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A METHODOLOGY FOR ESTIMATING AND COMPARING THE LIFECYCLES OF HIGH-BUILD AND CONVENTIONAL WATERBORNE PAVEMENT MARKINGS ON PRIMARY AND SECONDARY ROADS IN SOUTH CAROLINA

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A METHODOLOGY FOR ESTIMATING AND COMPARING THE LIFECYCLES OF
HIGH-BUILD AND CONVENTIONAL WATERBORNE PAVEMENT MARKINGS
ON PRIMARY AND SECONDARY ROADS IN SOUTH CAROLINA

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Civil Engineering

by
Joseph A. Robertson
December 2011

Accepted by:
Dr. Wayne Sarasua, Committee Chair
Dr. Jennifer Ogle
Dr. Jeff Davis

ABSTRACT

Highway pavement markings constitute a vital component of roadway transportation systems and provide crucial visual cues for the basic driver task of following the road. In 2008, the South Carolina Department of Transportation (SCDOT) initiated a multi-year study to evaluate pavement markings on non-interstate primary and secondary roads in South Carolina. This thesis discusses development of a methodology for estimating and comparing the lifecycles of high-build and conventional waterborne pavement markings based on retroreflectivity levels. The methodology was developed using nearly 3 years of field data from 66 sites throughout South Carolina. This thesis provides an overview of data collection and analysis methods employed in model development. Previous related work is highlighted, and obtained results and deduced conclusions are presented. The analysis indicates that high-build markings are predicted to considerably outlast waterborne markings and are also more cost-effective, based on cost per linear foot per year, for two-way ADT volume levels up to 1,600 vehicles per day.

DEDICATION

This thesis is dedicated to my parents Susan and Tommy, my brother Albert, and my fiancé Carlee. Thank you for all of your love and support over the years and for all you've done to help me achieve my goals.

ACKNOWLEDGEMENTS

I would like to acknowledge my advisor and committee chair, Dr. Wayne Sarasua, for all of his help and guidance on this research project, as well as the other members of my committee, Dr. Jeff Davis and Dr. Jennifer Ogle, for their insight and suggestions. I would also like to thank those who assisted in data collection and analysis, especially Joshua Johnson, much of whose data and research is included in this thesis. Finally, I would like to gratefully acknowledge the role of the South Carolina Department of Transportation in funding this project and providing valuable technical guidance.

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CHAPTER ONE

INTRODUCTION

Definition of Pavement Markings

Longitudinal pavement markings are a vital part of ensuring driver safety along roadway transportation systems. Markings are used to delineate travel lane boundaries and pavement edges, allowing drivers to clearly and easily distinguish where they should drive. Marking characteristics, such as color and layout configuration, also aid drivers in determining travel direction, passing zones, and separation of traffic flow. Most pavement markings are retroreflective, a characteristic which greatly enhances nighttime visibility of the markings.

Significance of Research

The main purpose of this thesis research is to create and compare models for the retroreflectivity degradation of high-build and waterborne pavement markings. Upon the creation of these models, it will be possible to compare the rates of degradation and potential lifecycles of these marking materials, which can be used to help choose a marking for a particular application as well as determine the frequency with which the markings should be replaced. The South Carolina Department of Transportation (SCDOT) has funded the research, which covers primary and secondary roads across South Carolina. Though similar research has been completed, these studies did not

contain all of the same characteristics, and none covered high-build marking performance. Research of similar content can be found in *Chapter 2: Literature Review*.

The main purpose of retroreflective pavement markings is to increase roadway safety by improving the nighttime visibility of the markings. Consequently, it is important that DOTs maintain pavement markings to remain within acceptable levels of retroreflectivity. However, the Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways (2009) does not currently stipulate minimum retroreflectivity values for pavement markings. The Federal Highway Administration (FHWA) has also not set minimum standards, though such standards are in the process of being created. Therefore, it will be extremely beneficial for the SCDOT to have policies in place that predict the degradation of pavement markings and allow for cost-effective management of these markings to comply with minimum retroreflectivity values.

Research Project Introduction

In February 2008, the SCDOT funded the research project which was originally set to last 30 months, but was extended in the summer of 2010 to allow for additional data collection. The new completion date is February 1, 2012. The objectives of the project are listed as follows:

- Develop a systematic and standardized methodology to quantitatively evaluate and compare pavement marking materials used on South Carolina's primary and secondary roads to track the performance and lifecycle of pavement markings from installation to the time of their replacement

- Develop a method for determining and comparing the maximum service lives for different types of markings
- Determine what type of material is best to use to provide a pavement marking program that is consistent throughout the state and based on best practices

Thesis Objectives

While the broad objectives of the research project cover white and yellow waterborne, high-build, and thermoplastic materials, the objectives of this thesis are much more specific, focusing only on white edge line high-build and waterborne pavement markings in an attempt to compare these two similar marking materials. The objectives for this thesis research are as follows:

- Develop and compare retroreflectivity degradation models for high-build and waterborne white edge pavement markings
- Determine if there is any significant difference in performance between marking brands included in the study
- Predict and compare maximum service lives for high-build and waterborne white edge pavement markings
- Use average marking installation costs in an effort to perform a lifecycle cost analysis for comparing high-build and waterborne white edge pavement markings

The following chapters contain the literature review and discussions of research methodology, data collection, analysis, results, conclusions, and recommendations.

CHAPTER TWO

LITERATURE REVIEW

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* (1), 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). Because the literature review was performed as a team, much of it can also be found in other theses related to this research, *One Year Performance of Waterborne Pavement Markings Used on Primary and Secondary Roads of South Carolina* (2), and *Long-Term Performance of Pavement Markings on Primary and Secondary Roads* (3).

Definition of Retroreflectivity

According to McGee and Mace (4), retroreflection is an event that occurs when “light rays strike a surface and are redirected directly back to the source of light.” The MUTCD (5) 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.” Smadi et al. (6) 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 (7). Figure 2.1 illustrates this event.

Figure 2.1: Three Step Process of Retroreflection in a Glass Bead (7)

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 (8), bead types range in size from smallest to largest as Type I to Type IV, respectively. High-build marking specifications (9) 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.

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 ($\text{mcd}/\text{m}^2/\text{lux}$) in the standard *E 808-01 (re-approved 2009) - Standard Practice for Describing Retroreflection* (10).

The current accepted standard for measurement of retroreflectivity of pavement marking materials using a portable retroreflectometer is *ASTM E 1710-05* (11). 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 (12)

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.

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 (13).

Accordingly, the FHWA did develop candidate MUTCD criteria, but it has not been approved and implemented as a policy yet (14).

Paniati and Schwab (1991) (15) 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 et al. (16) 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/m²/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 (14). 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/m²/lux on freeways and 80 mcd/m²/lux on collector and arterial roads. Unfortunately, the participants of the workshop could not reach an agreement to have these minimum values adopted as standards without further research.

The Minnesota Department of Transportation (MnDOT) (17) 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/m²/lux. As a result of the project, MnDOT uses 120 mcd/m²/lux as a minimum retroreflectivity threshold for its pavement marking management program.

Parker and Meja (18) 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/m²/lux for drivers under 55 and between 120 and 165 mcd/m²/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 (19), while pavement marking minimums are still pending.

An additional report by Debaillon, et al. in October 2007 (20) 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 (9) require that white high-build markings must maintain a minimum reflectance value of 350 mcd/lux/m² 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/m²/lux after installation, as described in a report by Rasdorf et. al. (21)

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 the 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 in the 2009 MUTCD, Section 3A.03, states that public agencies or officials having jurisdiction shall use a method designed to maintain retroreflectivity values at or above the minimum levels shown in Table 2.2. (22)

Table 2.2: MUTCD Proposed Minimum Maintained Retroreflectivity Levels for Longitudinal Pavement Markings (22)

	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 the established minimum levels.

Retroreflectivity Degradation Predictive Models

In 1997, Perrin, Martin, and Hansen (23) 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.

In 1999, Migletz et al. (24) 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.

Jung-Taek, 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 (25). 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:

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

where

Y =Retroreflectivity of pavement markings in mcd/m²/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. (26) 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: $\text{Mean } R_L = a + (b \cdot \text{CTP})$

Quadratic Model: $\text{Mean } R_L = a + (b \cdot \text{CTP}) + c \cdot (\text{CTP})^2$

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

In the study, the minimum threshold values were set to range between 85 – 150 mcd/m²/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 (27) 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/m²/lux

a , b = model coefficients

CTP = Cumulative Traffic Passages in million vehicles

In 2002, Abboud and Bowman (28, 29, 30) 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/m²/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:

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

where

R_L = Pavement Marking Retroreflectivity in mcd/m²/lux

$\ln$ = Natural Logarithm

VE = Vehicle Exposure in thousands of vehicles

Thamizharasan, A., Sarasua, W. A., Clarke, D., and Davis, W. J. (31) 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. (21) 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 $-75 \text{ mcd/m}^2/\text{lux}$ annually, with an average lifecycle of 34.2 months if a minimum threshold of $100 \text{ mcd/m}^2/\text{lux}$ and an average initial value of $310 \text{ mcd/m}^2/\text{lux}$ are used. 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.

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 (32) 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 (33) 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. (34) 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. (35) 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. (21), which determined that there is a significant difference in the rate of retroreflectivity degradation between edge lines and centerlines. White edge lines were determined to degrade -75 mcd/m²/lux annually while yellow centerlines were found to degrade at -25 mcd/m²/lux.

Environmental Effect on Pavement Markings

The Pavement Marking Handbook (36) 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 (8) require the air temperature to be at least 50° F before commencement of the laying operation for waterbased 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.

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 (37) 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 (38). Table 2.3 shows a comparison of various marking types including approximate cost and estimated lifespan, assuming that the 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.

Survey of States

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.

Primary Non-Interstate Routes (of 20)

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

Secondary Routes (of 18)

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.

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 thesis research is to develop reliable high-build models and compare their results to those of waterborne 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 (36) has suggested that as a rule-of-thumb, average pavement marking retroreflectivity values of 80-100 mcd/m²/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.

An important characteristic of this research is the approach of “leaving no stone unturned.” This thesis research observes a large number of variables including marking age, varying initial value, traffic volume, lane width, shoulder width, climate, marking thickness, and application rate for high-build and waterborne markings. This research is explained in detail in *Chapter 3: Research Methodology* and *Chapter 4: Data Analysis*.

CHAPTER THREE

RESEARCH METHODOLOGY

Project Commencement

Through preliminary meetings with the SCDOT 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 no more than 25 days prior to the research team being notified. The information included in the notification was road name, cross-streets nearest to the new marking, 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 large distribution of sites spread across South Carolina. For this reason, the research team became more selective in choosing potential sites as the site establishment period continued. 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.

Throughout the project, 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 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. Waterborne sites in Horry County were added during the second year of the project. This was to help account for abandoned sites as well as 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 is a primary objective of this thesis. Table 3.1 shows the number of high-build and waterbased white edge line sites that were established, as well as how many sites remain in the study.

Table 3.1: Established and Remaining Sites

Marking Material	Established Sites	Sites Currently Remaining
Waterbase (WB)	51	12
High Build (HB)	15	10
Total	66	22

Site Establishment

The initial site establishment period began in May 2008 and lasted through the beginning of August 2008. During this time, 44 waterborne white edge line sites were established across the state. After one year, seven additional waterborne sites were added in Horry county, as well as 15 high-build sites in Greenville and Spartanburg counties. The reason that high-build sites were only established in these two 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 roadways 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, 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 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 was given an identification number, which was painted beside the first template. 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. Examples of site establishment and numbering are shown in Figures 3.1 and 3.2.

Figure 3.1: Site Establishment

Figure 3.2: Site Numbering

Data Collection

After site establishment, the first round of data was collected at the site. This was done using the retroreflectometer, following its standard operating procedures. This included calibration of the unit at the beginning of each day to ensure consistent readings. An image of the retroreflectometer on a data collection point is shown in Figure 3.3.

Figure 3.3: Retroreflectometer Collecting Data

At the first data collection point, a printout of the GPS coordinates was created to aid in finding the site 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 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 3.4 at the end of this chapter. 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 round was completed in October 2011.

Section ID	14			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	11/17/09	
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 3.4: Sample Data Collection Sheet

CHAPTER FOUR

DATA ANALYSIS

Discussion of Site Sample Sizes

The primary objective of this research is to establish and compare retroreflectivity degradation models and life cycles for high-build and conventional waterborne white edge line pavement markings. Table 4.1 below shows the initial number of sites established for each marking material as compared to how many sites remain in the analysis.

Table 4.1: Summary of Sites

Marking Material	Initial Sites	Sites Lost to Restriping	Sites Lost to Repaving	Abandoned Sites	Total Lost Sites	Sites Remaining
Waterborne	51	17	5	17	39	12
High-Build	15	5	0	0	5	10
Total Sites	66	22	5	17	44	22

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 in the *Prematurely Lost Sites* section of this chapter. Reasons for site abandonment are explained in *Chapter 3: Research Methodology*.

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 4.2.

Table 4.2: 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. Bead density would have a significant impact on retroreflectivity, but was not included in the research.
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, making the variable insignificant.

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 white edge line high-build and waterborne markings.

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 retroreflectivity values significantly greater than the commonly accepted minimum

threshold of 100 mc/m²/lux. Statistics about these lost sites in this research is shown in Table 4.3.

Table 4.3: Statistics for Sites Restriped while $R_L > 100$

Marking Material	Total # of Lost Sites Due to Restriping	# of Restriped Sites with $R_L > 100$	% of Lost Sites with $R_L > 100$	Avg. R_L of Lost Sites with $R_L > 100$
Waterborne	17	14	82%	261
High-Build	5	5	100%	388
Total	22	19	86%	

As Table 4.3 shows, 82% of the waterborne and 100% of the high-build sites that were repainted during the study were done so while their retroreflectivity values were greater than 100 mcd/m²/lux. This equates to a total of 86% of all sites lost to restriping. 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.

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 those in charge of striping and those in charge of paving the roadways. 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. It is possible that better coordination between the departments in charge of striping and paving could prevent sites from being restriped if it is known that it will be repaved soon, thus removing the need to restripe the site, and then have to restripe it again after repaving.

Sites with Low Retroreflectivity Values

On the other hand, there are sites still in service with retroreflectivity values below the 100 mc/m²/lux threshold. The low nighttime visibility of these sites could be potentially dangerous for drivers. Table 4.4 displays statistics about these sites.

Table 4.4: 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 $R_L < 100$
Waterborne	12	5	42%	65
High-Build	10	0	0%	-
Total	22	5	23%	65

As shown in Table 4.4, there are five sites in the study that have retroreflectivity values less than 100 mc/m²/lux. All of these sites are waterborne sites and they make up 42% of the remaining waterborne sites and 23% of the total remaining sites (both marking types). 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.

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/m²/lux for high-build markings and 3 mcd/m²/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 & B contain high-build and waterborne tables, respectively, showing all data points (minus the omitted points) and their associated variables.

Graphs of high-build and waterborne marking retroreflectivity values over time are shown in Figures 4.1 and 4.2, respectively. The graph shows that the initial median retroreflectivity values for high-build markings (N=122) range from 300 to 500 mcd/m²/lux with relatively small changes in retroreflectivity levels more than 2 years

after placement. Figure 4.2 shows that initial retroreflectivity values vary greatly from 100 to 500 mc/m²/lux for waterborne markings (N=301) and they appear to degrade much faster than high-build. It should also be noted that the vertical axes of Figures 4.1 and 4.2 have been set to the same scale for ease of comparison.

Figure 4.1: High-Build White Edge Line Marking Performance

Figure 4.2: Waterborne White Edge Line Marking Performance

Discussion of Marking Brands

Across the state, various brands of materials are used for pavement markings. As stated in *Chapter 1: 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, for waterborne markings there were two brands in the study. Upon development of the marking performance graphs, it was determined that for waterborne markings, one brand performed better on average than the other. For anonymity purposes, these two marking types will be compared and described as “Brand A” and “Brand B.” However, it should be noted that “Brand A” for high-build markings is the same brand as “Brand A” for waterborne markings. A statistical comparison of these brands is shown in Table 4.5. Also, graphs of high-build and waterborne marking performances by brand are shown in Figures 4.3 and 4.4, respectively, with Brand A shown as solid lines and Brand B shown as dashed lines.

Table 4.5: Summary Statistics of Marking Brands

Marking Material	Brand	Initial # of Sites	Avg. Initial R_L	Avg. Annual Degradation ($\text{mcd/m}^2/\text{lux}$)
High-Build	Brand A	15	404	23
Waterborne	Brand A	40	335	56
	Brand B	11	244	48

Figure 4.3: High-Build Marking Performance

Figure 4.4: Waterborne Marking Performance By Brand

As shown in Table 4.5 and Figure 4.4, Brands A and B are significantly different. For waterborne markings, Brand B has an average initial retroreflectivity value of 244 mcd/m²/lux. This is much lower than the average initial value for Brand A, which is 335 mcd/m²/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. It should also be noted that of the 5 sites mentioned earlier in the chapter with R_L values less than 100, 4 of those sites were Brand B markings. From this research, it is apparent that there are performance differences amongst various pavement marking brands.

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 it significant). 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.

Median Retroreflectivity Stepwise Regression

Previously for this research, as described in *Long-Term Performance of Pavement Markings on Primary and Secondary Roads*(3), a stepwise regression analysis was performed using median retroreflectivity values as the independent variable and all other variables, including initial retroreflectivity values, as independent variables. However, from viewing the first round of data for all sites, it was determined that assuming an initial value would be a mistake, due to the varying initial retroreflectivity values. Consequently, it was decided that initial values should not be used as independent variables, mainly because the variability in initial values makes it evident that an initial value cannot be assumed. 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.

Alternatives to producing models that incorporate an initial values as a constant include a) producing models for retroreflectivity differences from initial values, and b) producing percent difference from initial values models for retroreflectivity. 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.

Since stepwise regression was completed for differences and percent differences, other previous conclusions about significant variables were ignored and re-evaluated in the difference and percent difference stepwise regression.

Retroreflectivity Difference Stepwise Regression

The first stepwise regression used absolute differences from initial retroreflectivity as the dependent variable and all other variables as independent. The variables found significant in this analysis are shown in Table 4.6.

Table 4.6: 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					

The results of this stepwise regression were similar to those using median retroreflectivity. Producing a model using these variables would be more useful than one using initial values as a variable. The R-squared values, however, were much lower using this type of analysis (0.24 for waterbased, 0.24 for high-build), as compared to using median values. This is because initial values were the major cause for higher R-squared values. This essentially meant that if initial retroreflectivity values were known for all road markings, the model could predict the life of each individual marking. Since the goal

of the research was to produce degradation models for markings as a whole, the sacrifice in R-squared values was necessary.

As Tables 4.6 shows, lane width was reported as significant for high-build markings in the stepwise regression using absolute differences. The decision on the use of this and other variables in the model is discussed in greater detail in the *Discussion of Possible Models* section of this chapter.

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.

Retroreflectivity Percent Difference Stepwise Regression

For this analysis, a new variable was created for percent difference from initial retroreflectivity using the formula $\%Difference = \frac{(Median - Initial)}{Initial} \times 100$.

This percent difference then became the dependent variable in the stepwise regression analysis. The variables found to be significant in the analysis are shown in Table 4.7.

Table 4.7: 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					

As shown in Table 4.7, the significant variables selected by this stepwise regression were the same as the regression using absolute differences. In comparison to the absolute difference analysis, the red values increased for both marking types, but much more so for waterbased (0.35 for waterbased, 0.24 for high-build). The waterbased R-squared value most likely had a greater increase because the retroreflectivity values for waterbased tend to degrade more rapidly than high-build, resulting in a greater percent change over time.

Table 4.7 also shows that days since initial reading and traffic volume are significant for both marking types. As stated in *Ch. 2: Literature Review*, 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 waterbased models, but not more so than using days alone with the constant set to zero. The decision of which variables to retain or disregard is discussed in detail in the *Discussion of Possible Models* section of this chapter.

Discussion of Possible Models

Because of the need to eliminate initial retroreflectivity as an independent variable in the model, both difference and percent difference from initial values were modeled. For both marking types, simple linear regression with a constant of zero was completed using a single independent variable because removing the constant allowed for a more accurate and realistic model. Temperature and humidity were not determined to be significant in the modeling of either marking type and are no longer mentioned. Also, a discussion of additional variables that were examined to determine their contribution to the model is included in this section.

Waterbased White Edge Lines

For waterbased 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 are constantly changing. 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 4.8.

Table 4.8: Waterbased White Edge Line Regression Scenarios

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

The first model was created using days since 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.

High-Build White Edge Line

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 4.9.

Table 4.9: 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, Volume, Lane Width	0.23	0.26
Single	Days	0.06	0.06

As shown in Table 4.9, CTP alone has a better data correlation than all of the other variables combined.

Summary of Possible Models

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 4.10. The final models created using these variables are discussed in the *Final Degradation Models* section of this chapter.

Table 4.10: Summary of Modeled Variables

Material	Variables Used	Notes
High-Build	Cumulative Traffic Passages (Difference and Percent Difference Models)	For agency application.
	Days (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 (Difference and Percent Difference Models)	For agency application

Final Degradation Models

Models were created for white edge lines for both marking types. The models created for both marking types were linear. In each case, the equations' constant was set to zero. This is because the retroreflectivity should be equal to the initial retroreflectivity value at zero days. 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 4.11 lists the models created and their R-squared values.

Table 4.11: Final Degradation Models

Material	Variables Used	Model	R ²
High Build	CTP	DIFF = -57.8900 (C)	0.32
		% DIFF = -15.6744 (C)	0.35
	Days Since Initial Reading	DIFF = -0.0436(D)	0.06
		% DIFF = -0.0112(D)	0.06
Waterborne	Days Since Initial Reading	DIFF = -0.1328(D)	0.21
		% DIFF = -0.0537(D)	0.33
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 and percent differences are shown in Figures 4.5 and 4.6, respectively. As shown in Figure 4.6, the percent difference models had higher R-squared values for high-build CTP and

waterborne days models than the absolute difference models with the same variables shown in Figure 4.5.

Figure 4.5A: Waterbased Differences vs. Days

Figure 4.5B High-Build Differences vs. Days

Figure 4.5C: High-Build Differences vs. CTP

Figure 4.5: Descriptive Graphs of Absolute Differences

Figure 4.6A: Waterborne % Differences vs. Days Figure 4.6B: High-Build % Differences vs. Days

Figure 4.6C: High-Build % Differences vs. CTP

Figure 4.6: Descriptive Graphs of Percent Differences

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 waterbased 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/m²/lux. The models can be used to determine current retroreflectivity as follows:

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

$$\text{Therefore, Retroreflectivity} = 300 - 53 = 247 \text{ mcd/m}^2/\text{lux}$$

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

$$\text{Therefore, Retroreflectivity} = 300 - (0.21)(300) = 237 \text{ mcd/m}^2/\text{lux}$$

Now suppose the minimum threshold for retroreflectivity of this marking is set to be 100 mcd/m²/lux. In this case, the difference is known to be -200 mcd/m²/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:

$$\text{DIFF} = -200 = -0.1328 (D)$$

$$\text{Solving for Days, Marking Life} \approx 1506 \text{ days} \approx 4.13 \text{ years}$$

$$\% \text{ DIFF} = -67\% = -0.0537 (D)$$

$$\text{Solving for Days, Marking Life} \approx 1248 \text{ days} \approx 3.42 \text{ years}$$

Further discussion of model performance is contained in the next section of this chapter.

Retroreflectivity Degradation Model Performance

Testing using field collected values of retroreflectivity is necessary to determine the anticipated performance of each model. Data from high-build and waterborne white edge sites were compared to model predicted values using initial recorded retroreflective values and number of days since application for waterborne and CTP for high-build. 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 4.12 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 and approximately 90 percent of the measured values for high-build white edge line 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 4.12 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 waterborne and high-build white edge 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 4.12, 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 4.12 are for the waterborne vs. days model and the high-build vs. CTP models only.

Table 4.12: Overall Model Performance and Over-Prediction of Retroreflectivity

Model Performance--proportion of predicted values with specified error margin					
Material	Model	<±10% Error	±10-20% Error	>±20% Error	<±20% Error
Waterborne White Edge (N=301)	DIFF	49%	16%	35%	65%
	% DIFF	41%	16%	43%	57%
High-Build White Edge (N=122)	DIFF	72%	20%	8%	92%
	% DIFF	68%	21%	11%	89%
Model Performance--proportion of values over predicted specified margin.					
Material	Model	<10% Over	10-20% Over	>20% Over	<20% Over
Waterborne White Edge (N=301)	DIFF	69%	10%	21%	79%
	% DIFF	47%	13%	40%	60%
High-Build White Edge (N=122)	DIFF	79%	13%	8%	92%
	% DIFF	71%	18%	11%	89%

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 white edge line high-build and waterbased markings. In this section, the service lives of waterborne and high-build 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 both waterborne and high-

build markings were used. Based on literature, a minimum threshold of 100 mcd/m²/lux was used as the lowest acceptable retroreflectivity value. Estimates of marking life for high-build and waterborne markings were calculated using the difference and % difference models. The results are shown in Table 4.13.

Table 4.13: Prediction of White Edge Marking Life

Material	Model	R ²	Average Initial Value	Estimated Marking Lives	
High-Build (N=122)	DIFF = -57.8900 (C)	0.32	404	5.25 CTP	
	% DIFF = -15.6744 (C)	0.35		4.80 CTP	
	DIFF = -0.0436(D)	0.06		6972 Days	19.10 Years
	% DIFF = -0.0112(D)	0.06		6718 Days	18.40 Years
Waterborne (N=310)	DIFF = -0.1328 (D)	0.21	307	1558 Days	4.27 Years
	% DIFF = -0.0537(D)	0.33		1255 Days	3.44 Years

For comparative purposes, the waterborne difference model using days only was compared to the high-build difference model using days only, which is shown in Figure 4.5B. The results show that when only marking age is considered, high-build 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 4.14.

Table 4.14: Waterborne and High-Build Lifecycle Estimates Using Marking Age

Marking Type	Average Initial Value	Model	Time (Years)							Annual Degradation (mcd/m ² /lux)
			1	2	3	4	5		20	
Waterborne	307	DIFF = -0.1328 (D)	259	210	162	113	65			-48
High-Build	404	DIFF = -0.0436 (D)	388	372	356	340	324		86	-16

Because retroreflectivity for waterborne markings is dependent on marking age only and CTP only for high-build 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 shown in Table 4.13. 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/m²/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 4.15.

Table 4.15: Model Predicted White Edge Marking Lifespans

			Time (Years)													
Marking Type	Avg. Initial Value		1	2	3	4	5	6	7	8		15	Est. Cost (\$/LF)	Cost (\$/LF/yr.)		
WB	307		259	210	162	113	65						0.09	0.018		
			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 4.15, high-build markings are predicted to outlast waterborne markings 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.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The objective of this research was to develop and compare degradation models for waterbased and high-build white edge line pavement markings. These models, once fully developed, may be used by SCDOT to determine how often to replace the pavement markings on primary and secondary roads in South Carolina. The research and analysis included in this thesis fulfilled the objectives of creating and comparing degradation models, service lives, and marking costs, from which many important conclusions were drawn. However, there are still some areas where improvement is needed, which are discussed in the *Recommendations* section of this chapter.

Research Conclusions

The objective of this research was to develop, compare, and evaluate degradation models for high-build and waterborne 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 5.1.

Table 5.1 Retroreflectivity Degradation Models

Material	Model	R ²	Average Initial Value	Estimated Marking Lives	
High-Build (N=122)	DIFF = -57.8900 (C)	0.32	404	5.25 CTP	
	% DIFF = -15.6744 (C)	0.35		4.80 CTP	
	DIFF = -0.0436(D)	0.06		6972 Days	19.10 Years
	% DIFF = -0.0112(D)	0.06		6718 Days	18.40 Years
Waterborne (N=310)	DIFF = -0.1328 (D)	0.21	307	1558 Days	4.27 Years
	% DIFF = -0.0537(D)	0.33		1255 Days	3.44 Years

Conclusions from this research are summarized as follows:

- As described in *Chapter 4: Data Analysis*, 19 sites, which make up 43% of the total lost sites included in the study, were repainted while their retroreflectivity values were still greater than 100 mcd/m²/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 five waterborne sites in the study mentioned in *Chapter 4: Data Analysis* that have retroreflectivity values less than 100 mc/m²/lux. These sites make up 23% 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 4.5, there is a significant difference in the performance of the two marking brands included in the study. It was concluded that for waterborne markings, Brand B had an average initial retroreflectivity value of 244 mcd/m²/lux, which is much lower than that of Brand A, 335 mcd/m²/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 of marking Brand B.
- As described in *Chapter 4: Data 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 5.1, for 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 5.1 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 depicted in Figures 4.5 and 4.6, 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.
- As tabulated in Table 4.10, 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 markings, and less than 10 percent for high-build markings. This concern could be effectively addressed through use of margin of safety factors.

- As summarized in Table 5.1, model estimated pavement-marking life was determined to be 3.44 years for waterborne markings and 4.80 million vehicle passages for high build markings, using percent difference retroreflectivity models, and 4.27 years and 5.25 million vehicle passages using absolute difference retroreflectivity models. This assumes the average initial values from the study and a minimum threshold value of 100 mcd/m²/lux.
- As summarized in Table 4.15, even though high-build marking installation costs are approximately double that of waterborne markings, observed durability and lifespan of high-build markings appear more desirable based on retroreflectivity degradation comparisons. Compared to waterborne markings, high-build markings are more cost-effective for volumes up to 1600 veh/day.

Recommendations

- Because the model predicted estimates for service marking lives exceed the length of the project, additional data collection would be necessary to verify these models for the remainder of pavement marking life. Also, because the high-build sites in the study are only on roads with AADTs up to 3500 veh/day, it would be

beneficial for SCDOT to conduct a similar study on high-build markings along roadways with higher 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 value standards should be set for contractors applying pavement markings. Using minimum initial values enable the models to predict the service life of markings, as well as allow for longer marking lives if the initial values are high enough. For more accurate results, the initial values should be measured so that the models may be applied. It is recommended that these initial values be close to the average initial values of the sites in this study, which were around 400 mcd/m²/lux for high-build markings and 300 mcd/m²/lux for waterborne markings.
- When minimum retroreflectivity thresholds are established, they should be extremely low. Currently, a threshold value of 100 mcd/m²/lux is commonly thought of as the minimum, but under dry conditions, this is still relatively high. Forcing DOTs to comply with high minimums 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.

In conclusion, the project upon which this thesis is based is set to end on February 1, 2012 with the submittal of the project's final report to SCDOT. The final report will include this research, as well as other research not mentioned here.

APPENDICES

Appendix A: High Build Marking Data

Site	Round	Initial	Median (mc/m ² /lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
86	1	412	412	25	200	0.0050	10	0	79	0.52
86	2	412	441	115	200	0.0230	10	0	76	0.47
86	3	412	457	219	200	0.0438	10	0	50	0.24
86	4	412	412	365	200	0.0730	10	0	84	0.58
86	5	412	469	429	200	0.0858	10	0	93	0.51
86	6	412	450	557	200	0.1114	10	0	73	0.26
86	7	412	481	659	200	0.1318	10	0	89	0.2
87	1	390	390	25	200	0.0050	10	0	80	0.52
87	2	390	386	115	200	0.0230	10	0	80	0.46
87	3	390	423	219	200	0.0438	10	0	50	0.28
87	4	390	383	365	200	0.0730	10	0	84	0.58
87	5	390	424	429	200	0.0858	10	0	92	0.5
87	7	390	432	659	200	0.1318	10	0	85	0.2
87	8	390	389	759	200	0.1518	10	0	99	0.4
87	9	390	389	864	200	0.1728	10	0	79	0.88
88	1	401	401	25	500	0.0125	9	0.5	82	0.5
88	2	401	362	115	500	0.0575	9	0.5	80	0.44
88	3	401	379	219	500	0.1095	9	0.5	51	0.3
88	4	401	379	365	500	0.1825	9	0.5	84	0.58
88	5	401	410	429	500	0.2145	9	0.5	101	0.36
88	6	401	293	557	500	0.2785	9	0.5	73	0.27
88	7	401	317	659	500	0.3295	9	0.5	77	0.2
88	8	401	321	759	500	0.3795	9	0.5	99	0.33
88	9	401	309	864	500	0.4320	9	0.5	78	0.88
89	1	448	448	24	200	0.0048	10	0	82	0.52
89	2	448	432	114	200	0.0228	10	0	81	0.44
89	3	448	469	218	200	0.0436	10	0	53	0.3
89	4	448	356	363	200	0.0726	10	0	85	0.58
89	5	448	458	428	200	0.0856	10	0	100	0.32
89	6	448	400	556	200	0.1112	10	0	73	0.27
89	7	448	496	658	200	0.1316	10	0	75	0.2
89	8	448	476	758	200	0.1516	10	0	94	0.34

Appendix A: High Build Marking Data (Continued)

Site	Round	Initial	Median (mc/m2/lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
90	1	386	386	25	200	0.0050	10	0	86	0.48
90	2	386	353	115	200	0.0230	10	0	83	0.44
90	3	386	345	219	200	0.0438	10	0	53	0.3
90	4	386	352	365	200	0.0730	10	0	55	0.58
90	5	386	384	429	200	0.0858	10	0	99	0.36
90	6	386	418	557	200	0.1114	10	0	73	0.27
90	7	386	410	659	200	0.1318	10	0	78	0.2
90	8	386	386	759	200	0.1518	10	0	93	0.42
90	9	386	407	864	200	0.1728	10	0	73	0.88
91	1	434	434	23	200	0.0046	10	0	84	0.47
91	2	434	432	113	200	0.0226	10	0	83	0.44
91	3	434	426	217	200	0.0434	10	0	53	0.3
91	4	434	423	362	200	0.0724	10	0	85	0.58
91	5	434	453	427	200	0.0854	10	0	97	0.41
91	6	434	438	555	200	0.1110	10	0	73	0.27
91	7	434	415	657	200	0.1314	10	0	79	0.2
91	8	434	440	757	200	0.1514	10	0	101	0.34
92	2	452	452	113	1000	0.1130	10	0.5	83	0.44
92	3	452	456	217	1000	0.2170	10	0.5	53	0.3
92	4	452	460	362	1000	0.3620	10	0.5	85	0.58
92	5	452	455	427	1000	0.4270	10	0.5	101	0.35
92	6	452	454	555	1000	0.5550	10	0.5	74	0.25
92	7	452	463	657	1000	0.6570	10	0.5	75	0.2
92	8	452	454	757	1000	0.7570	10	0.5	95	0.35
92	9	452	420	862	1000	0.8620	10	0.5	73	0.88
93	2	462	462	114	300	0.0342	9	0	83	0.44
93	3	462	466	218	300	0.0654	9	0	53	0.3
93	4	462	436	363	300	0.1089	9	0	55	0.58
93	5	462	444	428	300	0.1284	9	0	104	0.31
93	6	462	458	556	300	0.1668	9	0	71	0.27
93	7	462	464	658	300	0.1974	9	0	77	0.2
93	8	462	427	758	325	0.2464	9	0	104	0.31
93	9	462	407	863	325	0.2805	9	0	73	0.88
94	1	354	354	24	325	0.0078	9	0.5	84	0.48
94	2	354	388	114	325	0.0371	9	0.5	83	0.44
94	3	354	307	218	325	0.0709	9	0.5	54	0.3
94	4	354	294	363	325	0.1180	9	0.5	85	0.58
94	5	354	296	428	325	0.1391	9	0.5	104	0.36

Appendix A: High Build Marking Data (Continued)

Site	Round	Initial	Median (mc/m2/lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
95	1	312	312	19	600	0.0114	10	0.5	85	0.55
95	2	312	372	118	600	0.0708	10	0.5	83	0.5
95	3	312	345	196	600	0.1176	10	0.5	45	0.25
95	4	312	321	301	600	0.1806	10	0.5	60	0.25
95	5	312	261	409	600	0.2454	10	0.5	82	0.66
95	6	312	323	528	600	0.3168	10	0.5	87	0.2
95	7	312	268	632	600	0.3792	10	0.5	76	0.2
95	8	312	327	726	600	0.4356	10	0.5	77	0.45
95	9	312	322	839	600	0.5034	10	0.5	61	0.5
96	1	321	321	18	3500	0.0630	10	0.33	85	0.55
96	2	321	311	117	3500	0.4095	10	0.33	83	0.5
96	3	321	306	195	3500	0.6825	10	0.33	45	0.25
96	4	321	258	300	3500	1.0500	10	0.33	60	0.25
96	5	321	202	408	3500	1.4280	10	0.33	91	0.55
96	6	321	262	527	3500	1.8445	10	0.33	88	0.2
96	7	321	245	631	3500	2.2085	10	0.33	76	0.2
97	1	389	389	19	600	0.0114	10	0.33	86	0.51
97	2	389	417	118	600	0.0708	10	0.33	83	0.5
97	3	389	388	196	600	0.1176	10	0.33	45	0.25
97	4	389	373	301	600	0.1806	10	0.33	60	0.24
97	5	389	324	409	600	0.2454	10	0.33	94	0.5
97	6	389	288	528	600	0.3168	10	0.33	87	0.2
97	7	389	302	632	600	0.3792	10	0.33	76	0.2
97	8	389	280	726	600	0.4356	10	0.33	85	0.39
97	9	389	235	839	600	0.5034	10	0.33	61	0.5
98	1	462	462	19	1500	0.0285	10	0.33	84	0.52
98	2	462	417	118	1500	0.1770	10	0.33	83	0.4
98	3	462	345	196	1500	0.2940	10	0.33	45	0.3
98	4	462	429	301	1500	0.4515	10	0.33	60	0.25
98	5	462	425	409	1500	0.6135	10	0.33	93	0.49
98	6	462	451	528	1500	0.7920	10	0.33	87	0.2
98	7	462	419	632	1500	0.9480	10	0.33	74	0.2
98	8	462	396	726	1500	1.0890	10	0.33	85	0.39
98	9	462	400	839	1500	1.2585	10	0.33	61	0.5

Appendix A: High Build Marking Data (Continued)

Site	Round	Initial	Median (mc/m2/lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
99	1	352	352	19	1000	0.0190	10	0	86	0.52
99	2	352	350	118	1000	0.1180	10	0	84	0.41
99	3	352	315	196	1000	0.1960	10	0	45	0.3
99	4	352	335	301	1000	0.3010	10	0	60	0.25
99	5	352	284	409	1000	0.4090	10	0	92	0.51
99	6	352	288	528	1000	0.5280	10	0	85	0.2
99	7	352	333	632	1000	0.6320	10	0	73	0.2
99	8	352	311	726	1000	0.7260	10	0	87	0.38
99	9	352	305	839	1000	0.8390	10	0	61	0.5
150	1	465	465	19	500	0.0095	10	0.33	86	0.44
150	2	465	457	118	500	0.0590	10	0.33	83	0.4
150	3	465	493	196	500	0.0980	10	0.33	47	0.3
150	4	465	399	301	500	0.1505	10	0.33	61	0.25
150	5	465	464	409	500	0.2045	10	0.33	92	0.55
150	6	465	464	528	500	0.2640	10	0.33	86	0.2
150	7	465	472	632	500	0.3160	10	0.33	73	0.2
150	8	465	434	726	500	0.3630	10	0.33	90	0.34
150	9	465	428	839	500	0.4195	10	0.33	61	0.5

Appendix B: Waterborne Marking Data

Site	Round	Initial	Median (mc/m2/lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
1	1	232	232	27	4600	0.1242	-	-	83	0.48
1	2	232	240	98	4600	0.4508	-	-	96	0.32
1	3	232	205	256	4600	1.1776	-	-	29	0.20
2	1	257	257	14	19200	0.2688	-	0.2	83	0.28
2	2	257	262	98	19200	1.8816	-	0.2	81	0.38
2	3	257	252	246	19200	4.7232	-	0.2	59	0.33
2	4	257	214	334	19200	6.4128	-	0.2	73	0.27
2	5	257	201	439	19200	8.4288	-	0.2	79	0.62
3	1	169	169	13	6200	0.0806	10	0.2	84	0.37
3	2	169	166	98	6200	0.6076	10	0.2	90	0.33
3	3	169	94	231	6200	1.4322	10	0.2	60	0.20
3	4	169	132	334	6200	2.0708	10	0.2	73	0.20
3	5	169	115	438	6200	2.7156	10	0.2	83	0.52
3	6	169	107	532	6200	3.2984	10	0.2	73	0.53
3	7	169	95	689	6200	4.2718	10	0.2	59	0.2
3	8	169	96	797	6200	4.9414	10	0.2	78	0.53
3	9	169	101	901	6200	5.5862	10	0.2	98	0.25
3	10	169	102	1019	6200	6.3178	10	0.2	74	0.2
3	11	169	93	1125	6200	6.9750	10	0.2	90	0.38
4	1	116	116	13	11300	0.1469	10	1.5	79	0.58
4	2	116	93	98	11300	1.1074	10	1.5	89	0.36
4	3	116	84	231	11300	2.6103	10	1.5	60	0.20
4	4	116	69	334	11300	3.7742	10	1.5	73	0.20
4	5	116	56	438	11300	4.9494	10	1.5	85	0.52
5	1	355	355	22	7500	0.1650	-	2.0	85	0.20
5	2	355	328	98	7500	0.7350	-	2.0	91	0.31
5	3	355	267	231	7500	1.7325	-	2.0	60	0.31
5	4	355	234	334	7500	2.5050	-	2.0	90	0.25
5	5	355	100	447	7500	3.3525	-	2.0	82	0.53
5	6	355	182	541	7500	4.0575	-	2.0	75	0.53
5	7	355	119	698	7500	5.2350	-	2.0	60	0.2
5	8	355	124	806	7500	6.0450	-	2.0	83	0.51
5	9	355	125	910	7500	6.8250	-	2.0	94	0.22
5	10	355	95	1028	7500	7.7100	-	2.0	66	0.2
8	1	130	130	15	8200	0.1230	11	0.0	79	0.47
8	2	130	98	93	8200	0.7626	11	0.0	78	0.57
8	3	130	113	239	8200	1.9598	11	0.0	59	0.22
8	4	130	112	359	8200	2.9438	11	0.0	84	0.40

Appendix B: Waterborne Marking Data (Continued)

Site	Round	Initial	Median (mc/m ² /lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
14	1	337	337	28	1000	0.0280	11	6.0	77	0.35
14	2	337	349	96	1000	0.0960	11	6.0	94	0.40
14	3	337	330	242	1000	0.2420	11	6.0	33	0.25
14	4	337	308	352	1000	0.3520	11	6.0	85	0.42
14	5	337	322	460	1000	0.4600	11	6.0	80	0.60
14	6	337	284	552	1000	0.5520	11	6.0	66	0.56
14	7	337	227	690	1000	0.6900	11	6.0	58	0.2
14	8	337	206	798	1000	0.7980	11	6.0	85	0.44
14	9	337	222	902	1000	0.9020	11	6.0	90	0.33
14	10	337	163	1020	1000	1.0200	11	6.0	66	0.2
14	11	337	167	1126	1000	1.1260	11	6.0	103	0.21
24	1	319	319	21	25	0.0005	10	0.0	86	0.55
24	2	319	328	110	25	0.0028	10	0.0	81	0.47
24	3	319	236	243	25	0.0061	10	0.0	68	0.31
24	4	319	161	357	25	0.0089	10	0.0	82	0.53
24	5	319	118	464	25	0.0116	10	0.0	86	0.44
24	6	319	125	573	25	0.0143	10	0.0	52	0.26
27	1	261	261	21	50	0.0011	11	1.0	87	0.53
27	2	261	294	110	50	0.0055	11	1.0	86	0.40
27	3	261	251	243	50	0.0122	11	1.0	70	0.30
27	4	261	245	357	50	0.0179	11	1.0	81	0.53
27	5	261	238	464	50	0.0232	11	1.0	85	0.46
27	6	261	202	573	50	0.0287	11	1.0	52	0.26
28	1	269	269	21	150	0.0032	10	0.0	88	0.52
28	2	269	244	110	150	0.0165	10	0.0	86	0.40
28	3	269	239	243	150	0.0365	10	0.0	75	0.31
28	4	269	269	357	150	0.0536	10	0.0	87	0.50
28	5	269	282	464	150	0.0696	10	0.0	85	0.46
28	6	269	222	573	150	0.0860	10	0.0	52	0.26
29	1	398	398	23	3700	0.0851	10	0.3	-	-
29	2	398	284	131	3700	0.4847	10	0.3	72	0.46
29	3	398	319	242	3700	0.8954	10	0.3	60	0.27
29	4	398	337	360	3700	1.3320	10	0.3	81	0.71
29	5	398	250	470	3700	1.7390	10	0.3	76	0.49
29	6	398	197	592	3700	2.1904	10	0.3	28	0.23
30	1	461	461	23	1850	0.0426	10	0.5	-	-
30	2	461	468	131	1850	0.2424	10	0.5	72	-
30	3	461	419	242	1850	0.4477	10	0.5	60	-
30	4	461	372	360	1850	0.6660	10	0.5	86	0.62
30	5	461	380	470	1850	0.8695	10	0.5	77	0.49
30	6	461	383	592	1850	1.0952	10	0.5	28	0.23
31	1	356	356	22	500	0.0110	10	0.5	-	-
31	2	356	380	116	500	0.0580	10	0.5	74	0.30
31	3	356	339	242	500	0.1210	10	0.5	60	0.30
31	4	356	373	360	500	0.1800	10	0.5	88	0.56

Appendix B: Waterborne Marking Data (Continued)

Site	Round	Initial	Median (mc/m ² /lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
33	1	363	363	17	500	0.0085	10	0.5	-	-
33	2	363	261	116	500	0.0580	10	0.5	74	-
33	3	363	146	242	500	0.1210	10	0.5	60	-
33	4	363	250	360	500	0.1800	10	0.5	93	0.50
34	1	363	363	17	600	0.0102	10	0.5	-	-
34	2	363	331	116	600	0.0696	10	0.5	74	-
34	3	363	293	242	600	0.1452	10	0.5	60	-
34	4	363	232	360	600	0.2160	10	0.5	92	0.48
35	1	290	290	17	700	0.0119	10	0.3	-	-
35	2	290	281	116	700	0.0812	10	0.3	74	-
35	3	290	304	242	700	0.1694	10	0.3	60	-
35	4	290	338	360	700	0.2520	10	0.3	95	0.44
36	1	363	363	17	1150	0.0196	10	0.3	-	-
36	2	363	339	116	1150	0.1334	10	0.3	74	-
36	3	363	323	242	1150	0.2783	10	0.3	60	-
36	4	363	351	360	1150	0.4140	10	0.3	95	-
37	1	355	355	17	550	0.0094	9	0.2	-	-
37	2	355	353	116	550	0.0638	9	0.2	74	-
37	3	355	355	242	550	0.1331	9	0.2	60	-
37	4	355	286	371	550	0.2041	9	0.2	89	0.43
38	1	314	314	16	150	0.0024	-	0.2	-	-
38	2	314	308	116	150	0.0174	-	0.2	74	-
38	3	314	285	242	150	0.0363	-	0.2	60	-
38	4	314	313	360	150	0.0540	-	0.2	95	0.44
39	1	251	251	26	1450	0.0377	10	0.3	-	-
39	2	251	171	116	1450	0.1682	10	0.3	80	-
39	3	251	65	256	1450	0.3712	10	0.3	73	-
39	4	251	159	381	1450	0.5525	10	0.3	83	0.48
39	5	251	140	487	1450	0.7062	10	0.3	68	0.42
39	6	251	116	595	1450	0.8628	10	0.3	54	0.20
39	7	251	104	766	1450	1.1107	10	0.3	79	0.55
39	8	251	76	900	1450	1.3050	10	0.3	71	0.20
39	9	251	90	998	1450	1.4471	10	0.3	67	0.2
39	10	251	84	1103	1450	1.5994	10	0.3	102	0.37
39	11	251	74	1215	1450	1.7618	10	0.3	66	0.79
40	1	167	167	26	500	0.0130	9	-	-	-
40	2	167	133	116	500	0.0580	9	-	80	0.35
40	3	167	56	256	500	0.1280	9	-	77	0.30
40	4	167	76	381	500	0.1905	9	-	87	0.45
40	5	167	123	487	500	0.2435	9	-	73	0.41
40	6	167	118	595	500	0.2975	9	-	54	0.20
40	7	167	58	766	500	0.3830	9	-	87	0.48
40	8	167	51	900	500	0.4500	9	-	82	0.22
40	9	167	68	998	500	0.4990	9	-	76	0.2
40	10	167	65	1103	500	0.5515	9	-	102	0.32
40	11	167	61	1215	500	0.6075	9	-	67	0.74

Appendix B: Waterborne Marking Data (Continued)

Site	Round	Initial	Median (mc/m ² /lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
41	1	166	166	26	500	0.0130	9	0.0	-	-
41	2	166	139	116	500	0.0580	9	0.0	84	0.31
41	3	166	46	256	500	0.1280	9	0.0	80	0.30
41	4	166	80	381	500	0.1905	9	0.0	86	0.47
41	5	166	53	487	500	0.2435	9	0.0	73	0.39
41	6	166	83	595	500	0.2975	9	0.0	55	0.20
41	7	166	55	766	500	0.3830	9	0.0	94	0.45
41	8	166	80	900	500	0.4500	9	0.0	77	0.20
41	9	166	82	998	500	0.4990	9	0.0	78	0.2
41	10	166	67	1103	500	0.5515	9	0.0	107	0.29
41	11	166	67	1215	500	0.6075	9	0.0	66	0.79
42	1	122	122	26	500	0.0130	10	5.0	-	-
42	2	122	99	116	500	0.0580	10	5.0	83	0.33
42	3	122	83	256	500	0.1280	10	5.0	85	0.30
42	4	122	56	381	500	0.1905	10	5.0	87	0.44
42	5	122	40	487	500	0.2435	10	5.0	72	0.39
42	6	122	33	595	500	0.2975	10	5.0	55	0.20
42	7	122	29	766	500	0.3830	10	5.0	97	0.36
42	8	122	29	900	500	0.4500	10	5.0	78	0.21
42	9	122	28	998	500	0.4990	10	5.0	81	0.2
42	10	122	25	1103	500	0.5515	10	5.0	107	0.28
42	11	122	32	1215	500	0.6075	10	5.0	68	0.74
49	1	378	378	20	1450	0.0290	10	0.5	79	-
49	2	378	411	116	1450	0.1682	10	0.5	81	0.35
49	3	378	357	249	1450	0.3611	10	0.5	83	0.27
49	4	378	315	356	1450	0.5162	10	0.5	88	0.45
49	5	378	345	452	1450	0.6554	10	0.5	85	0.42
49	6	378	273	574	1450	0.8323	10	0.5	33	0.21
50	1	397	397	20	650	0.0130	10	1.0	79	-
50	2	397	439	116	650	0.0754	10	1.0	83	0.37
50	3	397	387	249	650	0.1619	10	1.0	88	0.37
50	4	397	378	356	650	0.2314	10	1.0	86	0.46
51	1	390	390	20	375	0.0075	10	0.2	79	-
51	2	390	288	116	375	0.0435	10	0.2	83	-
51	3	390	258	249	375	0.0934	10	0.2	88	-
51	4	390	303	356	375	0.1335	10	0.2	86	0.48
51	5	390	245	452	375	0.1695	10	0.2	84	0.39
51	6	390	300	574	375	0.2153	10	0.2	32	0.23
52	1	311	311	20	225	0.0045	10	10.0	79	-
52	2	311	171	116	225	0.0261	10	10.0	80	0.30
52	3	311	72	249	225	0.0560	10	10.0	88	0.30
52	4	311	144	356	225	0.0801	10	10.0	86	0.30
53	1	370	370	20	100	0.0020	9	0.0	79	-
53	2	370	215	116	100	0.0116	9	0.0	80	-
53	3	370	268	249	100	0.0249	9	0.0	88	-
53	4	370	222	356	100	0.0356	9	0.0	86	-
53	5	370	210	452	100	0.0452	9	0.0	84	0.39
53	6	370	220	574	100	0.0574	9	0.0	32	0.24

Appendix B: Waterborne Marking Data (Continued)

Site	Round	Initial	Median (mc/m ² /lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
54	1	360	360	20	100	0.0020	9	0.0	79	-
54	2	360	448	116	100	0.0116	9	0.0	83	0.27
54	3	360	331	249	100	0.0249	9	0.0	88	0.26
54	4	360	324	356	100	0.0356	9	0.0	86	0.46
55	1	429	429	20	600	0.0120	10	2.0	79	-
55	2	429	483	116	600	0.0696	10	2.0	83	0.46
55	3	429	392	249	600	0.1494	10	2.0	88	0.46
55	4	429	340	356	600	0.2136	10	2.0	85	0.46
55	5	429	353	452	600	0.2712	10	2.0	84	0.39
55	6	429	310	574	600	0.3444	10	2.0	31	0.24
56	1	378	378	20	275	0.0055	9	0.3	79	-
56	2	378	377	116	275	0.0319	9	0.3	83	0.24
56	3	378	350	249	275	0.0685	9	0.3	88	0.24
56	4	378	334	356	275	0.0979	9	0.3	84	0.43
57	1	294	294	16	350	0.0056	10	0.0	78	-
57	2	294	380	110	350	0.0385	10	0.0	83	0.38
57	3	294	393	246	350	0.0861	10	0.0	82	0.29
57	4	294	376	332	350	0.1162	10	0.0	94	0.49
58	1	376	376	17	1850	0.0315	10	0.3	78	-
58	2	376	254	110	1850	0.2035	10	0.3	74	0.38
58	3	376	204	246	1850	0.4551	10	0.3	82	0.29
58	4	376	169	332	1850	0.6142	10	0.3	95	0.50
59	1	419	419	17	3200	0.0544	11	0.0	78	-
59	2	419	390	110	3200	0.3520	11	0.0	85	0.35
59	3	419	377	246	3200	0.7872	11	0.0	80	0.29
59	4	419	355	343	3200	1.0976	11	0.0	88	0.45
59	5	419	343	436	3200	1.3952	11	0.0	81	0.44
59	6	419	265	558	3200	1.7856	11	0.0	32	0.23
60	1	375	375	17	500	0.0085	10	0.0	78	-
60	2	375	327	110	500	0.0550	10	0.0	85	-
60	3	375	295	246	500	0.1230	10	0.0	80	-
60	4	375	137	343	500	0.1715	10	0.0	88	0.44
61	1	334	334	17	75	0.0013	10	0.5	78	-
61	2	334	297	110	75	0.0083	10	0.5	84	0.38
61	3	334	282	246	75	0.0185	10	0.5	80	0.27
61	4	334	264	332	75	0.0249	10	0.5	87	0.56
61	5	334	253	436	75	0.0327	10	0.5	77	0.43
61	6	334	264	558	75	0.0419	10	0.5	32	0.23
61	7	334	214	729	75	0.0547	10	0.5	82	0.57
61	8	334	243	863	75	0.0647	10	0.5	77	0.22
61	9	334	235	981	75	0.0736	10	0.5	75	0.2
61	10	334	206	1078	75	0.0809	10	0.5	96	0.41
61	11	334	234	1185	75	0.0889	10	0.5	65	0.75

Appendix B: Waterborne Marking Data (Continued)

Site	Round	Initial	Median (mc/m2/lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
62	1	467	467	17	175	0.0030	10	0.5	78	-
62	2	467	446	110	175	0.0193	10	0.5	85	0.35
62	3	467	467	246	175	0.0431	10	0.5	83	0.28
62	4	467	389	332	175	0.0581	10	0.5	91	0.28
63	1	408	408	17	175	0.0030	9	0.5	78	-
63	2	408	401	110	175	0.0193	9	0.5	89	0.26
63	3	408	375	246	175	0.0431	9	0.5	86	0.27
63	4	408	334	332	175	0.0581	9	0.5	93	0.49
64	1	410	410	16	550	0.0088	10	0.3	78	-
64	2	410	416	110	550	0.0605	10	0.3	84	0.38
64	3	410	397	246	550	0.1353	10	0.3	86	0.28
64	4	410	408	332	550	0.1826	10	0.3	93	0.49
117	1	332	332	29	425	0.0123	10	-	87	0.40
117	2	332	311	80	425	0.0340	10	-	75	0.54
117	3	332	313	227	425	0.0965	10	-	84	0.53
117	4	332	306	294	425	0.1250	10	-	87	0.41
117	5	332	393	475	425	0.2019	10	-	42	0.34
117	6	332	408	536	425	0.2278	10	-	63	0.23
118	1	237	237	29	325	0.0094	10	0.5	87	0.40
118	2	237	241	80	325	0.0260	10	0.5	75	0.52
118	3	237	196	227	325	0.0738	10	0.5	85	0.52
118	4	237	196	294	325	0.0956	10	0.5	85	0.58
118	5	237	363	475	325	0.1544	10	0.5	42	0.26
118	6	237	377	536	325	0.1742	10	0.5	63	0.23
118	7	237	387	661	325	0.2148	10	0.5	88	-
118	8	237	300	796	325	0.2587	10	0.5	57	-
118	9	237	298	933	325	0.3032	10	0.5	70	-
119	1	407	407	29	900	0.0261	11	1.5	87	0.40
119	2	407	367	80	900	0.0720	11	1.5	76	0.52
119	3	407	357	227	900	0.2043	11	1.5	85	0.52
119	4	407	373	294	900	0.2646	11	1.5	87	0.43
119	5	407	264	475	900	0.4275	11	1.5	40	0.37
119	6	407	250	536	900	0.4824	11	1.5	63	0.24

Appendix B: Waterborne Marking Data (Continued)

Site	Round	Initial	Median (mc/m2/lux)	Days Since Application	AADT (vehicles/day)	CTP (million vehicles)	Lane Width (ft)	Shoulder Width (ft)	Temp. (F)	Humidity
120	1	314	314	29	850	0.0247	9	-	85	0.40
120	2	314	298	80	850	0.0680	9	-	76	0.50
120	3	314	310	227	850	0.1930	9	-	85	0.50
120	4	314	309	294	850	0.2499	9	-	84	0.48
120	5	314	338	475	850	0.4038	9	-	36	0.39
120	6	314	328	536	850	0.4556	9	-	63	0.27
120	7	314	322	661	850	0.5619	9	-	93	-
120	8	314	298	796	850	0.6766	9	-	55	-
120	9	314	286	933	850	0.7931	9	-	71	-
120	10	314	317	1026	850	0.8721	9	-	80	-
151	1	352	352	20	1000	0.0200	-	0.5	89	0.53
152	1	172	172	20	1000	0.0200	-	-	95	0.42
152	2	172	139	123	1000	0.1230	-	-	83	0.55
152	3	172	133	202	1000	0.2020	-	-	46	0.35
152	4	172	127	298	1000	0.2980	-	-	80	0.27
152	5	172	124	420	1000	0.4200	-	-	93	0.68
152	6	172	135	522	1000	0.5220	-	-	81	0.2
152	7	172	116.5	634	1000	0.6340	-	-	79	0.2
152	8	172	104	762	1000	0.7620	-	-	98	0.33
152	9	172	118	869	1000	0.8690	-	-	70	0.6
153	1	294	294	20	1000	0.0200	-	-	90	0.43
154	1	309	309	19	1000	0.0190	-	-	91	0.41
155	1	316	316	19	2700	0.0513	-	-	95	0.38
155	2	316	251	122	2700	0.3294	-	-	81	0.42
155	3	316	247	201	2700	0.5427	-	-	47	0.35
155	4	316	259	297	2700	0.8019	-	-	81	0.27
155	5	316	213	419	2700	1.1313	-	-	89	0.67
155	6	316	277	521	2700	1.4067	-	-	80	0.2
155	7	316	241	633	2700	1.7091	-	-	80	0.29
155	8	316	241	761	2700	2.0547	-	-	100	0.34
156	1	303	303	19	2600	0.0494	-	-	92	0.4
156	2	303	302	122	2600	0.3172	-	-	80	0.46
156	3	303	257	201	2600	0.5226	-	-	47	0.35
156	4	303	228	297	2600	0.7722	-	-	81	0.27
156	5	303	216	419	2600	1.0894	-	-	90	0.6
156	6	303	216	521	2600	1.3546	-	-	83	0.2
156	7	303	198	633	2600	1.6458	-	-	77	0.3
156	8	303	191	761	2600	1.9786	-	-	101	0.35
156	9	303	166	868	2600	2.2568	-	-	70	0.6
157	1	237	237	18	1000	0.0180	-	-	93	0.39
157	2	237	285	121	1000	0.1210	-	-	86	0.51
157	3	237	229	200	1000	0.2000	-	-	48	0.35
157	4	237	179	296	1000	0.2960	-	-	81	0.27
157	5	237	159	418	1000	0.4180	-	-	88	0.6
157	6	237	110	520	1000	0.5200	-	-	84	0.2
157	7	237	124	632	1000	0.6320	-	-	77	0.3
157	8	237	118	760	1000	0.7600	-	-	102	0.32
157	9	237	103	867	1000	0.8670	-	-	70	0.6

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