	10	0	73	0.27	200
E HMA	Brand A	91	7	434	415	634	0.1268	10	0	79	0.2	200
E HMA	Brand A	91	8	434	440	734	0.1468	10	0	101	0.34	200
E HMA	Brand A	92	2	452	452	0	0.0000	10	0.5	83	0.44	1000
E HMA	Brand A	92	3	452	456	104	0.1040	10	0.5	53	0.3	1000
E HMA	Brand A	92	4	452	460	249	0.2490	10	0.5	85	0.58	1000
E HMA	Brand A	92	5	452	455	314	0.3140	10	0.5	101	0.35	1000
E HMA	Brand A	92	6	452	454	442	0.4420	10	0.5	74	0.25	1000
E HMA	Brand A	92	7	452	463	544	0.5440	10	0.5	75	0.2	1000
E HMA	Brand A	92	8	452	454	644	0.6440	10	0.5	95	0.35	1000
E HMA	Brand A	92	9	452	420	749	0.7490	10	0.5	73	0.88	1000
E HMA	Brand A	93	2	462	462	0	0.0000	9	0	83	0.44	300
E HMA	Brand A	93	3	462	466	104	0.0312	9	0	53	0.3	300
E HMA	Brand A	93	4	462	436	249	0.0747	9	0	55	0.58	300
E HMA	Brand A	93	5	462	444	314	0.0942	9	0	104	0.31	300
E HMA	Brand A	93	6	462	458	442	0.1326	9	0	71	0.27	300
E HMA	Brand A	93	7	462	464	544	0.1632	9	0	77	0.2	300
E HMA	Brand A	93	8	462	427	644	0.2093	9	0	104	0.31	325
E HMA	Brand A	93	9	462	407	749	0.2434	9	0	73	0.88	325
N HMA	Brand A	94	1	354	354	0	0.0000	9	0.5	84	0.48	325
N HMA	Brand A	94	2	354	388	90	0.0293	9	0.5	83	0.44	325
N HMA	Brand A	94	3	354	307	194	0.0631	9	0.5	54	0.3	325
N HMA	Brand A	94	4	354	294	339	0.1102	9	0.5	85	0.58	325
N HMA	Brand A	94	5	354	296	404	0.1313	9	0.5	104	0.36	325
N HMA	Brand A	95	1	312	312	0	0.0000	10	0.5	85	0.55	600
N HMA	Brand A	95	2	312	372	99	0.0594	10	0.5	83	0.5	600
N HMA	Brand A	95	3	312	345	177	0.1062	10	0.5	45	0.25	600
N HMA	Brand A	95	4	312	321	282	0.1692	10	0.5	60	0.25	600
N HMA	Brand A	95	5	312	261	390	0.2340	10	0.5	82	0.66	600
N HMA	Brand A	95	6	312	323	509	0.3054	10	0.5	87	0.2	600
N HMA	Brand A	95	7	312	268	613	0.3678	10	0.5	76	0.2	600
N HMA	Brand A	95	8	312	327	707	0.4242	10	0.5	77	0.45	600
N HMA	Brand A	95	9	312	322	820	0.4920	10	0.5	61	0.5	600
E HMA	Brand A	96	1	321	321	0	0.0000	10	0.33	85	0.55	3500
E HMA	Brand A	96	2	321	311	99	0.3465	10	0.33	83	0.5	3500
E HMA	Brand A	96	3	321	306	177	0.6195	10	0.33	45	0.25	3500
E HMA	Brand A	96	4	321	258	282	0.9870	10	0.33	60	0.25	3500
E HMA	Brand A	96	5	321	202	390	1.3650	10	0.33	91	0.55	3500
E HMA	Brand A	96	6	321	262	509	1.7815	10	0.33	88	0.2	3500
E HMA	Brand A	96	7	321	245	613	2.1455	10	0.33	76	0.2	3500
E HMA	Brand A	97	1	389	389	0	0.0000	10	0.33	86	0.51	600
E HMA	Brand A	97	2	389	417	99	0.0594	10	0.33	83	0.5	600
E HMA	Brand A	97	3	389	388	177	0.1062	10	0.33	45	0.25	600
E HMA	Brand A	97	4	389	373	282	0.1692	10	0.33	60	0.24	600
E HMA	Brand A	97	5	389	324	390	0.2340	10	0.33	94	0.5	600
E HMA	Brand A	97	6	389	288	509	0.3054	10	0.33	87	0.2	600

Pavement Type	Brand	Site	Round	Initial	Median	Days Since Initial Reading	CTP (mv)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity	AADT
E HMA	Brand A	97	7	389	302	613	0.3678	10	0.33	76	0.2	600
E HMA	Brand A	97	8	389	280	707	0.4242	10	0.33	85	0.39	600
E HMA	Brand A	97	9	389	235	820	0.4920	10	0.33	61	0.5	600
N HMA	Brand A	98	1	462	462	0	0.0000	10	0.33	84	0.52	1500
N HMA	Brand A	98	2	462	417	99	0.1485	10	0.33	83	0.4	1500
N HMA	Brand A	98	3	462	345	177	0.2655	10	0.33	45	0.3	1500
N HMA	Brand A	98	4	462	429	282	0.4230	10	0.33	60	0.25	1500
N HMA	Brand A	98	5	462	425	390	0.5850	10	0.33	93	0.49	1500
N HMA	Brand A	98	6	462	451	509	0.7635	10	0.33	87	0.2	1500
N HMA	Brand A	98	7	462	419	613	0.9195	10	0.33	74	0.2	1500
N HMA	Brand A	98	8	462	396	707	1.0605	10	0.33	85	0.39	1500
N HMA	Brand A	98	9	462	400	820	1.2300	10	0.33	61	0.5	1500
N HMA	Brand A	99	1	352	352	0	0.0000	10	0	86	0.52	1000
N HMA	Brand A	99	2	352	350	99	0.0990	10	0	84	0.41	1000
N HMA	Brand A	99	3	352	315	177	0.1770	10	0	45	0.3	1000
N HMA	Brand A	99	4	352	335	282	0.2820	10	0	60	0.25	1000
N HMA	Brand A	99	5	352	284	390	0.3900	10	0	92	0.51	1000
N HMA	Brand A	99	6	352	288	509	0.5090	10	0	85	0.2	1000
N HMA	Brand A	99	7	352	333	613	0.6130	10	0	73	0.2	1000
N HMA	Brand A	99	8	352	311	707	0.7070	10	0	87	0.38	1000
N HMA	Brand A	99	9	352	305	820	0.8200	10	0	61	0.5	1000
E HMA	Brand A	150	1	465	465	0	0.0000	10	0.33	86	0.44	500
E HMA	Brand A	150	2	465	457	99	0.0495	10	0.33	83	0.4	500
E HMA	Brand A	150	3	465	493	177	0.0885	10	0.33	47	0.3	500
E HMA	Brand A	150	4	465	399	282	0.1410	10	0.33	61	0.25	500
E HMA	Brand A	150	5	465	464	390	0.1950	10	0.33	92	0.55	500
E HMA	Brand A	150	6	465	464	509	0.2545	10	0.33	86	0.2	500
E HMA	Brand A	150	7	465	472	613	0.3065	10	0.33	73	0.2	500
E HMA	Brand A	150	8	465	434	707	0.3535	10	0.33	90	0.34	500
E HMA	Brand A	150	9	465	428	820	0.4100	10	0.33	61	0.5	500

Appendix C: Thermoplastic White Edge Data

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	15	1	501	501	0	*	0.42	84.0	*	*
E HMA	Brand A	15	2	501	505	95	*	0.4	109.0	*	*
E HMA	Brand A	15	3	501	240	237	*	0.25	34.0	*	*
E HMA	Brand A	15	4	501	319	349	*	0.54	76.0	*	*
E HMA	Brand A	15	5	501	338	440	*	0.49	91.0	*	*
E HMA	Brand A	15	6	501	239	548	*	0.52	57.0	*	*
E HMA	Brand A	15	7	501	172	661	*	0.29	74.0	*	*
E HMA	Brand A	16	1	449	449	0	*	0.42	86.0	*	*
E HMA	Brand A	16	2	449	347	95	*	0.35	105.0	*	*
E HMA	Brand A	16	3	449	396	237	*	0.25	35.0	*	*
E HMA	Brand A	16	4	449	320	349	*	0.53	76.0	*	*
E HMA	Brand A	16	5	449	490	440	*	0.57	87.0	*	*
E HMA	Brand A	17	1	461	461	0	*	0.42	87.0	*	*
E HMA	Brand A	17	2	461	528	95	*	0.28	104.0	*	*
E HMA	Brand A	17	3	461	112	237	*	0.25	36.0	*	*
E HMA	Brand A	17	4	461	391	349	*	0.49	82.0	*	*
E HMA	Brand A	17	5	461	418	440	*	0.39	92.0	*	*
E HMA	Brand A	17	6	461	261	548	*	0.53	67.0	*	*
E HMA	Brand A	17	7	461	262	661	*	0.2	73.0	*	*
E HMA	Brand E	18	1	449	449	0	2600	0.55	88	11	0.5
E HMA	Brand E	18	2	449	597	102	2600	0.57	93.9	11	0.5
E HMA	Brand E	18	3	449	673	241	2600	0.20	70	11	0.5
E HMA	Brand E	18	4	449	734	353	2600	0.52	85	11	0.5
E HMA	Brand E	18	5	449	658	439	2600	0.67	81.3	11	0.5
E HMA	Brand E	18	6	449	420	563	2600	0.30	52	11	0.5
E HMA	Brand E	18	7	449	338	667	2600	0.29	81	11	0.5
E HMA	Brand E	18	8	449	338	785	2600	0.60	95	11	0.5
E HMA	Brand E	18	9	449	365	891	2600	0.21	69	11	0.5
E HMA	Brand E	18	10	449	416	1003	2600	0.20	74	11	0.5
E HMA	Brand E	18	11	449	434	1119	2600	0.51	96	11	0.5
E HMA	Brand E	18	12	449	474	1240	2600	0.61	69	11	0.5
E HMA	Brand E	19	1	446	446	0	4400	0.51	91	11	0.5
E HMA	Brand E	19	2	446	509	102	4400	0.57	93.9	11	0.5
E HMA	Brand E	19	3	446	522	241	4400	0.20	70	11	0.5
E HMA	Brand E	19	4	446	617	353	4400	0.52	85	11	0.5
E HMA	Brand E	19	5	446	642	439	4400	0.55	87.4	11	0.5
E HMA	Brand E	19	6	446	452	563	4400	0.30	52	11	0.5
E HMA	Brand E	19	7	446	354	667	4400	0.29	81	11	0.5

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand E	19	8	446	416	785	4400	0.47	104	11	0.5
E HMA	Brand E	19	9	446	361	891	4400	0.22	66	11	0.5
E HMA	Brand E	19	10	446	325	1003	4400	0.20	74	11	0.5
E HMA	Brand E	19	11	446	430	1119	4400	0.51	92	11	0.5
E HMA	Brand E	19	12	446	473	1240	4400	0.71	69	11	0.5
E HMA	Brand E	21	1	455	455	0	8600	0.45	93	12	0.5
E HMA	Brand E	21	2	455	411	102	8600	0.48	90	12	0.5
E HMA	Brand E	21	3	455	516	241	8600	0.20	65	12	0.5
E HMA	Brand E	21	4	455	443	353	8600	0.42	85	12	0.5
E HMA	Brand E	21	5	455	525	439	8600	0.48	92.7	12	0.5
E HMA	Brand E	21	6	455	491	563	8600	0.30	42	12	0.5
E HMA	Brand E	21	7	455	688	667	8600	0.29	81	12	0.5
E HMA	Brand E	21	8	455	760	785	8600	0.41	108	12	0.5
E HMA	Brand E	21	9	455	565	891	8600	0.24	62	12	0.5
E HMA	Brand E	21	10	455	452	1003	8600	0.20	73	12	0.5
E HMA	Brand E	21	11	455	325	1119	8600	0.32	102	12	0.5
E HMA	Brand E	21	12	455	321	1240	8600	0.61	70	12	0.5
E HMA	Brand C	23	1	429	429	0	100	0.36	90	11	1
E HMA	Brand C	23	2	429	469	107	100	0.47	74	11	1
E HMA	Brand C	23	3	429	575	247	100	0.20	74.8	11	1
E HMA	Brand C	23	4	429	549	355	100	0.52	85	11	1
E HMA	Brand C	23	5	429	625	440	100	0.44	82.6	11	1
E HMA	Brand C	23	6	429	689	553	100	0.30	46	11	1
E HMA	Brand C	23	7	429	615	649	100	0.20	57	11	1
E HMA	Brand C	23	8	429	640	764	100	0.51	86	11	1
E HMA	Brand C	23	9	429	660	853	100	0.20	81	11	1
E HMA	Brand C	23	10	429	630	973	100	0.10	45	11	1
E HMA	Brand C	23	11	429	630	1083	100	0.41	81	11	1
E HMA	Brand C	23	12	429	611	1184	100	0.67	77	11	1
E HMA	Brand A	76	1	430	430	0	*	-	-	*	*
E HMA	Brand A	76	2	430	381	112	*	0.31	70.0	*	*
E HMA	Brand A	76	3	430	417	227	*	0.2	90.0	*	*
E HMA	Brand A	76	4	430	377	272	*	0.42	85.0	*	*
E HMA	Brand A	76	5	430	277	387	*	0.5	85.0	*	*
E HMA	Brand A	80	1	446	446	0	150	0.57	74	11	1
E HMA	Brand A	80	2	446	429	90	150	0.43	94	11	1
E HMA	Brand A	80	3	446	488.5	199	150	0.32	66	11	1
E HMA	Brand A	80	4	446	365	277	150	0.25	48	11	1
E HMA	Brand A	80	5	446	484	353	150	0.60	56	11	1

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	80	6	446	513	445	150	0.84	86	11	1
E HMA	Brand A	80	7	446	423	549	150	0.37	55	11	1
E HMA	Brand A	80	8	446	275	661	150	0.48	69	11	1
E HMA	Brand A	80	9	446	261	790	150	0.62	92	11	1
E HMA	Brand A	80	10	446	309	896	150	0.65	75	11	1
E HMA	Brand A	81	1	435	435	0	150	0.55	77	11	1
E HMA	Brand A	81	2	435	485	90	150	0.45	95	11	1
E HMA	Brand A	81	3	435	473	199	150	0.39	57	11	1
E HMA	Brand A	81	4	435	386	277	150	0.28	48	11	1
E HMA	Brand A	81	5	435	552	353	150	0.60	56	11	1
E HMA	Brand A	81	6	435	559	445	150	0.68	88	11	1
E HMA	Brand A	81	7	435	649	549	150	0.34	59	11	1
E HMA	Brand A	81	8	435	468	661	150	0.40	73	11	1
E HMA	Brand A	81	9	435	599	790	150	0.57	94	11	1
E HMA	Brand A	81	10	435	554	896	150	0.65	75	11	1
E HMA	Brand A	82	1	460	460	0	3700	0.47	82	11	1
E HMA	Brand A	82	2	460	472	90	3700	0.47	94	11	1
E HMA	Brand A	82	3	460	511	199	3700	0.41	57	11	1
E HMA	Brand A	82	4	460	504	277	3700	0.28	49	11	1
E HMA	Brand A	82	5	460	536	353	3700	0.60	56	11	1
E HMA	Brand A	82	6	460	578	445	3700	0.60	93	11	1
E HMA	Brand A	82	7	460	610	549	3700	0.31	62	11	1
E HMA	Brand A	82	8	460	472	661	3700	0.38	76	11	1
E HMA	Brand A	82	9	460	378	790	3700	0.55	95	11	1
E HMA	Brand A	82	10	460	306	896	3700	0.65	75	11	1
E HMA	Brand A	83	1	459	459	0	4800	0.41	91	11	1
E HMA	Brand A	83	2	459	437	90	4800	0.61	87	11	1
E HMA	Brand A	83	3	459	534	199	4800	0.40	61	11	1
E HMA	Brand A	83	4	459	496	277	4800	0.25	49	11	1
E HMA	Brand A	83	5	459	535	353	4800	0.60	56	11	1
E HMA	Brand A	83	6	459	550	445	4800	0.53	91	11	1
E HMA	Brand A	83	7	459	311	549	4800	0.26	71	11	1
E HMA	Brand A	83	8	459	125	661	4800	0.36	78	11	1
E HMA	Brand A	83	9	459	181	790	4800	0.52	96	11	1
E HMA	Brand A	83	10	459	231	896	4800	0.65	75	11	1
E HMA	Brand A	84	1	418	418	0	4800	0.42	83	11	1
E HMA	Brand A	84	2	418	424	90	4800	0.66	84	11	1
E HMA	Brand A	84	3	418	479	199	4800	0.39	61	11	1
E HMA	Brand A	84	4	418	280	277	4800	0.25	49	11	1

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	84	5	418	549	353	4800	0.60	56	11	1
E HMA	Brand A	84	6	418	514	445	4800	0.57	90	11	1
E HMA	Brand A	84	7	418	605	549	4800	0.24	72	11	1
E HMA	Brand A	84	8	418	524	661	4800	0.37	76	11	1
E HMA	Brand A	84	9	418	343	790	4800	0.50	101	11	1
E HMA	Brand A	84	10	418	225	896	4800	0.65	75	11	1
E HMA	Brand A	85	1	462	462	0	*	0.46	79.0	*	*
E HMA	Brand A	85	2	462	482	90	*	0.4	97.0	*	*
E HMA	Brand A	85	3	462	514	199	*	0.39	59.0	*	*
E HMA	Brand A	85	4	462	494	277	*	0.28	48.0	*	*
E HMA	Brand A	85	5	462	446	353	*	-	-	*	*
E HMA	Brand A	85	6	462	488	445	*	0.73	84.0	*	*
N HMA	Brand D	100	1	435	435	0	15700	0.51	84	12	5
N HMA	Brand D	100	2	435	509	100	15700	0.60	87	12	5
N HMA	Brand D	100	3	435	533	212	15700	0.58	78	12	5
N HMA	Brand D	100	4	435	578	359	15700	0.51	80	12	5
N HMA	Brand D	100	5	435	665	400	15700	0.68	86	12	5
N HMA	Brand D	100	6	435	660	578	15700	0.25	57	12	5
N HMA	Brand D	100	7	435	474	762	15700	0.4	86	12	5
N HMA	Brand D	100	8	435	345	901	15700	0.4	49	12	5
N HMA	Brand D	100	9	435	325	1038	15700	0.4	72	12	5
N HMA	Brand D	100	10	435	367	1131	15700	0.4	76	12	5
N HMA	Brand D	100	11	435	477	1272	15700	0.4	71	12	5
N HMA	Brand F	101	1	395	395	0	1750	0.35	103	12	2
N HMA	Brand F	101	2	395	509	166	1750	0.40	77	12	2
N HMA	Brand F	101	3	395	510	260	1750	0.4	48	12	2
N HMA	Brand F	101	4	395	420	399	1750	0.49	76	12	2
N HMA	Brand F	101	5	395	584	459	1750	0.56	85	12	2
N HMA	Brand F	101	6	395	548	611	1750	0.33	43	12	2
N HMA	Brand F	101	7	395	637	672	1750	0.31	53	12	2
N HMA	Brand F	101	8	395	680	799	1750	0.4	86	12	2
N HMA	Brand F	101	9	395	563	929	1750	0.4	63	12	2
N HMA	Brand F	101	10	395	139	1071	1750	0.4	70	12	2
N HMA	Brand F	101	11	395	190	1164	1750	0.4	84	12	2
N HMA	Brand F	101	12	395	249	1305	1750	0.4	70	12	2
N HMA	Brand D	102	1	458	458	0	7000	0.75	90	11	2
N HMA	Brand D	102	2	458	485	118	7000	0.40	73	11	2
N HMA	Brand D	102	3	458	349	256	7000	0.40	70	11	2
N HMA	Brand D	102	4	458	509	374	7000	0.40	79	11	2

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
N HMA	Brand D	102	5	458	373	526	7000	0.27	44	11	2
N HMA	Brand D	102	6	458	335	587	7000	0.23	46	11	2
N HMA	Brand D	102	7	458	238	714	7000	0.4	86	11	2
N HMA	Brand D	102	8	458	268	844	7000	0.4	63	11	2
N HMA	Brand D	102	9	458	206	986	7000	0.4	70	11	2
N HMA	Brand D	102	10	458	176	1079	7000	0.4	76	11	2
N HMA	Brand D	102	11	458	288	1220	7000	0.4	73	11	2
N HMA	Brand D	103	1	344	344	0	750	0.5	91	11	2
N HMA	Brand D	103	2	344	393	101	750	0.40	77	11	2
N HMA	Brand D	103	3	344	366	239	750	0.24	68	11	2
N HMA	Brand D	103	4	344	450	351	750	0.41	82.8	11	2
N HMA	Brand D	103	5	344	466	450	750	0.38	71	11	2
N HMA	Brand D	103	6	344	376	579	750	0.2	48	11	2
N HMA	Brand D	103	7	344	304	710	750	0.45	92	11	2
N HMA	Brand D	103	8	344	273	838	750	0.2	75	11	2
N HMA	Brand D	103	9	344	243	949	750	0.2	77	11	2
N HMA	Brand D	103	10	344	252	1078	750	0.34	95	11	2
N HMA	Brand D	103	11	344	241	1185	750	0.88	50	11	2
N HMA	Brand D	104	1	288	288	0	500	0.4	95	11	2
N HMA	Brand D	104	2	288	505	101	500	0.40	77	11	2
N HMA	Brand D	104	3	288	641	239	500	0.25	69	11	2
N HMA	Brand D	104	4	288	597	351	500	0.37	85.1	11	2
N HMA	Brand D	104	5	288	599	450	500	0.38	71	11	2
N HMA	Brand D	104	6	288	637	579	500	0.2	48	11	2
N HMA	Brand D	104	7	288	611	710	500	0.45	95	11	2
N HMA	Brand D	104	8	288	668	838	500	0.2	72	11	2
N HMA	Brand D	104	9	288	628	949	500	0.2	77	11	2
N HMA	Brand D	104	10	288	480	1078	500	0.36	95	11	2
N HMA	Brand D	104	11	288	327	1185	500	0.88	50	11	2
N HMA	Brand D	105	1	388	388	0	250	0.4	96	10	2
N HMA	Brand D	105	2	388	452	101	250	0.40	76	10	2
N HMA	Brand D	105	3	388	575	239	250	0.22	66	10	2
N HMA	Brand D	105	4	388	670	351	250	0.30	88	10	2
N HMA	Brand D	105	5	388	651	450	250	0.34	71	10	2
N HMA	Brand D	105	6	388	761	579	250	0.2	50	10	2
N HMA	Brand D	105	7	388	794	710	250	0.34	99	10	2
N HMA	Brand D	105	8	388	754	838	250	0.21	72	10	2
N HMA	Brand D	105	9	388	675	949	250	0.2	74	10	2
N HMA	Brand D	105	10	388	435	1078	250	0.48	102	10	2

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
N HMA	Brand C	106	1	380	380	0	*	0.66	95.0	*	*
N HMA	Brand C	106	2	380	421	113	*	0.8	72.0	*	*
N HMA	Brand C	106	3	380	449	210	*	0.62	50.0	*	*
N HMA	Brand C	106	4	380	584	328	*	0.63	73.0	*	*
E HMA	Brand C	107	1	400	400	0	*	0.62	96.0	*	*
E HMA	Brand C	107	2	400	407	113	*	0.81	75.0	*	*
E HMA	Brand C	107	3	400	443	210	*	0.25	68.0	*	*
E HMA	Brand C	107	4	400	536	328	*	0.6	73.0	*	*
E HMA	Brand C	107	5	400	555	480	*	0.35	42.0	*	*
E HMA	Brand C	107	6	400	554	541	*	0.29	52.0	*	*
E HMA	Brand C	107	7	400	505	668	*	0.78	81.0	*	*
E HMA	Brand C	108	1	404	404	0	*	0.72	86.0	*	*
E HMA	Brand C	108	2	404	337	113	*	0.81	73.0	*	*
E HMA	Brand C	108	3	404	401	262	*	0.65	77.0	*	*
E HMA	Brand C	108	4	404	500	332	*	0.61	79.0	*	*
E HMA	Brand C	108	5	404	475	480	*	0.24	52.0	*	*
E HMA	Brand C	108	6	404	450	544	*	0.54	50.0	*	*
E HMA	Brand C	108	7	404	492	664	*	0.78	79.0	*	*

Appendix D: Waterborne Yellow Centerline Data

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	2	1	162	162	0	19200	0	82.9	-	0.17
E HMA	Brand A	2	2	162	162	84	19200	0.38	80.6	-	0.17
E HMA	Brand A	2	3	162	143	232	19200	0.33	59	-	0.17
E HMA	Brand A	2	4	162	161	320	19200	0.27	73	-	0.17
E HMA	Brand A	2	5	162	152	425	19200	0.62	79.3	-	0.17
E HMA	Brand A	3	1	135	135	0	6,200	0.37	83.8	10	0.17
E HMA	Brand A	3	2	135	124	85	6200	0.33	89.8	10	0.17
E HMA	Brand A	3	3	135	102	218	6200	0.20	60	10	0.17
E HMA	Brand A	3	4	135	78	321	6200	0.27	73	10	0.17
E HMA	Brand A	3	5	135	79	425	6200	0.52	83.1	10	0.17
E HMA	Brand A	3	6	135	65	519	6200	0.53	73.4	10	0.17
E HMA	Brand A	3	7	135	43	676	6200	0.2	59	10	0.17
E HMA	Brand A	3	8	135	41	784	6200	0.53	78	10	0.17
E HMA	Brand A	3	9	135	41	888	6200	0.25	98	10	0.17
E HMA	Brand A	3	10	135	38	1006	6200	0.2	74	10	0.17
E HMA	Brand A	3	11	135	40	1112	6200	0.38	90	10	0.17
E HMA	Brand A	4	1	166	166	0	11,300	0.58	79	10	1.5
E HMA	Brand A	4	2	166	149	84	11300	0.36	89.2	10	1.5
E HMA	Brand A	4	3	166	150	217	11300	0.20	60	10	1.5
E HMA	Brand A	4	4	166	145	320	11300	0.27	73	10	1.5
E HMA	Brand A	4	5	166	137	425	11300	0.52	84.6	10	1.5
E HMA	Brand A	5	1	116	116	0	7,500	0.37	84.7	-	3
E HMA	Brand A	5	2	116	114	75	7500	0.31	90.5	-	3
E HMA	Brand A	5	3	116	72	208	7500	0.20	60	-	3
E HMA	Brand A	5	4	116	60	311	7500	0.25	90	-	3
E HMA	Brand A	5	5	116	41	425	7500	0.53	82.2	-	3
E HMA	Brand A	5	6	116	41	519	7500	0.53	75	-	3
E HMA	Brand A	5	7	116	34	676	7500	0.2	60	-	3
E HMA	Brand A	5	8	116	27	784	7500	0.51	83	-	3
E HMA	Brand A	5	9	116	26	888	7500	0.22	94	-	3
E HMA	Brand A	5	10	116	25	1006	7500	0.2	66	-	3
E HMA	Brand A	6	1	159	159	0	2,900	0.54	78.8	9	-
E HMA	Brand A	6	2	159	145	72	2900	0.57	77.1	9	-
E HMA	Brand A	6	3	159	99	218	2900	0.33	59	9	-
E HMA	Brand A	6	4	159	88	306	2900	0.26	90	9	-
E HMA	Brand A	6	5	159	71	418	2900	0.60	78.3	9	-
E HMA	Brand A	6	6	159	58	512	2900	0.57	71	9	-
E HMA	Brand A	6	7	159	51	669	2900	0.2	59	9	-
E HMA	Brand A	6	8	159	47	777	2900	0.44	93	9	-
E HMA	Brand A	6	9	159	46	881	2900	0.26	94	9	-
E HMA	Brand A	6	10	159	38	999	2900	0.2	71	9	-
E HMA	Brand A	6	11	159	36	1105	2900	0.2	102	9	-
E HMA	Brand A	7	1	149	149	0	8,100	0.42	76.8	11	-
E HMA	Brand A	7	2	149	145	73	8100	0.60	78.1	11	-
E HMA	Brand A	7	3	149	136	219	8100	0.33	59	11	-
E HMA	Brand A	7	4	149	115	307	8100	0.26	90	11	-

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	7	5	149	82	418	8100	0.60	78.8	11	-
E HMA	Brand A	8	1	97	97	0	8,200	0.47	71.6	11	0
E HMA	Brand A	8	2	97	94	78	8200	0.57	77.6	11	0
E HMA	Brand A	8	3	97	100	224	8200	0.33	59	11	0
E HMA	Brand A	8	4	97	99	344	8200	0.40	84	11	0
E HMA	Brand A	12	1	158	158	0	1,000	0.34	75.2	9	-
E HMA	Brand A	12	2	158	145	68	1000	0.63	79.3	9	-
E HMA	Brand A	12	3	158	128	214	1000	0.25	33	9	-
E HMA	Brand A	12	4	158	125	324	1000	0.40	84	9	-
E HMA	Brand A	12	5	158	125	432	1000	0.58	76.8	9	-
E HMA	Brand A	12	6	158	111	524	1000	0.40	72	9	-
E HMA	Brand A	12	7	158	98	662	1000	0.20	58	9	-
E HMA	Brand A	12	8	158	103	770	1000	0.44	93	9	-
E HMA	Brand A	12	9	158	99	874	1000	0.30	92	9	-
E HMA	Brand A	12	10	158	88	992	1000	0.2	75	9	-
E HMA	Brand A	12	11	158	85	1098	1000	0.21	100	9	-
E HMA	Brand A	13	1	155	155	0	6,600	0.35	76.8	10	-
E HMA	Brand A	13	2	155	162	69	6600	0.52	83.8	10	-
E HMA	Brand A	13	3	155	149	215	6600	0.25	33	10	-
E HMA	Brand A	13	4	155	129	325	6600	0.40	84	10	-
E HMA	Brand A	13	5	155	130	432	6600	0.61	79.1	10	-
E HMA	Brand A	13	6	155	48	524	6600	0.51	66.7	10	-
E HMA	Brand A	13	7	155	92	662	6600	0.2	58	10	-
E HMA	Brand A	13	8	155	92	770	6600	0.46	91	10	-
E HMA	Brand A	13	9	155	91	874	6600	0.32	85	10	-
E HMA	Brand A	13	10	155	75	992	6600	0.2	69	10	-
E HMA	Brand A	13	11	155	68	1098	6600	0.2	103	10	-
E HMA	Brand A	14	1	137	137	0	1,000	0.35	76.8	11	6
E HMA	Brand A	14	2	137	121	68	1000	0.40	94.3	11	6
E HMA	Brand A	14	3	137	117	214	1000	0.25	33	11	6
E HMA	Brand A	14	4	137	101	324	1000	0.42	85	11	6
E HMA	Brand A	14	5	137	89	432	1000	0.6	80.4	11	6
E HMA	Brand A	14	6	137	81	524	1000	0.56	66	11	6
E HMA	Brand A	14	7	137	66	662	1000	0.2	58	11	6
E HMA	Brand A	14	8	137	61	770	1000	0.44	85	11	6
E HMA	Brand A	14	9	137	60	874	1000	0.33	90	11	6
E HMA	Brand A	14	10	137	41	992	1000	0.2	71	11	6
E HMA	Brand A	14	11	137	38	1098	1000	0.21	103	11	6
E HMA	Brand A	24	1	104	104	0	25	0.55	86	10	0
E HMA	Brand A	24	2	104	88	89	25	0.47	81.3	10	0
E HMA	Brand A	24	3	104	93	222	25	0.31	68	10	0
E HMA	Brand A	24	4	104	63	336	25	0.53	81.7	10	0
E HMA	Brand A	24	5	104	62	443	25	0.44	86	10	0
E HMA	Brand A	24	6	104	51	552	25	0.26	52	10	0
E HMA	Brand A	25	1	134	134	0	250	0.54	86	11	0
E HMA	Brand A	25	2	134	133	89	250	0.47	81.3	11	0
E HMA	Brand A	25	3	134	132	222	250	0.31	68	11	0

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	25	4	134	125	336	250	0.41	91	11	0
E HMA	Brand A	25	5	134	119	443	250	0.44	86	11	0
E HMA	Brand A	25	6	134	111	552	250	0.26	52	11	0
E HMA	Brand A	26	1	61	61	0	450	0.53	87	10	-
E HMA	Brand A	26	2	61	65	89	450	0.40	86	10	-
E HMA	Brand A	26	3	61	71	222	450	0.32	70	10	-
E HMA	Brand A	26	4	61	58	336	450	0.48	83.5	10	-
E HMA	Brand A	26	5	61	47	443	450	0.44	86	10	-
E HMA	Brand A	26	6	61	50	552	450	0.26	52	10	-
E HMA	Brand A	27	1	160	160	0	50	0.53	87	11	1
E HMA	Brand A	27	2	160	129	89	50	0.40	86	11	1
E HMA	Brand A	27	3	160	128	222	50	0.30	70	11	1
E HMA	Brand A	27	4	160	126	336	50	0.53	80.6	11	1
E HMA	Brand A	27	5	160	124	443	50	0.46	85	11	1
E HMA	Brand A	27	6	160	112	552	50	0.26	52	11	1
E HMA	Brand A	28	1	171	171	0	150	0.52	88	10	0
E HMA	Brand A	28	2	171	160	89	150	0.40	86	10	0
E HMA	Brand A	28	3	171	144	222	150	0.31	75	10	0
E HMA	Brand A	28	4	171	146	336	150	0.50	86.7	10	0
E HMA	Brand A	28	5	171	149	443	150	0.46	85	10	0
E HMA	Brand A	28	6	171	129	552	150	0.26	52	10	0
E HMA	Brand A	29	1	218	218	0	3,700	-	-	10	0.33
E HMA	Brand A	29	2	218	222	108	3700	0.46	71.8	10	0.33
E HMA	Brand A	29	3	218	155	219	3700	0.27	60	10	0.33
E HMA	Brand A	29	4	218	162	337	3700	0.71	80.8	10	0.33
E HMA	Brand A	29	5	218	156	447	3700	0.49	76.3	10	0.33
E HMA	Brand A	29	6	218	149	569	3700	0.23	28	10	0.33
E HMA	Brand A	30	1	155	155	0	1,850	-	-	10	0.5
E HMA	Brand A	30	2	155	194	108	1850	0.46	71.8	10	0.5
E HMA	Brand A	30	3	155	130	219	1850	0.27	60	10	0.5
E HMA	Brand A	30	4	155	162	337	1850	0.62	85.5	10	0.5
E HMA	Brand A	30	5	155	163	447	1850	0.49	76.8	10	0.5
E HMA	Brand A	30	6	155	160	569	1850	0.23	29	10	0.5
E HMA	Brand A	31	1	176	176	0	500	-	-	10	0.5
E HMA	Brand A	31	2	176	179	94	500	0.30	74	10	0.5
E HMA	Brand A	31	3	176	158	220	500	0.27	60	10	0.5
E HMA	Brand A	31	4	176	168	338	500	0.56	87.6	10	0.5
E HMA	Brand A	32	1	157	157	0	325	-	-	9	0.33
E HMA	Brand A	32	2	157	164	94	325	0.30	74	9	0.33
E HMA	Brand A	32	3	157	149	220	325	0.27	60	9	0.33
E HMA	Brand A	32	4	157	150	338	325	0.55	89.4	9	0.33
E HMA	Brand A	34	1	121	121	0	600	-	-	10	0.5
E HMA	Brand A	34	2	121	124	99	600	0.30	74	10	0.5
E HMA	Brand A	34	3	121	108	225	600	0.27	60	10	0.5
E HMA	Brand A	34	4	121	99	343	600	0.48	92.1	10	0.5
E HMA	Brand A	37	1	147	147	0	550	-	-	9	0.17
E HMA	Brand A	37	2	147	166	99	550	0.30	74	9	0.17

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	37	3	147	149	225	550	0.27	60	9	0.17
E HMA	Brand A	37	4	147	150	354	550	0.43	89.4	9	0.17
E HMA	Brand A	38	1	100	100	0	150	-	-	-	0.17
E HMA	Brand A	38	2	100	120	100	150	0.30	74	-	0.17
E HMA	Brand A	38	3	100	112	226	150	0.27	60	-	0.17
E HMA	Brand A	38	4	100	101	344	150	0.44	95	-	0.17
E HMA	Brand B	39	1	114	114	0	1,450	-	-	10	0.25
E HMA	Brand B	39	2	114	92	90	1450	0.30	80	10	0.25
E HMA	Brand B	39	3	114	52	230	1450	0.27	72.5	10	0.25
E HMA	Brand B	39	4	114	65	355	1450	0.48	82.9	10	0.25
E HMA	Brand B	39	5	114	72	461	1450	0.42	68	10	0.25
E HMA	Brand B	39	6	114	65	569	1450	0.20	54	10	0.25
E HMA	Brand B	39	7	114	50	740	1450	0.55	79	10	0.25
E HMA	Brand B	39	8	114	52	874	1450	0.20	71	10	0.25
E HMA	Brand B	39	9	114	56	972	1450	0.2	67	10	0.25
E HMA	Brand B	39	10	114	53	1077	1450	0.37	102	10	0.25
E HMA	Brand B	39	11	114	62	1189	1450	0.79	66	10	0.25
E HMA	Brand B	40	1	52	52	0	500	-	-	9	-
E HMA	Brand B	40	2	52	45	90	500	0.35	80	9	-
E HMA	Brand B	40	3	52	28	230	500	0.30	76.6	9	-
E HMA	Brand B	40	4	52	30	355	500	0.45	87.4	9	-
E HMA	Brand B	40	5	52	29	461	500	0.41	73.4	9	-
E HMA	Brand B	40	6	52	30	569	500	0.20	54	9	-
E HMA	Brand B	40	7	52	22	740	500	0.48	87	9	-
E HMA	Brand B	40	8	52	21	874	500	0.22	82	9	-
E HMA	Brand B	40	9	52	24	972	500	0.2	76	9	-
E HMA	Brand B	40	10	52	20	1077	500	0.32	102	9	-
E HMA	Brand B	40	11	52	22	1189	500	0.74	67	9	-
E HMA	Brand B	41	1	32	32	0	500	-	-	9	0
E HMA	Brand B	41	2	32	31	90	500	0.31	84	9	0
E HMA	Brand B	41	3	32	26	230	500	0.30	82	9	0
E HMA	Brand B	41	4	32	23	355	500	0.47	85.5	9	0
E HMA	Brand B	41	5	32	22	461	500	0.39	73.4	9	0
E HMA	Brand B	41	6	32	24	569	500	0.20	55	9	0
E HMA	Brand B	41	7	32	27	740	500	0.45	94	9	0
E HMA	Brand B	41	8	32	28	874	500	0.20	77	9	0
E HMA	Brand B	41	9	32	31	972	500	0.2	78	9	0
E HMA	Brand B	41	10	32	30	1077	500	0.29	107	9	0
E HMA	Brand B	41	11	32	34	1189	500	0.79	66	9	0
E HMA	Brand B	42	1	44	44	0	500	-	-	10	5
E HMA	Brand B	42	2	44	40	90	500	0.33	83	10	5
E HMA	Brand B	42	3	44	33	230	500	0.30	85.3	10	5
E HMA	Brand B	42	4	44	28	355	500	0.44	87.3	10	5
E HMA	Brand B	42	5	44	30	461	500	0.39	72	10	5
E HMA	Brand B	42	6	44	27	569	500	0.20	55	10	5
E HMA	Brand B	42	7	44	23	740	500	0.36	97	10	5
E HMA	Brand B	42	8	44	24	874	500	0.21	78	10	5

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand B	42	9	44	23	972	500	0.2	81	10	5
E HMA	Brand B	42	10	44	21	1077	500	0.28	107	10	5
E HMA	Brand B	42	11	44	26	1189	500	0.74	68	10	5
E HMA	Brand B	43	1	103	103	0	200	-	-	-	-
E HMA	Brand B	43	2	103	112	115	200	0.31	82.6	-	-
E HMA	Brand B	43	3	103	54	255	200	0.29	83.7	-	-
E HMA	Brand B	44	1	148	148	0	4,700	-	-	19	2
E HMA	Brand B	44	2	148	153	91	4700	0.33	84.7	19	2
E HMA	Brand B	44	3	148	56	231	4700	0.30	82.2	19	2
E HMA	Brand B	44	4	148	97	356	4700	0.47	87	19	2
E HMA	Brand B	44	5	148	91	461	4700	0.37	75	19	2
E HMA	Brand B	44	6	148	84	569	4700	0.20	56	19	2
E HMA	Brand B	44	7	148	60	740	4700	0.32	96	19	2
E HMA	Brand B	44	8	148	48	874	4700	0.20	79	19	2
E HMA	Brand B	44	9	148	50	972	4700	0.2	76	19	2
E HMA	Brand B	44	10	148	47	1077	4700	0.23	108	19	2
E HMA	Brand B	44	11	148	54	1189	4700	0.74	68	19	2
E HMA	Brand B	45	1	125	125	0	500	-	-	19	-
E HMA	Brand B	45	2	125	122	91	500	0.33	84.7	19	-
E HMA	Brand B	45	3	125	95	231	500	0.30	82.9	19	-
E HMA	Brand B	45	4	125	99	356	500	0.40	87.8	19	-
E HMA	Brand B	45	5	125	94	461	500	0.37	76	19	-
E HMA	Brand B	45	6	125	82	569	500	0.20	56	19	-
E HMA	Brand B	45	7	125	55	740	500	0.32	95	19	-
E HMA	Brand B	45	8	125	35	874	500	0.22	73	19	-
E HMA	Brand B	45	9	125	37	972	500	0.2	74	19	-
E HMA	Brand B	45	10	125	30	1077	500	0.23	107	19	-
E HMA	Brand B	45	11	125	40	1189	500	0.74	69	19	-
E HMA	Brand B	46	1	41	41	0	500	-	-	17	-
E HMA	Brand B	46	2	41	39	91	500	0.31	83.5	17	-
E HMA	Brand B	46	3	41	28	231	500	0.31	82	17	-
E HMA	Brand B	46	4	41	23	356	500	0.40	87.8	17	-
E HMA	Brand B	46	5	41	23	461	500	0.37	76	17	-
E HMA	Brand B	46	6	41	19	569	500	0.20	56	17	-
E HMA	Brand B	46	7	41	19	740	500	0.32	95	17	-
E HMA	Brand B	46	8	41	18	874	500	0.22	69	17	-
E HMA	Brand B	46	9	41	20	972	500	0.2	75	17	-
E HMA	Brand B	46	10	41	19	1077	500	0.23	105	17	-
E HMA	Brand B	46	11	41	27	1189	500	0.74	68	17	-
E HMA	Brand B	47	1	62	62	0	500	-	-	17	-
E HMA	Brand B	47	2	62	60	90	500	0.31	82.8	17	-
E HMA	Brand B	47	3	62	40	230	500	0.30	84.7	17	-
E HMA	Brand B	47	4	62	36	355	500	0.40	87.8	17	-
E HMA	Brand B	47	5	62	62	461	500	0.35	76	17	-
E HMA	Brand B	47	6	62	32	569	500	0.20	56	17	-
E HMA	Brand B	47	7	62	30	740	500	0.33	98	17	-
E HMA	Brand B	48	1	125	125	0	500	-	-	13	-

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand B	48	2	125	127	90	500	0.33	83	13	-
E HMA	Brand B	48	3	125	53	230	500	0.31	84.2	13	-
E HMA	Brand B	48	4	125	66	355	500	0.40	87.8	13	-
E HMA	Brand B	48	5	125	38	461	500	0.35	76	13	-
E HMA	Brand B	48	6	125	50	569	500	0.20	56	13	-
E HMA	Brand B	48	7	125	35	740	500	0.31	100	13	-
E HMA	Brand B	48	8	125	31	874	500	0.22	73	13	-
E HMA	Brand B	48	9	125	28	972	500	0.2	74	13	-
E HMA	Brand B	48	10	125	23	1077	500	0.24	104	13	-
E HMA	Brand B	48	11	125	29	1189	500	0.74	69	13	-
E HMA	Brand A	49	1	119	119	0	1,450	-	79	10	0.5
E HMA	Brand A	49	2	119	146	96	1450	0.35	81	10	0.5
E HMA	Brand A	49	3	119	121	229	1450	0.27	83	10	0.5
E HMA	Brand A	49	4	119	117	336	1450	0.45	88	10	0.5
E HMA	Brand A	49	5	119	119	432	1450	0.42	84.6	10	0.5
E HMA	Brand A	49	6	119	116	554	1450	0.21	33	10	0.5
E HMA	Brand A	50	1	145	145	0	650	-	79	10	1
E HMA	Brand A	50	2	145	167	96	650	0.37	83	10	1
E HMA	Brand A	50	3	145	142	229	650	0.27	88	10	1
E HMA	Brand A	50	4	145	142	336	650	0.46	86	10	1
E HMA	Brand A	52	1	122	122	0	225	-	79	10	10
E HMA	Brand A	52	2	122	135	96	225	0.30	80	10	10
E HMA	Brand A	52	3	122	82	229	225	0.27	88	10	10
E HMA	Brand A	52	4	122	84	336	225	0.46	86	10	10
E HMA	Brand A	53	1	161	161	0	100	-	79	9	0
E HMA	Brand A	53	2	161	181	96	100	0.30	80	9	0
E HMA	Brand A	53	3	161	111	229	100	0.27	88	9	0
E HMA	Brand A	53	4	161	112	336	100	0.46	86	9	0
E HMA	Brand A	53	5	161	116	432	100	0.39	84.2	9	0
E HMA	Brand A	53	6	161	88	554	100	0.24	32	9	0
E HMA	Brand A	54	1	124	124	0	100	-	79	9	0
E HMA	Brand A	54	2	124	153	96	100	0.27	80	9	0
E HMA	Brand A	54	3	124	120	229	100	0.26	88	9	0
E HMA	Brand A	54	4	124	116	336	100	0.46	86	9	0
E HMA	Brand A	55	1	189	189	0	600	-	80	10	2
E HMA	Brand A	55	2	189	215	96	600	0.30	83	10	2
E HMA	Brand A	55	3	189	156	229	600	0.26	88	10	2
E HMA	Brand A	55	4	189	141	336	600	0.46	84.7	10	2
E HMA	Brand A	55	5	189	135	432	600	0.39	84.4	10	2
E HMA	Brand A	55	6	189	130	554	600	0.24	31	10	2
E HMA	Brand A	56	1	153	153	0	275	-	80	9	0.33
E HMA	Brand A	56	2	153	183	96	275	0.27	83	9	0.33
E HMA	Brand A	56	3	153	149	229	275	0.26	88	9	0.33
E HMA	Brand A	56	4	153	145	336	275	0.43	83.7	9	0.33
E HMA	Brand A	57	1	195	195	0	350	-	78	10	0
E HMA	Brand A	57	2	195	192	94	350	0.38	74	10	0
E HMA	Brand A	57	3	195	169	230	350	0.29	82	10	0

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	57	4	195	169	316	350	0.49	94	10	0
E HMA	Brand A	58	1	168	168	0	1,850	-	78	10	0.33
E HMA	Brand A	58	2	168	150	93	1850	0.38	74	10	0.33
E HMA	Brand A	58	3	168	106	229	1850	0.29	82	10	0.33
E HMA	Brand A	58	4	168	108	315	1850	0.50	95	10	0.33
E HMA	Brand A	59	1	141	141	0	3,200	-	78	11	0
E HMA	Brand A	59	2	141	136	93	3200	0.35	85	11	0
E HMA	Brand A	59	3	141	103	229	3200	0.29	80	11	0
E HMA	Brand A	59	4	141	98	326	3200	0.45	87.8	11	0
E HMA	Brand A	59	5	141	94	419	3200	0.44	81	11	0
E HMA	Brand A	59	6	141	99	541	3200	0.23	32	11	0
E HMA	Brand A	60	1	167	167	0	500	-	78	10	0
E HMA	Brand A	60	2	167	133	93	500	0.35	85	10	0
E HMA	Brand A	60	3	167	112	229	500	0.29	80	10	0
E HMA	Brand A	60	4	167	90	326	500	0.44	88.3	10	0
E HMA	Brand A	61	1	79	79	0	75	-	79	10	0.5
E HMA	Brand A	61	2	79	69	93	75	0.38	84	10	0.5
E HMA	Brand A	61	3	79	60	229	75	0.27	80	10	0.5
E HMA	Brand A	61	4	79	56	315	75	0.56	87.1	10	0.5
E HMA	Brand A	61	5	79	58	419	75	0.43	76.8	10	0.5
E HMA	Brand A	61	6	79	53	541	75	0.23	32	10	0.5
E HMA	Brand A	62	1	195	195	0	175	-	79	10	0.5
E HMA	Brand A	62	2	195	187	93	175	0.35	85	10	0.5
E HMA	Brand A	62	3	195	182	229	175	0.28	83	10	0.5
E HMA	Brand A	62	4	195	176	315	175	0.56	91	10	0.5
E HMA	Brand A	63	1	178	178	0	175	-	79	9	0.5
E HMA	Brand A	63	2	178	170	93	175	0.26	89	9	0.5
E HMA	Brand A	63	3	178	149	229	175	0.27	86	9	0.5
E HMA	Brand A	63	4	178	128	315	175	0.49	93	9	0.5
E HMA	Brand A	64	1	191	191	0	550	-	79	10	0.33
E HMA	Brand A	64	2	191	186	94	550	0.38	84	10	0.33
E HMA	Brand A	64	3	191	177	230	550	0.28	86	10	0.33
E HMA	Brand A	64	4	191	168	316	550	0.49	93	10	0.33
E HMA	Brand A	72	1	132	132	0	1,000	-	-	10	0
E HMA	Brand A	72	2	132	130	70	1000	0.31	78	10	0
E HMA	Brand A	72	3	132	123	201	1000	0.39	79	10	0
E HMA	Brand A	72	4	132	115	297	1000	0.42	89.6	10	0
E HMA	Brand A	72	5	132	111	399	1000	0.44	82.8	10	0
E HMA	Brand A	72	6	132	87	521	1000	0.22	33	10	0
E HMA	Brand A	72	7	132	98	692	1000	0.42	97	10	0
E HMA	Brand A	72	8	132	101	826	1000	0.2	86	10	0
E HMA	Brand A	72	9	132	99	944	1000	0.21	71	10	0
Chip Seal	Brand A	109	1	195	195	0	50	0.5	88	-	-
Chip Seal	Brand A	109	2	195	180	112	50	0.67	72	-	-
Chip Seal	Brand A	109	3	195	195	259	50	0.50	83	-	-
Chip Seal	Brand A	110	1	175	175	0	50	0.50	90	10	-
Chip Seal	Brand A	110	2	175	167	90	50	0.54	77	10	-

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
Chip Seal	Brand A	110	3	175	173	237	50	0.49	82	10	-
Chip Seal	Brand A	110	4	175	157	304	50	0.59	84	10	-
Chip Seal	Brand A	110	5	175	163	479	50	0.28	50	10	-
Chip Seal	Brand A	110	6	175	152	540	50	0.24	60	10	-
Chip Seal	Brand A	111	1	168	168	0	250	0.50	93	9.5	-
Chip Seal	Brand A	111	2	168	135	90	250	0.67	67	9.5	-
Chip Seal	Brand A	111	3	168	143	237	250	0.50	83	9.5	-
Chip Seal	Brand A	111	4	168	180	304	250	0.66	86	9.5	-
Chip Seal	Brand A	111	5	168	165	479	250	0.29	50	9.5	-
Chip Seal	Brand A	111	6	168	135	540	250	0.23	63	9.5	-
Chip Seal	Brand A	112	1	129	129	0	60	0.50	90	9.5	-
Chip Seal	Brand A	112	2	129	118	90	60	0.67	69	9.5	-
Chip Seal	Brand A	112	3	129	116	237	60	0.46	83	9.5	-
Chip Seal	Brand A	112	4	129	119	304	60	0.63	87	9.5	-
Chip Seal	Brand A	112	5	129	113	479	60	0.30	50	9.5	-
Chip Seal	Brand A	112	6	129	111.5	540	60	0.23	63	9.5	-
Chip Seal	Brand A	112	7	129	113	661	60	-	88	9.5	-
Chip Seal	Brand A	112	8	129	109	800	60	-	55	9.5	-
Chip Seal	Brand A	112	9	129	110	937	60	-	71	9.5	-
Chip Seal	Brand A	112	10	129	104	1030	60	-	91	9.5	-
Chip Seal	Brand A	112	11	129	109	1171	60	-	74	9.5	-
Chip Seal	Brand A	113	1	171	171	0	60	0.50	90	9	-
Chip Seal	Brand A	113	2	171	145	90	60	0.65	69	9	-
Chip Seal	Brand A	113	3	171	129	237	60	0.48	84	9	-
Chip Seal	Brand A	113	4	171	131	304	60	0.57	86	9	-
Chip Seal	Brand A	113	5	171	116	479	60	0.32	49	9	-
Chip Seal	Brand A	113	6	171	105	540	60	0.22	63	9	-
Chip Seal	Brand A	113	7	171	100	661	60	-	88	9	-
Chip Seal	Brand A	113	8	171	100	800	60	-	55	9	-
Chip Seal	Brand A	113	9	171	100	937	60	-	73	9	-
Chip Seal	Brand A	113	10	171	81	1030	60	-	93	9	-
Chip Seal	Brand A	113	11	171	74	1171	60	-	73	9	-
Chip Seal	Brand A	114	1	194	194	0	75	0.50	89	10	1
Chip Seal	Brand A	114	2	194	167	90	75	0.64	72	10	1
Chip Seal	Brand A	114	3	194	171	237	75	0.47	83	10	1
Chip Seal	Brand A	114	4	194	227	304	75	0.57	86	10	1
Chip Seal	Brand A	114	5	194	203	479	75	0.32	45	10	1
Chip Seal	Brand A	114	6	194	199	540	75	0.22	64	10	1
Chip Seal	Brand A	114	7	194	195	638	75	0.57	86	10	1
Chip Seal	Brand A	115	1	161	161	0	5,300	0.50	88	11	-
Chip Seal	Brand A	115	2	161	99	98	5300	0.54	78	11	-
Chip Seal	Brand A	115	3	161	72	245	5300	0.54	82	11	-
Chip Seal	Brand A	115	4	161	167	312	5300	0.55	86	11	-
Chip Seal	Brand A	115	5	161	95	477	5300	0.23	53	11	-
Chip Seal	Brand A	115	6	161	81	530	5300	0.23	60	11	-
Chip Seal	Brand A	115	7	161	69	661	5300	0.28	93	11	-
Chip Seal	Brand A	115	8	161	53	800	5300	-	51	11	-

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
Chip Seal	Brand A	115	9	161	52	937	5300	-	73	11	-
Chip Seal	Brand A	116	1	114	114	0	700	0.45	87	10	-
Chip Seal	Brand A	116	2	114	112	51	700	0.54	75	10	-
Chip Seal	Brand A	116	3	114	101	198	700	0.48	82	10	-
Chip Seal	Brand A	116	4	114	101	265	700	0.49	85	10	-
Chip Seal	Brand A	116	5	114	73	446	700	0.27	43	10	-
Chip Seal	Brand A	116	6	114	74	507	700	0.22	63	10	-
Chip Seal	Brand A	116	7	114	66	632	700	-	88	10	-
Chip Seal	Brand A	116	8	114	55	767	700	-	56	10	-
Chip Seal	Brand A	116	9	114	54	904	700	-	70	10	-
Chip Seal	Brand A	116	10	114	57	997	700	-	80	10	-
Chip Seal	Brand A	117	1	108	108	0	425	0.40	87	10	-
Chip Seal	Brand A	117	2	108	105	51	425	0.54	75	10	-
Chip Seal	Brand A	117	3	108	101	198	425	0.53	84	10	-
Chip Seal	Brand A	117	4	108	101	265	425	0.41	87	10	-
Chip Seal	Brand A	117	5	108	150	446	425	0.34	42	10	-
Chip Seal	Brand A	117	6	108	154	507	425	0.23	63	10	-
Chip Seal	Brand A	117	7	108	146	632	425	-	88	10	-
Chip Seal	Brand A	118	1	184	184	0	325	0.40	87	10	0.5
Chip Seal	Brand A	118	2	184	175	51	325	0.52	75	10	0.5
Chip Seal	Brand A	118	3	184	184	198	325	0.52	85	10	0.5
Chip Seal	Brand A	118	4	184	182	265	325	0.58	85	10	0.5
Chip Seal	Brand A	118	5	184	168	446	325	0.26	42	10	0.5
Chip Seal	Brand A	118	6	184	160	507	325	0.23	63	10	0.5
Chip Seal	Brand A	118	7	184	152	632	325	-	88	10	0.5
Chip Seal	Brand A	118	8	184	154	767	325	-	57	10	0.5
Chip Seal	Brand A	118	9	184	142	904	325		70	10	0.5
Chip Seal	Brand A	119	1	204	204	0	900	0.40	87	11	1.5
Chip Seal	Brand A	119	2	204	189	51	900	0.52	76	11	1.5
Chip Seal	Brand A	119	3	204	184	198	900	0.52	85	11	1.5
Chip Seal	Brand A	119	4	204	193	265	900	0.43	87	11	1.5
Chip Seal	Brand A	119	5	204	57	446	900	0.37	40	11	1.5
Chip Seal	Brand A	119	6	204	57	507	900	0.24	63	11	1.5
Chip Seal	Brand A	119	7	204	57	632	900	-	92	11	1.5
Chip Seal	Brand A	120	1	167	167	0	850	0.40	85	9	-
Chip Seal	Brand A	120	2	167	142	51	850	0.50	76	9	-
Chip Seal	Brand A	120	3	167	139	198	850	0.50	85	9	-
Chip Seal	Brand A	120	4	167	140	265	850	0.48	84	9	-
Chip Seal	Brand A	120	5	167	160	446	850	0.39	36	9	-
Chip Seal	Brand A	120	6	167	145	507	850	0.27	63	9	-
Chip Seal	Brand A	120	7	167	135	767	850	-	93	9	-
Chip Seal	Brand A	120	8	167	131	767	850	-	55	9	-
Chip Seal	Brand A	120	9	167	129	904	850	-	71	9	-
E HMA	Brand B	151	1	146	146	0	1,000	0.53	89.2	-	-
E HMA	Brand B	152	1	155	155	0	1,000	0.42	95.2	-	-
E HMA	Brand B	152	2	155	130	103	1,000	0.55	83.3	-	-
E HMA	Brand B	152	3	155	102	182	1,000	0.35	46	-	-

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand B	152	4	155	79	278	1,000	0.27	80	-	-
E HMA	Brand B	152	5	155	78	400	1,000	0.68	93	-	-
E HMA	Brand B	152	6	155	67	502	1,000	0.2	81	-	-
E HMA	Brand B	152	7	155	59	614	1,000	0.2	79	-	-
E HMA	Brand B	152	8	155	73	742	1,000	0.33	98	-	-
E HMA	Brand B	152	9	155	73	849	1,000	0.6	70	-	-
E HMA	Brand B	153	1	166	166	0	1,000	0.43	90.3	-	-
E HMA	Brand B	154	1	132	132	0	1,000	0.41	91.4	-	-
E HMA	Brand B	155	1	158	158	0	2,700	0.38	94.8	-	-
E HMA	Brand B	155	2	158	149	103	2,700	0.42	81.3	-	-
E HMA	Brand B	155	3	158	128	182	2,700	0.35	47	-	-
E HMA	Brand B	155	4	158	108	278	2,700	0.27	81	-	-
E HMA	Brand B	155	5	158	96	400	2,700	0.67	89	-	-
E HMA	Brand B	155	6	158	92	502	2,700	0.2	80	-	-
E HMA	Brand B	155	7	158	84	614	2,700	0.29	80	-	-
E HMA	Brand B	155	8	158	79	742	2,700	0.34	100	-	-
E HMA	Brand B	156	1	180	180	0	2600	0.40	92	-	-
E HMA	Brand B	156	2	180	187	103	2600	0.46	80.1	-	-
E HMA	Brand B	156	3	180	169	182	2600	0.35	47	-	-
E HMA	Brand B	156	4	180	162	278	2600	0.27	81	-	-
E HMA	Brand B	156	5	180	165	400	2600	0.6	90	-	-
E HMA	Brand B	156	6	180	156	502	2600	0.2	83	-	-
E HMA	Brand B	156	7	180	152	614	2600	0.3	77	-	-
E HMA	Brand B	156	8	180	142	742	2600	0.35	101	-	-
E HMA	Brand B	156	9	180	133	849	2600	0.6	70	-	-
E HMA	Brand B	157	1	120	120	0	1,000	0.39	93	-	-
E HMA	Brand B	157	2	120	89	103	1,000	0.51	85.6	-	-
E HMA	Brand B	157	3	120	67	182	1,000	0.35	48	-	-
E HMA	Brand B	157	4	120	36	278	1,000	0.27	81	-	-
E HMA	Brand B	157	5	120	31	400	1,000	0.6	88	-	-
E HMA	Brand B	157	6	120	22	502	1,000	0.2	84	-	-
E HMA	Brand B	157	7	120	34	614	1,000	0.3	77	-	-
E HMA	Brand B	157	8	120	31	742	1,000	0.32	102	-	-
E HMA	Brand B	157	9	120	28	849	1,000	0.6	70	-	-

Appendix E: Thermoplastic Yellow Centerline Data

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	15	1	260	260	0	*	0.42	84.0	*	*
E HMA	Brand A	15	2	260	287	95	*	0.4	109.0	*	*
E HMA	Brand A	15	3	260	182	236	*	0.25	34.0	*	*
E HMA	Brand A	15	4	260	147	349	*	0.54	76.0	*	*
E HMA	Brand A	15	5	260	181	440	*	0.49	91.0	*	*
E HMA	Brand A	15	6	260	139	548	*	0.52	57.0	*	*
E HMA	Brand A	15	7	260	145	661	*	0.29	74.0	*	*
E HMA	Brand E	18	1	272	272	0	2600	0.55	88	11	0.5
E HMA	Brand E	18	2	272	359	102	2600	0.57	93.9	11	0.5
E HMA	Brand E	18	3	272	316	241	2600	0.20	70	11	0.5
E HMA	Brand E	18	4	272	311	353	2600	0.52	85	11	0.5
E HMA	Brand E	18	5	272	188	439	2600	0.67	81.3	11	0.5
E HMA	Brand E	18	6	272	172	563	2600	0.30	52	11	0.5
E HMA	Brand E	18	7	272	187	667	2600	0.29	81	11	0.5
E HMA	Brand E	18	8	272	328	785	2600	0.60	95	11	0.5
E HMA	Brand E	18	9	272	248	891	2600	0.21	69	11	0.5
E HMA	Brand E	18	10	272	262	1003	2600	0.29	74	11	0.5
E HMA	Brand E	18	11	272	280	1119	2600	0.51	96	11	0.5
E HMA	Brand E	18	12	272	272	1240	2600	0.61	69	11	0.5
E HMA	Brand E	21	1	266	266	0	8600	0.45	93	12	0.5
E HMA	Brand E	21	2	266	293	102	8600	0.48	90	12	0.5
E HMA	Brand E	21	3	266	195	241	8600	0.20	65	12	0.5
E HMA	Brand E	21	4	266	131	353	8600	0.42	85	12	0.5
E HMA	Brand E	21	5	266	158	439	8600	0.48	92.7	12	0.5
E HMA	Brand E	21	6	266	104	563	8600	0.30	42	12	0.5
E HMA	Brand E	21	7	266	165	667	8600	0.29	81	12	0.5
E HMA	Brand E	21	8	266	248	785	8600	0.41	95	12	0.5
E HMA	Brand E	21	9	266	179	891	8600	0.24	62	12	0.5
E HMA	Brand E	21	10	266	170	1003	8600	0.20	73	12	0.5
E HMA	Brand E	21	11	266	169	1119	8600	0.32	102	12	0.5
E HMA	Brand E	21	12	266	164	1240	8600	0.61	70	12	0.5
E HMA	Brand E	22	1	263	263	0	5200	0.40	93	12	0.5
E HMA	Brand E	22	2	263	287	107	5200	0.47	74	12	0.5
E HMA	Brand E	22	3	263	284	247	5200	0.20	74.8	12	0.5
E HMA	Brand E	22	4	263	129	355	5200	0.40	74.8	12	0.5
E HMA	Brand E	22	5	263	141	440	5200	0.63	79.5	12	0.5
E HMA	Brand E	22	6	263	149	553	5200	0.30	42	12	0.5
E HMA	Brand E	22	7	263	131	649	5200	0.20	55	12	0.5
E HMA	Brand E	22	8	263	209	764	5200	0.55	86	12	0.5
E HMA	Brand E	22	9	263	245	853	5200	0.22	80	12	0.5
E HMA	Brand E	22	10	263	213	973	5200	0.15	42	12	0.5
E HMA	Brand E	22	11	263	229	1083	5200	0.45	84	12	0.5
E HMA	Brand E	22	12	263	272	1184	5200	0.58	76	12	0.5
E HMA	Brand G	23	1	302	302	0	100	0.36	90	11	1
E HMA	Brand G	23	2	302	409	107	100	0.47	74	11	1
E HMA	Brand G	23	3	302	384	247	100	0.20	74.8	11	1

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand G	23	4	302	420	355	100	0.52	85	11	1
E HMA	Brand G	23	5	302	443	440	100	0.44	82.6	11	1
E HMA	Brand G	23	6	302	435	553	100	0.30	46	11	1
E HMA	Brand G	23	7	302	330	649	100	0.20	57	11	1
E HMA	Brand G	23	8	302	148	764	100	0.51	86	11	1
E HMA	Brand G	23	9	302	137	853	100	0.20	81	11	1
E HMA	Brand G	23	10	302	151	973	100	0.10	45	11	1
E HMA	Brand G	23	11	302	174	1083	100	0.41	88	11	1
E HMA	Brand G	23	12	302	215	1184	100	0.67	77	11	1
New HMA	Brand A	70	1	285	285	0	*	-	-	*	*
New HMA	Brand A	70	2	285	318	95	*	0.32	74.0	*	*
New HMA	Brand A	70	3	285	310	226	*	0.22	87.0	*	*
New HMA	Brand A	70	4	285	352	322	*	0.44	89.0	*	*
New HMA	Brand A	70	5	285	421	400	*	0.41	79.0	*	*
New HMA	Brand A	70	6	285	353	522	*	0.23	32.0	*	*
New HMA	Brand A	71	1	301	301	0	*	-	-	*	*
New HMA	Brand A	71	2	301	265	95	*	0.3	78.0	*	*
New HMA	Brand A	71	3	301	251	226	*	0.39	79.0	*	*
New HMA	Brand A	71	4	301	332	322	*	0.42	90.0	*	*
New HMA	Brand A	71	5	301	134	400	*	0.44	82.0	*	*
New HMA	Brand A	71	6	301	106	522	*	0.22	32.0	*	*
New HMA	Brand A	73	1	320	320	0	*	-	-	*	*
New HMA	Brand A	73	2	320	309	95	*	0.32	76.0	*	*
New HMA	Brand A	73	3	320	302	226	*	0.21	87.0	*	*
New HMA	Brand A	73	4	320	345	322	*	0.42	90.0	*	*
New HMA	Brand A	73	5	320	174	400	*	0.44	84.0	*	*
New HMA	Brand A	73	6	320	118	522	*	0.22	33.0	*	*
E HMA	Brand A	74	1	193	193	0	*	-	-	*	*
E HMA	Brand A	74	2	193	159	114	*	0.31	70.0	*	*
E HMA	Brand A	74	3	193	140	227	*	0.2	90.0	*	*
E HMA	Brand A	74	4	193	117	272	*	0.42	85.0	*	*
E HMA	Brand A	74	5	193	56	387	*	0.54	83.0	*	*
E HMA	Brand A	75	1	245	245	0	19500	0.40	95	11	1
E HMA	Brand A	75	2	245	197	112	19500	0.31	70	11	1
E HMA	Brand A	75	3	245	178	227	19500	0.20	90	11	1
E HMA	Brand A	75	4	245	187	272	19500	0.20	90	11	1
E HMA	Brand A	75	5	245	178	387	19500	0.52	84	11	1
E HMA	Brand A	75	6	245	119	499	19500	0.30	48	11	1
E HMA	Brand A	75	7	245	130	603	19500	0.29	81	11	1
E HMA	Brand A	75	8	245	245	721	19500	0.49	97	11	1
E HMA	Brand A	75	9	245	186	827	19500	0.24	62	11	1
E HMA	Brand A	75	10	245	167	939	19500	0.20	77	11	1
E HMA	Brand A	75	11	245	162	1055	19500	0.40	99	11	1
E HMA	Brand A	75	12	245	211	1176	19500	0.61	66	11	1
E HMA	Brand A	76	1	262	262	0	*	-	-	*	*
E HMA	Brand A	76	2	262	231	114	*	0.31	70.0	*	*
E HMA	Brand A	76	3	262	188	227	*	0.2	90.0	*	*
E HMA	Brand A	76	4	262	194	272	*	0.42	85.0	*	*

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	76	5	262	180	387	*	0.5	83.0	*	*
E HMA	Brand A	80	1	276	276	0	150	0.57	74	11	1
E HMA	Brand A	80	2	276	249	90	150	0.43	94	11	1
E HMA	Brand A	80	3	276	279	199	150	0.32	66	11	1
E HMA	Brand A	80	4	276	208	277	150	0.25	48	11	1
E HMA	Brand A	80	5	276	184	353	150	0.40	84	11	1
E HMA	Brand A	80	6	276	164	445	150	0.84	86	11	1
E HMA	Brand A	80	7	276	174	549	150	0.37	55	11	1
E HMA	Brand A	80	8	276	175	661	150	0.48	69	11	1
E HMA	Brand A	80	9	276	239	790	150	0.62	92	11	1
E HMA	Brand A	80	10	276	252	896	150	0.65	75	11	1
E HMA	Brand A	81	1	265	265	0	150	0.55	77	11	1
E HMA	Brand A	81	2	265	242	90	150	0.45	95	11	1
E HMA	Brand A	81	3	265	249	199	150	0.39	57	11	1
E HMA	Brand A	81	4	265	181	277	150	0.28	48	11	1
E HMA	Brand A	81	5	265	155	353	150	0.40	90	11	1
E HMA	Brand A	81	6	265	127	445	150	0.68	88	11	1
E HMA	Brand A	81	7	265	122	549	150	0.34	59	11	1
E HMA	Brand A	81	8	265	118	661	150	0.40	73	11	1
E HMA	Brand A	81	9	265	150	790	150	0.57	94	11	1
E HMA	Brand A	81	10	265	169	896	150	0.65	75	11	1
E HMA	Brand A	82	1	301	301	0	3700	0.47	82	11	1
E HMA	Brand A	82	2	301	304	90	3700	0.47	94	11	1
E HMA	Brand A	82	3	301	317	199	3700	0.41	57	11	1
E HMA	Brand A	82	4	301	229	277	3700	0.28	49	11	1
E HMA	Brand A	82	5	301	164	353	3700	0.40	90	11	1
E HMA	Brand A	82	6	301	109	445	3700	0.60	93	11	1
E HMA	Brand A	82	7	301	143	549	3700	0.31	62	11	1
E HMA	Brand A	82	8	301	142	661	3700	0.38	76	11	1
E HMA	Brand A	82	9	301	201	790	3700	0.55	95	11	1
E HMA	Brand A	82	10	301	206	896	3700	0.65	75	11	1
E HMA	Brand A	83	1	291	291	0	4800	0.41	91	11	1
E HMA	Brand A	83	2	291	268	90	4800	0.61	87	11	1
E HMA	Brand A	83	3	291	298	199	4800	0.40	61	11	1
E HMA	Brand A	83	4	291	244	277	4800	0.25	49	11	1
E HMA	Brand A	83	5	291	198	353	4800	0.40	70	11	1
E HMA	Brand A	83	6	291	99	445	4800	0.53	91	11	1
E HMA	Brand A	83	7	291	125	549	4800	0.26	71	11	1
E HMA	Brand A	83	8	291	125	661	4800	0.36	76	11	1
E HMA	Brand A	83	9	291	184	790	4800	0.52	96	11	1
E HMA	Brand A	83	10	291	218	896	4800	0.65	75	11	1
E HMA	Brand A	84	1	267	267	0	4800	0.42	83	11	1
E HMA	Brand A	84	2	267	274	90	4800	0.66	84	11	1
E HMA	Brand A	84	3	267	303	199	4800	0.39	61	11	1
E HMA	Brand A	84	4	267	294	277	4800	0.25	49	11	1
E HMA	Brand A	84	5	267	326	353	4800	0.40	48	11	1
E HMA	Brand A	84	6	267	141	445	4800	0.57	90	11	1
E HMA	Brand A	84	7	267	112	549	4800	0.24	72	11	1

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	84	8	267	132	661	4800	0.37	76	11	1
E HMA	Brand A	84	9	267	152	790	4800	0.50	101	11	1
E HMA	Brand A	84	10	267	216	896	4800	0.65	75	11	1
E HMA	Brand A	85	1	256	256	0	*	0.46	79.0	*	*
E HMA	Brand A	85	2	256	252	90	*	0.4	97.0	*	*
E HMA	Brand A	85	3	256	273	138	*	0.39	59.0	*	*
E HMA	Brand A	85	4	256	241	277	*	0.28	48.0	*	*
E HMA	Brand A	85	5	256	208	353	*	-	-	*	*
E HMA	Brand A	85	6	256	125	445	*	0.73	84.0	*	*
New HMA	Brand D	100	1	224	224	0	15700	0.51	84	12	5
New HMA	Brand D	100	2	224	317	100	15700	0.60	87	12	5
New HMA	Brand D	100	3	224	321	212	15700	0.58	78	12	5
New HMA	Brand D	100	4	224	321	359	15700	0.51	80	12	5
New HMA	Brand D	100	5	224	201	400	15700	0.68	86	12	5
New HMA	Brand D	100	6	224	136	578	15700	0.25	57	12	5
New HMA	Brand D	100	7	224	206	762	15700	0.4	86	12	5
New HMA	Brand D	100	8	224	256	901	15700	0.40	49	12	5
New HMA	Brand D	100	9	224	248	1038	15700	0.40	72	12	5
New HMA	Brand D	100	10	224	280	1131	15700	0.40	76	12	5
New HMA	Brand D	100	11	224	300	1272	15700	0.40	71	12	5
New HMA	Brand F	101	1	154	154	0	1750	0.35	103	12	2
New HMA	Brand F	101	2	154	171	105	1750	0.40	77	12	2
New HMA	Brand F	101	3	154	202	199	1750	0.40	48	12	2
New HMA	Brand F	101	4	154	207	338	1750	0.49	76	12	2
New HMA	Brand F	101	5	154	241	398	1750	0.56	85	12	2
New HMA	Brand F	101	6	154	158	550	1750	0.33	43	12	2
New HMA	Brand F	101	7	154	117	611	1750	0.31	53	12	2
New HMA	Brand F	101	8	154	166	738	1750	0.40	86	12	2
New HMA	Brand F	101	9	154	200	868	1750	0.40	63	12	2
New HMA	Brand F	101	10	154	168	1010	1750	0.40	70	12	2
New HMA	Brand F	101	11	154	238	1103	1750	0.40	84	12	2
New HMA	Brand F	101	12	154	248	1244	1750	0.40	70	12	2
New HMA	Brand D	102	1	307	307	0	7000	0.75	90	11	2
New HMA	Brand D	102	2	307	345	118	7000	0.40	73	11	2
New HMA	Brand D	102	3	307	313	256	7000	0.40	70	11	2
New HMA	Brand D	102	4	307	255	374	7000	0.40	79	11	2
New HMA	Brand D	102	5	307	129	526	7000	0.27	44	11	2
New HMA	Brand D	102	6	307	123	587	7000	0.23	46	11	2
New HMA	Brand D	102	7	307	151	714	7000	0.4	86	11	2
New HMA	Brand D	102	8	307	193	844	7000	0.40	63	11	2
New HMA	Brand D	102	9	307	168	986	7000	0.40	70	11	2
New HMA	Brand D	102	10	307	151	1079	7000	0.40	76	11	2
New HMA	Brand D	102	11	307	180	1220	7000	0.40	73	11	2
New HMA	Brand D	103	1	207	207	0	750	0.50	91	11	2
New HMA	Brand D	103	2	207	142	101	750	0.40	77	11	2
New HMA	Brand D	103	3	207	58	239	750	0.24	68	11	2
New HMA	Brand D	103	4	207	93	351	750	0.41	82.8	11	2
New HMA	Brand D	103	5	207	101	450	750	0.38	71	11	2

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
New HMA	Brand D	103	6	207	56	579	750	0.2	48	11	2
New HMA	Brand D	103	7	207	117	710	750	0.45	92	11	2
New HMA	Brand D	103	8	207	69	838	750	0.2	75	11	2
New HMA	Brand D	103	9	207	66	949	750	0.2	77	11	2
New HMA	Brand D	103	10	207	87	1078	750	0.34	95	11	2
New HMA	Brand D	103	11	207	96	1185	750	0.5	88	11	2
New HMA	Brand D	104	1	185	185	0	500	0.40	95	11	2
New HMA	Brand D	104	2	185	326	101	500	0.40	77	11	2
New HMA	Brand D	104	3	185	320	239	500	0.25	69	11	2
New HMA	Brand D	104	4	185	344	351	500	0.37	85.1	11	2
New HMA	Brand D	104	5	185	188	450	500	0.38	71	11	2
New HMA	Brand D	104	6	185	84	579	500	0.2	48	11	2
New HMA	Brand D	104	7	185	128	710	500	0.45	95	11	2
New HMA	Brand D	104	8	185	181	838	500	0.2	72	11	2
New HMA	Brand D	104	9	185	177	949	500	0.2	77	11	2
New HMA	Brand D	104	10	185	234	1078	500	0.36	95	11	2
New HMA	Brand D	104	11	185	276	1185	500	0.88	50	11	2

Appendix F: Waterborne Yellow Skip Data

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days After App	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	1	1	182	181.5	27	4600	0.48	82.6	-	-
E HMA	Brand A	1	2	182	173	98	4600	0.32	95.9	-	-
E HMA	Brand A	1	3	182	174.5	256	4600	0.20	29	-	-
E HMA	Brand A	1	4	182	154	366	4600	-	77	-	-
E HMA	Brand A	25	1	130	130	21	250	0.54	86	11	0
E HMA	Brand A	25	2	130	124	110	250	0.47	81.3	11	0
E HMA	Brand A	25	3	130	140.5	243	250	0.31	68	11	0
E HMA	Brand A	25	4	130	124.5	357	250	0.41	91	11	0
E HMA	Brand A	25	5	130	135	464	250	0.44	86	11	0
E HMA	Brand A	25	6	130	122	573	250	0.26	52	11	0
E HMA	Brand A	28	1	142	142	21	150	0.52	88	10	0
E HMA	Brand A	28	2	142	138	110	150	0.40	86	10	0
E HMA	Brand A	28	3	142	116.5	243	150	0.31	75	10	0
E HMA	Brand A	28	4	142	117	357	150	0.50	86.7	10	0
E HMA	Brand A	28	5	142	115	464	150	0.46	85	10	0
E HMA	Brand A	28	6	142	88.5	573	150	0.26	52	10	0
E HMA	Brand A	30	1	146	145.5	23	1850	-	-	10	0.5
E HMA	Brand A	30	2	146	166.5	131	1850	0.46	71.8	10	0.5
E HMA	Brand A	30	3	146	104	242	1850	0.27	60	10	0.5
E HMA	Brand A	30	4	146	148.5	360	1850	0.62	85.5	10	0.5
E HMA	Brand A	30	5	146	147	470	1850	0.49	76.8	10	0.5
E HMA	Brand A	30	6	146	142.5	592	1850	0.23	29	10	0.5
E HMA	Brand A	31	1	173	172.5	22	500	-	-	10	0.5
E HMA	Brand A	31	2	173	170	116	500	0.30	74	10	0.5
E HMA	Brand A	31	3	173	137.5	242	500	0.27	60	10	0.5
E HMA	Brand A	31	4	173	138.5	360	500	0.56	87.6	10	0.5
E HMA	Brand A	32	1	160	160	22	325	-	-	9	0.33
E HMA	Brand A	32	2	160	139.5	116	325	0.30	74	9	0.33
E HMA	Brand A	32	3	160	128	242	325	0.27	60	9	0.33
E HMA	Brand A	32	4	160	131.5	360	325	0.55	89.4	9	0.33
E HMA	Brand A	34	1	125	125	17	600	-	-	10	0.5
E HMA	Brand A	34	2	125	120.5	116	600	0.30	74	10	0.5
E HMA	Brand A	34	3	125	104.5	242	600	0.27	60	10	0.5
E HMA	Brand A	34	4	125	92.5	360	600	0.48	92.1	10	0.5
E HMA	Brand A	35	1	128	128	17	700	-	-	10	0.33
E HMA	Brand A	35	2	128	140.5	116	700	0.30	74	10	0.33
E HMA	Brand A	35	3	128	127	242	700	0.27	60	10	0.33
E HMA	Brand A	35	4	128	149.5	360	700	0.44	95	10	0.33
E HMA	Brand A	36	1	102	102	17	1150	-	-	10	0.33
E HMA	Brand A	36	2	102	103.5	116	1150	0.30	74	10	0.33
E HMA	Brand A	36	3	102	110.5	242	1150	0.27	60	10	0.33
E HMA	Brand A	36	4	102	99	360	1150	0.44	95	10	0.33

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days After App	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	51	1	173	173	20	375	-	79	10	0.17
E HMA	Brand A	51	2	173	201.5	116	375	0.37	83	10	0.17
E HMA	Brand A	51	3	173	171.5	249	375	0.27	88	10	0.17
E HMA	Brand A	51	4	173	179.5	356	375	0.48	85.5	10	0.17
E HMA	Brand A	51	5	173	183	452	375	0.39	84	10	0.17
E HMA	Brand A	51	6	173	168	574	375	0.23	32	10	0.17
E HMA	Brand B	151	1	169	168.5	20	1000	0.53	89.2	-	-
E HMA	Brand B	153	1	157	156.5	20	1000	0.43	90.3	-	-
E HMA	Brand B	156	1	169	169	19	2600	0.40	92	-	-
E HMA	Brand B	156	2	169	148.5	122	2600	0.46	80.1	-	-
E HMA	Brand B	156	3	169	144.5	201	2600	0.35	47	-	-
E HMA	Brand B	156	4	169	122	297	2600	0.27	81	-	-
E HMA	Brand B	156	5	169	118.0	419	2600	0.60	90	-	-
E HMA	Brand B	156	6	169	104.0	521	2600	0.20	83	-	-
E HMA	Brand B	156	7	169	104.0	633	2600	0.30	77	-	-
E HMA	Brand B	156	8	169	91.0	761	2600	0.35	101	-	-
E HMA	Brand B	156	9	169	90.0	868	2600	0.60	70	-	-

Appendix G: Thermoplastic Yellow Skip Data

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	15	1	270	270	0	-	0.42	84.0	-	-
E HMA	Brand A	15	2	270	271	95	-	0.4	109.0	-	-
E HMA	Brand A	15	3	270	206	236	-	0.25	34.0	-	-
E HMA	Brand A	15	4	270	179	349	-	0.54	76.0	-	-
E HMA	Brand A	15	5	270	164	440	-	0.49	91.0	-	-
E HMA	Brand A	15	6	270	141	548	-	0.52	57.0	-	-
E HMA	Brand A	15	7	270	121	661	-	0.29	74.0	-	-
E HMA	Brand A	16	1	277	277	0	-	0.42	86.0	-	-
E HMA	Brand A	16	2	277	271	95	-	0.35	105.0	-	-
E HMA	Brand A	16	3	277	132	237	-	0.25	35.0	-	-
E HMA	Brand A	16	4	277	120	349	-	0.53	76.0	-	-
E HMA	Brand A	16	5	277	139	440	-	0.57	87.0	-	-
E HMA	Brand A	16	6	277	154	548	-	0.57	61.0	-	-
E HMA	Brand A	17	1	281	281	0	-	0.42	87.0	-	-
E HMA	Brand A	17	2	281	262	95	-	0.28	104.0	-	-
E HMA	Brand A	17	3	281	98	237	-	0.25	36.0	-	-
E HMA	Brand A	17	4	281	215	349	-	0.49	82.0	-	-
E HMA	Brand A	17	5	281	255	440	-	0.39	92.0	-	-
E HMA	Brand A	17	6	281	201	548	-	0.53	67.0	-	-
E HMA	Brand A	17	7	281	164	661	-	0.2	73.0	-	-
E HMA	Brand E	19	1	258	258	0	4400	0.51	91	11	0.5
E HMA	Brand E	19	2	258	242	102	4400	0.57	93.9	11	0.5
E HMA	Brand E	19	3	258	121	241	4400	0.20	70	11	0.5
E HMA	Brand E	19	4	258	96	353	4400	0.52	85	11	0.5
E HMA	Brand E	19	5	258	128	439	4400	0.55	87.4	11	0.5
E HMA	Brand E	19	6	258	126	563	4400	0.30	52	11	0.5
E HMA	Brand E	19	7	258	158	667	4400	0.29	81	11	0.5
E HMA	Brand E	19	8	258	262	785	4400	0.47	104	11	0.5
E HMA	Brand E	19	9	258	221	891	4400	0.22	66	11	0.5
E HMA	Brand E	19	10	258	202	1003	4400	0.20	74	11	0.5
E HMA	Brand E	19	11	258	238	1119	4400	0.51	92	11	0.5
E HMA	Brand E	19	12	258	221	1240	4400	0.71	69	11	0.5
E HMA	Brand E	21	1	446	446	0	8600	0.45	93	12	0.5
E HMA	Brand E	21	2	446	499	102	8600	0.48	90	12	0.5
E HMA	Brand E	21	3	446	443	241	8600	0.20	65	12	0.5
E HMA	Brand E	21	4	446	294	353	8600	0.42	85	12	0.5
E HMA	Brand E	21	5	446	228	439	8600	0.48	92.7	12	0.5

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand E	21	6	446	197	563	8600	0.30	42	12	0.5
E HMA	Brand E	21	7	446	241	667	8600	0.29	81	12	0.5
E HMA	Brand E	21	8	446	377	785	8600	0.41	108	12	0.5
E HMA	Brand E	21	9	446	316	891	8600	0.24	62	12	0.5
E HMA	Brand E	21	10	446	300	1003	8600	0.20	73	12	0.5
E HMA	Brand E	21	11	446	319	1119	8600	0.32	102	12	0.5
E HMA	Brand E	21	12	446	356	1240	8600	0.61	70	12	0.5
E HMA	Brand A	80	1	276	276	0	150	0.57	74	11	1
E HMA	Brand A	80	2	276	249	90	150	0.43	94	11	1
E HMA	Brand A	80	3	276	279	199	150	0.32	66	11	1
E HMA	Brand A	80	4	276	208	277	150	0.25	48	11	1
E HMA	Brand A	80	5	276	184	353	150	0.60	56	11	1
E HMA	Brand A	80	6	276	164	445	150	0.84	86	11	1
E HMA	Brand A	80	7	276	174	549	150	0.37	55	11	1
E HMA	Brand A	80	8	276	175	661	150	0.48	69	11	1
E HMA	Brand A	80	9	276	239	790	150	0.62	92	11	1
E HMA	Brand A	80	10	276	252	896	150	0.65	75	11	1
E HMA	Brand A	81	1	265	265	0	150	0.55	77	11	1
E HMA	Brand A	81	2	265	242	90	150	0.45	95	11	1
E HMA	Brand A	81	3	265	249	199	150	0.39	57	11	1
E HMA	Brand A	81	4	265	181	277	150	0.28	48	11	1
E HMA	Brand A	81	5	265	155	353	150	0.60	56	11	1
E HMA	Brand A	81	6	265	127	445	150	0.68	88	11	1
E HMA	Brand A	81	7	265	122	549	150	0.34	59	11	1
E HMA	Brand A	81	8	265	118	661	150	0.40	73	11	1
E HMA	Brand A	81	9	265	150	790	150	0.57	94	11	1
E HMA	Brand A	81	10	265	169	896	150	0.65	75	11	1
E HMA	Brand A	82	1	301	301	0	3700	0.47	82	11	1
E HMA	Brand A	82	2	301	304	90	3700	0.47	94	11	1
E HMA	Brand A	82	3	301	317	199	3700	0.41	57	11	1
E HMA	Brand A	82	4	301	229	277	3700	0.28	49	11	1
E HMA	Brand A	82	5	301	164	353	3700	0.60	56	11	1
E HMA	Brand A	82	6	301	109	445	3700	0.60	93	11	1
E HMA	Brand A	82	7	301	143	549	3700	0.31	62	11	1
E HMA	Brand A	82	8	301	142	661	3700	0.38	76	11	1
E HMA	Brand A	82	9	301	201	790	3700	0.55	95	11	1
E HMA	Brand A	82	10	301	206	896	3700	0.65	75	11	1
E HMA	Brand A	83	1	291	291	0	4800	0.41	91	11	1

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
E HMA	Brand A	83	2	291	268	90	4800	0.61	87	11	1
E HMA	Brand A	83	3	291	298	199	4800	0.40	61	11	1
E HMA	Brand A	83	4	291	244	277	4800	0.25	49	11	1
E HMA	Brand A	83	5	291	198	353	4800	0.60	56	11	1
E HMA	Brand A	83	6	291	99	445	4800	0.53	91	11	1
E HMA	Brand A	83	7	291	125	549	4800	0.26	71	11	1
E HMA	Brand A	83	8	291	125	661	4800	0.36	78	11	1
E HMA	Brand A	83	9	291	184	790	4800	0.52	96	11	1
E HMA	Brand A	83	10	291	218	896	4800	0.65	75	11	1
E HMA	Brand A	84	1	267	267	0	4800	0.42	83	11	1
E HMA	Brand A	84	2	267	274	90	4800	0.66	84	11	1
E HMA	Brand A	84	3	267	303	199	4800	0.39	61	11	1
E HMA	Brand A	84	4	267	294	277	4800	0.25	49	11	1
E HMA	Brand A	84	5	267	326	353	4800	0.60	56	11	1
E HMA	Brand A	84	6	267	141	445	4800	0.57	90	11	1
E HMA	Brand A	84	7	267	112	549	4800	0.24	72	11	1
E HMA	Brand A	84	8	267	132	661	4800	0.37	76	11	1
E HMA	Brand A	84	9	267	152	790	4800	0.50	101	11	1
E HMA	Brand A	84	10	267	216	896	4800	0.65	75	11	1
N HMA	Brand D	100	1	207	207	0	15700	0.51	84	12	5
N HMA	Brand D	100	2	207	330	100	15700	0.60	87	12	5
N HMA	Brand D	100	3	207	337	212	15700	0.58	78	12	5
N HMA	Brand D	100	4	207	320	359	15700	0.51	80	12	5
N HMA	Brand D	100	5	207	222	400	15700	0.68	86	12	5
N HMA	Brand D	100	6	207	136	578	15700	0.25	57	12	5
N HMA	Brand D	100	7	207	203	762	15700	0.4	86	12	5
N HMA	Brand D	100	8	207	256	901	15700	0.4	49	12	5
N HMA	Brand D	100	9	207	247	1038	15700	0.4	72	12	5
N HMA	Brand D	100	10	207	270	1131	15700	0.4	76	12	5
N HMA	Brand D	100	11	207	293	1272	15700	0.4	71	12	5
N HMA	Brand D	102	1	305	305	0	7000	0.75	90	11	2
N HMA	Brand D	102	2	305	337	118	7000	0.40	73	11	2
N HMA	Brand D	102	3	305	321	256	7000	0.40	70	11	2
N HMA	Brand D	102	4	305	382	374	7000	0.40	79	11	2
N HMA	Brand D	102	5	305	240	526	7000	0.27	44	11	2
N HMA	Brand D	102	6	305	172	587	7000	0.23	46	11	2
N HMA	Brand D	102	7	305	137	714	7000	0.4	86	11	2
N HMA	Brand D	102	8	305	152	844	7000	0.4	63	11	2

Pavement	Brand	Site #	Round	Initial Retro	Median Retro	Days Since Initial	Traffic Volume	Humidity	Temp	Lane Width	Shoulder Width
N HMA	Brand D	102	9	305	144	986	7000	0.4	70	11	2
N HMA	Brand D	102	10	305	144	1079	7000	0.4	76	11	2
N HMA	Brand D	102	11	305	175	1220	7000	0.4	73	11	2
N HMA	Brand D	105	1	212	212	0	250	0.4	96	10	2
N HMA	Brand D	105	2	212	329	101	250	0.40	76	10	2
N HMA	Brand D	105	3	212	286	239	250	0.22	66	10	2
N HMA	Brand D	105	4	212	418	351	250	0.30	88	10	2
N HMA	Brand D	105	5	212	450	450	250	0.34	71	10	2
N HMA	Brand D	105	6	212	153	579	250	0.2	50	10	2
N HMA	Brand D	105	7	212	128	710	250	0.34	99	10	2
N HMA	Brand D	105	8	212	183	838	250	0.21	72	10	2
N HMA	Brand D	105	9	212	119	949	250	0.2	74	10	2
N HMA	Brand D	105	10	212	240	1078	250	0.48	102	10	2
N HMA	Brand C	106	1	438	438	0	-	0.66	95.0	-	-
N HMA	Brand C	106	2	438	433	113	-	0.8	72.0	-	-
N HMA	Brand C	106	3	438	418	210	-	0.62	50.0	-	-
N HMA	Brand C	106	4	438	501	328	-	0.63	73.0	-	-
E HMA	Brand C	107	1	275	275	0	-	0.62	96.0	-	-
E HMA	Brand C	107	2	275	231	113	-	0.81	75.0	-	-
E HMA	Brand C	107	3	275	214	210	-	0.25	68.0	-	-
E HMA	Brand C	107	4	275	209	328	-	0.6	73.0	-	-
E HMA	Brand C	107	5	275	98	480	-	0.35	42.0	-	-
E HMA	Brand C	107	6	275	78	541	-	0.29	52.0	-	-
E HMA	Brand C	107	7	275	142	668	-	0.78	81.0	-	-
E HMA	Brand C	108	1	267	267	0	-	0.72	86.0	-	-
E HMA	Brand C	108	2	267	264	113	-	0.81	73.0	-	-
E HMA	Brand C	108	3	267	256	262	-	0.65	77.0	-	-
E HMA	Brand C	108	4	267	253	332	-	0.61	79.0	-	-
E HMA	Brand C	108	5	267	117	480	-	0.24	52.0	-	-
E HMA	Brand C	108	6	267	86	544	-	0.54	50.0	-	-
E HMA	Brand C	108	7	267	99	664	-	0.78	79.0	-	-

Appendix H: Waterborne White Edge on Chip Seal Lookup Table

Days Since Initial	Initial Retroreflectivity (mc/m2/lux)								
	500	**450**	**400**	**350**	**300**	**250**	**200**	**150**	**100**
50	495	445	395	345	295	245	195	145	95
100	490	440	390	340	290	240	190	140	90
150	486	436	386	336	286	236	186	136	86
200	481	431	381	331	281	231	181	131	81
250	476	426	376	326	276	226	176	126	76
300	471	421	371	321	271	221	171	121	71
350	466	416	366	316	266	216	166	116	66
400	462	412	362	312	262	212	162	112	62
450	457	407	357	307	257	207	157	107	57
500	452	402	352	302	252	202	152	102	52
550	447	397	347	297	247	197	147	97	47
600	442	392	342	292	242	192	142	92	42
650	438	388	338	288	238	188	138	88	38
700	433	383	333	283	233	183	133	83	33
750	428	378	328	278	228	178	128	78	28
800	423	373	323	273	223	173	123	73	23
850	418	368	318	268	218	168	118	68	18
900	414	364	314	264	214	164	114	64	14
950	409	359	309	259	209	159	109	59	9
1000	404	354	304	254	204	154	104	54	4
1050	399	349	299	249	199	149	99	49	
1100	394	344	294	244	194	144	94	44	
1150	389	339	289	239	189	139	89	39	
1200	385	335	285	235	185	135	85	35	
1250	380	330	280	230	180	130	80	30	
1300	375	325	275	225	175	125	75	25	
	RL = Initial - 0.0961D								

Appendix I: Waterborne White Edge on Existing HMA Lookup Table

		Initial Retroreflectivity (mc/m2/lux)								
		500	450	400	350	300	250	200	150	100
Days Since Initial	50	493	443	393	343	293	243	193	143	93
	100	485	435	385	335	285	235	185	135	85
	150	478	428	378	328	278	228	178	128	78
	200	470	420	370	320	270	220	170	120	70
	250	463	413	363	313	263	213	163	113	63
	300	455	405	355	305	255	205	155	105	55
	350	448	398	348	298	248	198	148	98	48
	400	440	390	340	290	240	190	140	90	40
	450	433	383	333	283	233	183	133	83	33
	500	425	375	325	275	225	175	125	75	25
	550	418	368	318	268	218	168	118	68	18
	600	410	360	310	260	210	160	110	60	10
	650	403	353	303	253	203	153	103	53	3
	700	395	345	295	245	195	145	95	45	
	750	388	338	288	238	188	138	88	38	
	800	381	331	281	231	181	131	81	31	
	850	373	323	273	223	173	123	73	23	
	900	366	316	266	216	166	116	66	16	
	950	358	308	258	208	158	108	58	8	
	1000	351	301	251	201	151	101	51	1	
	1050	343	293	243	193	143	93	43		
	1100	336	286	236	186	136	86	36		
	1150	328	278	228	178	128	78	28		
	1200	321	271	221	171	121	71	21		
	1250	313	263	213	163	113	63	13		
	1300	306	256	206	156	106	56	6		
	RL = Initial - 0.1493D									

Appendix J: High-Build White Edge on Existing HMA (CTP) Lookup Table

	Initial Retroreflectivity (mc/m2/lux)								
CTP (Million Vehicles)	**500**	**450**	**400**	**350**	**300**	**250**	**200**	**150**	**100**
0.1	494	444	394	344	294	244	194	144	94
0.2	488	438	388	338	288	238	188	138	88
0.3	483	433	383	333	283	233	183	133	83
0.4	477	427	377	327	277	227	177	127	77
0.5	471	421	371	321	271	221	171	121	71
0.6	465	415	365	315	265	215	165	115	65
0.7	460	410	360	310	260	210	160	110	60
0.8	454	404	354	304	254	204	154	104	54
0.9	448	398	348	298	248	198	148	98	48
1.0	442	392	342	292	242	192	142	92	42
1.1	436	386	336	286	236	186	136	86	36
1.2	431	381	331	281	231	181	131	81	31
1.3	425	375	325	275	225	175	125	75	25
1.4	419	369	319	269	219	169	119	69	19
1.5	413	363	313	263	213	163	113	63	13
1.6	408	358	308	258	208	158	108	58	8
1.7	402	352	302	252	202	152	102	52	2
1.8	396	346	296	246	196	146	96	46	
1.9	390	340	290	240	190	140	90	40	
2.0	384	334	284	234	184	134	84	34	
2.1	379	329	279	229	179	129	79	29	
2.2	373	323	273	223	173	123	73	23	
2.3	367	317	267	217	167	117	67	17	
2.4	361	311	261	211	161	111	61	11	
2.5	356	306	256	206	156	106	56	6	
2.6	350	300	250	200	150	100	50		
RL = Initial - 57.771C									

Appendix K: High-Build White Edge on Existing HMA (Days) Lookup Table

Days Since Initial		Initial Retroreflectivity (mc/m2/lux)								
		500	450	400	350	300	250	200	150	100
	50	498	448	398	348	298	248	198	148	98
	100	496	446	396	346	296	246	196	146	96
	150	494	444	394	344	294	244	194	144	94
	200	492	442	392	342	292	242	192	142	92
	250	490	440	390	340	290	240	190	140	90
	300	489	439	389	339	289	239	189	139	89
	350	487	437	387	337	287	237	187	137	87
	400	485	435	385	335	285	235	185	135	85
	450	483	433	383	333	283	233	183	133	83
	500	481	431	381	331	281	231	181	131	81
	550	479	429	379	329	279	229	179	129	79
	600	477	427	377	327	277	227	177	127	77
	650	475	425	375	325	275	225	175	125	75
	700	473	423	373	323	273	223	173	123	73
	750	471	421	371	321	271	221	171	121	71
	800	469	419	369	319	269	219	169	119	69
	850	467	417	367	317	267	217	167	117	67
	900	466	416	366	316	266	216	166	116	66
	950	464	414	364	314	264	214	164	114	64
	1000	462	412	362	312	262	212	162	112	62
	1050	460	410	360	310	260	210	160	110	60
	1100	458	408	358	308	258	208	158	108	58
	1150	456	406	356	306	256	206	156	106	56
	1200	454	404	354	304	254	204	154	104	54
	1250	452	402	352	302	252	202	152	102	52
	1300	450	400	350	300	250	200	150	100	50
	RL = Initial - 0.0383D									

Appendix L: High-Build White Edge on New HMA (CTP) Lookup Table

CTP (Million Vehicles)	Initial Retroreflectivity (mc/m2/lux)								
	500	**450**	**400**	**350**	**300**	**250**	**200**	**150**	**100**
0.1	494	444	394	344	294	244	194	144	94
0.2	488	438	388	338	288	238	188	138	88
0.3	483	433	383	333	283	233	183	133	83
0.4	477	427	377	327	277	227	177	127	77
0.5	471	421	371	321	271	221	171	121	71
0.6	465	415	365	315	265	215	165	115	65
0.7	459	409	359	309	259	209	159	109	59
0.8	453	403	353	303	253	203	153	103	53
0.9	448	398	348	298	248	198	148	98	48
1.0	442	392	342	292	242	192	142	92	42
1.1	436	386	336	286	236	186	136	86	36
1.2	430	380	330	280	230	180	130	80	30
1.3	424	374	324	274	224	174	124	74	24
1.4	419	369	319	269	219	169	119	69	19
1.5	413	363	313	263	213	163	113	63	13
1.6	407	357	307	257	207	157	107	57	7
1.7	401	351	301	251	201	151	101	51	1
1.8	395	345	295	245	195	145	95	45	
1.9	390	340	290	240	190	140	90	40	
2.0	384	334	284	234	184	134	84	34	
2.1	378	328	278	228	178	128	78	28	
2.2	372	322	272	222	172	122	72	22	
2.3	366	316	266	216	166	116	66	16	
2.4	360	310	260	210	160	110	60	10	
2.5	355	305	255	205	155	105	55	5	
2.6	349	299	249	199	149	99	49		

RL = Initial - 58.128C

Appendix M: High-Build White Edge on New HMA (Days) Lookup Table

Days Since Initial		Initial Retroreflectivity (mc/m2/lux)								
		500	**450**	**400**	**350**	**300**	**250**	**200**	**150**	**100**
	50	497	447	397	347	297	247	197	147	97
	100	494	444	394	344	294	244	194	144	94
	150	491	441	391	341	291	241	191	141	91
	200	488	438	388	338	288	238	188	138	88
	250	485	435	385	335	285	235	185	135	85
	300	482	432	382	332	282	232	182	132	82
	350	479	429	379	329	279	229	179	129	79
	400	476	426	376	326	276	226	176	126	76
	450	474	424	374	324	274	224	174	124	74
	500	471	421	371	321	271	221	171	121	71
	550	468	418	368	318	268	218	168	118	68
	600	465	415	365	315	265	215	165	115	65
	650	462	412	362	312	262	212	162	112	62
	700	459	409	359	309	259	209	159	109	59
	750	456	406	356	306	256	206	156	106	56
	800	453	403	353	303	253	203	153	103	53
	850	450	400	350	300	250	200	150	100	50
	900	447	397	347	297	247	197	147	97	47
	950	444	394	344	294	244	194	144	94	44
	1000	441	391	341	291	241	191	141	91	41
	1050	438	388	338	288	238	188	138	88	38
	1100	435	385	335	285	235	185	135	85	35
	1150	432	382	332	282	232	182	132	82	32
	1200	429	379	329	279	229	179	129	79	29
	1250	427	377	327	277	227	177	127	77	27
	1300	424	374	324	274	224	174	124	74	24

RL = Initial - 0.0588D

Appendix N: Waterborne Yellow Centerline on Existing HMA Lookup Table

		Initial Retroreflectivity (mc/m2/lux)						
		250	**225**	**200**	**175**	**150**	**125**	**100**
Days Since Initial	**50**	246	221	196	171	146	121	96
	100	243	218	193	168	143	118	93
	150	239	214	189	164	139	114	89
	200	235	210	185	160	135	110	85
	250	231	206	181	156	131	106	81
	300	228	203	178	153	128	103	78
	350	224	199	174	149	124	99	74
	400	220	195	170	145	120	95	70
	450	216	191	166	141	116	91	66
	500	213	188	163	138	113	88	63
	550	209	184	159	134	109	84	59
	600	205	180	155	130	105	80	55
	650	201	176	151	126	101	76	51
	700	198	173	148	123	98	73	48
	750	194	169	144	119	94	69	44
	800	190	165	140	115	90	65	40
	850	187	162	137	112	87	62	37
	900	183	158	133	108	83	58	33
	950	179	154	129	104	79	54	29
	1000	175	150	125	100	75	50	25
	1050	172	147	122	97	72	47	22
	1100	168	143	118	93	68	43	18
	1150	164	139	114	89	64	39	14
	1200	160	135	110	85	60	35	10
	1250	157	132	107	82	57	32	7
	1300	153	128	103	78	53	28	3
	RL = Initial - 0.0747D							

Appendix O: Waterborne Yellow Centerline on Chip Seal Lookup Table

		Initial Retroreflectivity (mc/m2/lux)						
		250	**225**	**200**	**175**	**150**	**125**	**100**
Days Since Initial	**50**	247	222	197	172	147	122	97
	100	244	219	194	169	144	119	94
	150	241	216	191	166	141	116	91
	200	237	212	187	162	137	112	87
	250	234	209	184	159	134	109	84
	300	231	206	181	156	131	106	81
	350	228	203	178	153	128	103	78
	400	225	200	175	150	125	100	75
	450	222	197	172	147	122	97	72
	500	219	194	169	144	119	94	69
	550	216	191	166	141	116	91	66
	600	212	187	162	137	112	87	62
	650	209	184	159	134	109	84	59
	700	206	181	156	131	106	81	56
	750	203	178	153	128	103	78	53
	800	200	175	150	125	100	75	50
	850	197	172	147	122	97	72	47
	900	194	169	144	119	94	69	44
	950	191	166	141	116	91	66	41
	1000	187	162	137	112	87	62	37
	1050	184	159	134	109	84	59	34
	1100	181	156	131	106	81	56	31
	1150	178	153	128	103	78	53	28
	1200	175	150	125	100	75	50	25
	1250	172	147	122	97	72	47	22
	1300	169	144	119	94	69	44	19
	RL = Initial - 0.0626D							

Appendix P: Thermoplastic Yellow Centerline on Existing HMA Lookup Table

		Initial Retroreflectivity (mc/m2/lux)						
		400	**350**	**300**	**250**	**200**	**150**	**100**
Days Since Initial	**50**	395	345	295	245	195	145	95
	100	390	340	290	240	190	140	90
	150	385	335	285	235	185	135	85
	200	380	330	280	230	180	130	80
	250	375	325	275	225	175	125	75
	300	370	320	270	220	170	120	70
	350	365	315	265	215	165	115	65
	400	360	310	260	210	160	110	60
	450	355	305	255	205	155	105	55
	500	350	300	250	200	150	100	50
	550	344	294	244	194	144	94	44
	600	339	289	239	189	139	89	39
	650	334	284	234	184	134	84	34
	700	329	279	229	179	129	79	29
	750	324	274	224	174	124	74	24
	800	319	269	219	169	119	69	19
	850	314	264	214	164	114	64	14
	900	309	259	209	159	109	59	9
	950	304	254	204	154	104	54	4
	1000	299	249	199	149	99	49	
	RL = Initial - 0.101D							

Appendix Q: Thermoplastic Yellow Centerline on New HMA Lookup Table

		Initial Retroreflectivity (mc/m2/lux)						
		400	**350**	**300**	**250**	**200**	**150**	**100**
Days Since Initial	**50**	398	348	298	248	198	148	98
	100	396	346	296	246	196	146	96
	150	394	344	294	244	194	144	94
	200	392	342	292	242	192	142	92
	250	390	340	290	240	190	140	90
	300	388	338	288	238	188	138	88
	350	386	336	286	236	186	136	86
	400	384	334	284	234	184	134	84
	450	382	332	282	232	182	132	82
	500	380	330	280	230	180	130	80
	550	378	328	278	228	178	128	78
	600	376	326	276	226	176	126	76
	650	374	324	274	224	174	124	74
	700	372	322	272	222	172	122	72
	750	370	320	270	220	170	120	70
	800	368	318	268	218	168	118	68
	850	366	316	266	216	166	116	66
	900	364	314	264	214	164	114	64
	950	362	312	262	212	162	112	62
	1000	360	310	260	210	160	110	60
	1050	358	308	258	208	158	108	58
	1100	356	306	256	206	156	106	56
	1150	354	304	254	204	154	104	54
	1200	352	302	252	202	152	102	52
	1250	350	300	250	200	150	100	50
	1300	348	298	248	198	148	98	48

RL = Initial - 0.0399D

Appendix R: Waterborne Yellow Skip on Existing HMA Lookup Table

		Initial Retroreflectivity (mc/m2/lux)				
		200	**175**	**150**	**125**	**100**
Days Since Initial	**50**	197	172	147	122	97
	100	194	169	144	119	94
	150	191	166	141	116	91
	200	188	163	138	113	88
	250	185	160	135	110	85
	300	182	157	132	107	82
	350	179	154	129	104	79
	400	176	151	126	101	76
	450	173	148	123	98	73
	500	170	145	120	95	70
	550	167	142	117	92	67
	600	164	139	114	89	64
	650	161	136	111	86	61
	700	158	133	108	83	58
	750	155	130	105	80	55
	800	152	127	102	77	52
	850	150	125	100	75	50
	900	147	122	97	72	47
	950	144	119	94	69	44
	1000	141	116	91	66	41
	1050	138	113	88	63	38
	1100	135	110	85	60	35
	1150	132	107	82	57	32
	1200	129	104	79	54	29
	1250	126	101	76	51	26
	1300	123	98	73	48	23
	RL = Initial - 0.0594D					

Appendix S: Thermoplastic Yellow Skip on Existing HMA Lookup Table

Days Since Initial	Initial Retroreflectivity (mc/m2/lux) 550	500	450	400	350	300	250	200	150
50	542	492	442	392	342	292	242	192	142
100	534	484	434	384	334	284	234	184	134
150	527	477	427	377	327	277	227	177	127
200	519	469	419	369	319	269	219	169	119
250	511	461	411	361	311	261	211	161	111
300	503	453	403	353	303	253	203	153	103
350	496	446	396	346	296	246	196	146	96
400	488	438	388	338	288	238	188	138	88
450	480	430	380	330	280	230	180	130	80
500	472	422	372	322	272	222	172	122	72
550	465	415	365	315	265	215	165	115	65
600	457	407	357	307	257	207	157	107	57
650	449	399	349	299	249	199	149	99	49
700	441	391	341	291	241	191	141	91	41
750	434	384	334	284	234	184	134	84	34
800	426	376	326	276	226	176	126	76	26
850	418	368	318	268	218	168	118	68	18
900	410	360	310	260	210	160	110	60	10
950	403	353	303	253	203	153	103	53	3
1000	395	345	295	245	195	145	95	45	
1050	387	337	287	237	187	137	87	37	
1100	379	329	279	229	179	129	79	29	
1150	372	322	272	222	172	122	72	22	
1200	364	314	264	214	164	114	64	14	
1250	356	306	256	206	156	106	56	6	

RL = Initial - 0.1551D

Appendix T: Thermoplastic Yellow Skip on New HMA Lookup Table

	Initial Retroreflectivity (mc/m2/lux)									
Days Since Initial	**550**	**500**	**450**	**400**	**350**	**300**	**250**	**200**	**150**	**100**
50	549	499	449	399	349	299	249	199	149	99
100	547	497	447	397	347	297	247	197	147	97
150	546	496	446	396	346	296	246	196	146	96
200	544	494	444	394	344	294	244	194	144	94
250	543	493	443	393	343	293	243	193	143	93
300	541	491	441	391	341	291	241	191	141	91
350	540	490	440	390	340	290	240	190	140	90
400	538	488	438	388	338	288	238	188	138	88
450	537	487	437	387	337	287	237	187	137	87
500	536	486	436	386	336	286	236	186	136	86
550	534	484	434	384	334	284	234	184	134	84
600	533	483	433	383	333	283	233	183	133	83
650	531	481	431	381	331	281	231	181	131	81
700	530	480	430	380	330	280	230	180	130	80
750	528	478	428	378	328	278	228	178	128	78
800	527	477	427	377	327	277	227	177	127	77
850	526	476	426	376	326	276	226	176	126	76
900	524	474	424	374	324	274	224	174	124	74
950	523	473	423	373	323	273	223	173	123	73
1000	521	471	421	371	321	271	221	171	121	71
1050	520	470	420	370	320	270	220	170	120	70
1100	518	468	418	368	318	268	218	168	118	68
1150	517	467	417	367	317	267	217	167	117	67
1200	515	465	415	365	315	265	215	165	115	65
1250	514	464	414	364	314	264	214	164	114	64
1300	513	463	413	363	313	263	213	163	113	63
RL = Initial - 0.0288D										

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1)	Total printing cost:	$237.50
2)	Total number of documents:	25
3)	Cost per unit:	$9.50