FINAL REPORT

FHWA/IN/JTRP-2002/22

Sign Retroreflectivity Study

By

Austin Bischoff
Graduate Research Assistant

Darcy Bullock
Professor of Civil Engineering

School of Civil Engineering
Purdue University

Joint Transportation Research Program
Project No: C-36-59HH
File No: 8-5-34
SPR- 2482

Conducted in Cooperation with the
Indiana Department of Transportation
and the
U.S. Department of Transportation
Federal Highway Administration

Purdue University
West Lafayette, IN 47907

December, 2002

ACKNOWLEDGMENTS

We would like to acknowledge the following people who served on the SAC committee for this project:

- Gary Bowser – Indiana Department of Transportation
- Mike Hofman – Indiana Department of Transportation
- Dennis Lee – Federal Highway Administration
- Shuo Li – Indiana Department of Transportation
- Randy Morris – Indiana Department of Transportation

We are particularly grateful for the assistance provided by Randy Morris, from the Crawfordsville district, who assisted in the initial data collection during the summer of 2001.

We would also like to thank the people from 3M who lent us their 820 retroreflectometer for use in comparing the 820 to the ART 920 as well as comparing signs that failed the proposed minimums and/or 4 to 1 ratio.

In addition we would like to thank the following students for their help and participation in the data collection for this study: John Beha, Matt DeVille, Kevin Lee, Jeff Martinkia, Andrew Nichols, Luke Nuber, and Siddarth Shankar.

INDOT Research

TECHNICAL *Summary*

Technology Transfer and Project Implementation Information

TRB Subject Code:51-6 Compatibility of Standards *December 2002*
Publication No.: FHWA/IN/JTRP-2002/22, SPR-2482 *Final Report*

Sign Retroreflectivity Study

Introduction

Signing is a big yearly cost to state DOT's in sign maintenance and replacement costs. In 2001 the Indiana Department of Transportation (INDOT) replaced 14,930 signs at a cost of $1,067,931 and did maintenance work on 34,084 signs at a cost of $2,136,076. These values include the cost of the material used for making the sign, equipment use, and labor costs. Replacement is defined as a sign being replaced because it is ten years of age or older. Maintenance is defined as signs needing to be cleaned or replaced due to knockdowns or vandalism. Currently the replacement of interstate and highway signs, which are ten years or older, is about one-third of the entire cost of the INDOT sign maintenance and replacement program.

Recently, guidelines have been proposed by the Federal Highway Administration (FHWA) for minimum retroreflectivity of traffic signs for state, county, and city roads in the United States. The purpose of this study was to evaluate if the majority of the signs currently by INDOT will meet the new minimum requirements proposed by the FHWA. In addition, this study provides quantitative data to assess the effectiveness of the current sign replacement program used by the Indiana Department of Transportation (INDOT) and determine if the current ten year replacement schedule is adequate to keep the State of Indiana in compliance with the new guidelines or if adjustments need to be made. This study was limited to ASTM Type III sheeting.

Findings

Given the data analysis performed on the data collected from the field the vast majority of the signs are expected to meet the proposed retroreflectivity minimums with no change in the current 10 year replacement policy. Only a very small percentage of the sample taken violated the most conservative minimums for each of the color categories. Over 98% of the signs in the field under normal circumstances should not only meet but exceed the proposed retroreflectivity minimums for any speed or size sign (Table 1).

Currently, the proposed minimums are different requirements for different size and speeds for each color group. We have found that this needlessly complicates field inspection because the majority of the signs pass the most conservative minimums for each of the color groups.

The majority of the signs with red backgrounds and white legends will meet the proposed white to red ratio requirement because the performance of the white ASTM Type III sheeting is so good that for the most part the retroreflectivity does not change as the sign ages.

Currently INDOT districts replace traffic signs in a ten year cycle. This is typically done using one of two methods. The first is done by replacing signs as sections of highways and interstates are repaved. The other is done based on inspection of the signs age. From the literature review done for this study, we recommend adding a third replacement procedure based upon an annual or bi-annual night observation technique. This allows trained personnel to travel at night time when the signs are most needed and make sure that they are adequate for use in the field. Unlike using a retroreflectometer at night one can see the how the entire face of the sign performs and be able to catch dead spots on the sign face. Also unlike using a retroreflectometer this method is not as cost and labor intensive as doing night inspections.

Based upon our experience with the retroreflectometers, we found that the values obtained varied somewhat depending upon which instrument was used. This raises some concern with regards to state liability. Perhaps the proposed FHWA minimums should be augmented with a tolerance value. This current values would be interpreted as a minimum safe values, and some slightly higher values would be used a guidelines for replacement. Such a procedure would have negligible impact on the amount of signs replaced, but would provide consistency among agencies on sign replacement.

Table 1: Data Set Compliance with Proposed Retroreflectivity Minimums

Sample Compliance With Proposed Retroreflectivity Minimums				
Color	Number of Signs	Minimum Reference	Highest Retroreflectivty Minimum (cd/lx/m2)	% of Signs Below Minimum
Red	415	FHWA 2001	8	1.0%
		FHWA 2002		
		Carlson 2003	7	0.7%
White	683	FHWA 2001	70	0.0%
		FHWA 2002	88	0.0%
		Carlson 2003	50	0.0%
Yellow	243	FHWA 2001	55	1.2%
		FHWA 2002	84	2.1%
		Carlson 2003	75	1.6%

Implementation

From the analyses done it is recommended that the life cycle of traffic signs with white and yellow backgrounds can be safely extended for at least two years to 12 years, providing there are is no apparent damage or defects. Red, however, should not be left out in the field for longer than 10 years because the red coloring at that point has faded too much. Such a policy could save INDOT up to $27,000 per year in material costs.

Currently, the dominant vendor of ASTM Type III sheeting to INDOT is 3M. That was the material exclusively evaluated in this study. However, additional vendors are beginning to introduce their material into the state. It is proposed that INDOT construct an outdoor test stand in one of their districts, and annually randomly select several samples to hang of each sheeting vendors color palette for long term monitoring. It is very important these samples be randomly selected from INDOT stock (but different lots), independent of the vendor. Details regarding the product vendor, manufacture date, installation date, and lot number would be recorded on the back of the sample. Annual monitoring of this test stand would provide an early warning to INDOT of impending problems with a particular vendor's Type III sheeting. Such an outdoor test stand could be constructed very economically because the size the samples would probably be constructed from small scraps of material too small to use on an ordinary sign.

Contacts

For more information:

Prof. Darcy Bullock
Principal Investigator
School of Civil Engineering
Purdue University
West Lafayette IN 47907
Phone: (765) 494-2226
Fax: (765) 496-1105

Indiana Department of Transportation
Division of Research
1205 Montgomery Street
P.O. Box 2279
West Lafayette, IN 47906
Phone: (765) 463-1521
Fax: (765) 497-1665

Purdue University
Joint Transportation Research Program
School of Civil Engineering
West Lafayette, IN 47907-1284
Phone: (765) 494-9310
Fax: (765) 496-1105

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/IN/JTRP-2002/22	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Sign Retroreflectivity Study		5. Report Date December 2002
		6. Performing Organization Code
7. Author(s) Austin Bischoff and Darcy Bullock		8. Performing Organization Report No. FHWA/IN/JTRP-2002/22
9. Performing Organization Name and Address Joint Transportation Research Program 1284 Civil Engineering Building Purdue University West Lafayette, IN 47907-1284		10. Work Unit No.
		11. Contract or Grant No. SPR-2482
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

Signing is a big yearly cost to state DOT's in sign maintenance and replacement costs. In 2001 the Indiana Department of Transportation (INDOT) replaced 14,930 signs at a cost of $1,067,931 and did maintenance work on 34,084 signs at a cost of $2,136,076. Recently, guidelines have been proposed by the Federal Highway Administration (FHWA) for minimum retroreflectivity of traffic signs for state, county, and city roads in the United States. The purpose of this study was to evaluate if the majority of the signs currently used by INDOT will meet the new minimum requirements proposed by the FHWA. In addition, this study provides quantitative data to assess the effectiveness of the current sign replacement program used by the Indiana Department of Transportation (INDOT) and determine if the current ten year replacement schedule is adequate to keep the State of Indiana in compliance with the new guidelines or if adjustments need to be made. This study was limited to ASTM Type III sheeting.

The data analysis performed on the data collected from the field showed the vast majority of the signs are expected to meet the proposed retroreflectivity minimums with no change in the current 10 year replacement policy. Over 98% of the signs in the field under normal circumstances should not only meet but exceed the proposed retroreflectivity minimums for any speed or size sign. It is recommended that the life cycle of traffic signs with white and yellow backgrounds can be safely extended for at least two years to 12 years, providing there are is no apparent damage or defects. Red, however, should not be left out in the field for longer than 10 years because the red coloring at that point has faded too much. Such a policy could save INDOT at least $27,000/year in material costs.

17. Key Words	18. Distribution Statement
Retroreflectivity, Sign, Sheeting, Visibility, Deterioration.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	108	

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

IMPLEMENTATION REPORT

From the analyses done it is recommended that the life cycle of traffic signs with white and yellow backgrounds can be safely extended for at least two years to 12 years, providing there are is no apparent damage or defects. Red, however, should not be left out in the field for longer than 10 years because the red coloring at that point has faded too much. Such a policy could save INDOT at least $27,000/year in material costs.

Currently, the dominant vendor of ASTM Type III sheeting to INDOT is 3M. That was the material exclusively evaluated in this study. However, additional vendors are beginning to introduce their material into the state. It is proposed that INDOT construct an outdoor test stand in one of their districts, and annually randomly select several samples to hang of each sheeting vendors color palette for long term monitoring. It is very important these samples be randomly selected from INDOT stock (but different lots), independent of the vendor. Details regarding the product vendor, manufacture date, installation date, and lot number would be recorded on the back of the sample. Annual monitoring of this test stand would provide an early warning to INDOT of impending problems with a particular vendor's Type III sheeting. Such an outdoor test stand could be constructed very economically because the size the samples would probably be constructed from small scraps of material too small to use on an ordinary sign.

CHAPTER 1. INTRODUCTION

Since the earliest days of transportation there has been a need for signs and markers to provide drivers with information and warnings. In order for drivers to be able to read these signs the signs must either be illuminated with an external light source or be made with a sheeting that has certain retroreflective properties. These retroreflective properties allow the light from the headlamps of a vehicle to be reflected back to the source enabling the driver to read and interpret the sign at night.

Recently, guidelines have been proposed by the Federal Highway Administration (FHWA) for minimum retroreflectivity of traffic signs for state, county, and city roads in the United States. The purpose of this report is to evaluate if the majority of the signs currently used by INDOT will meet the new minimum requirements proposed by the FHWA. Also, this report will discuss the current sign replacement program used by the Indiana Department of Transportation (INDOT) and determine if the current ten year replacement schedule is adequate to keep the State of Indiana in compliance with the new guidelines or if adjustments need to be made. This study was limited to ASTM Type III sheeting.

Signing of interstates and state highways is a big yearly cost to state DOT's in sign maintenance and replacement costs. In 2001 the Indiana Department of Transportation (INDOT) replaced 14,930 signs at a cost of $1,067,931 and did maintenance work on 34,084 signs at a cost of $2,136,076. These values include only the cost of equipment use and labor. Replacement is defined as a sign being replaced because it is ten years of age or older. Maintenance is defined as signs needing to be cleaned or replaced due to knockdowns or vandalism. Currently the replacement of interstate and highway signs, which are ten years or older, is about one-third of the entire cost of the INDOT sign maintenance and replacement program. A full break down of the year 2001 labor costs for INDOT are shown in Table 1-1 and Table 1-2.

Table 1-1: INDOT Sign Replacement Costs for 2001

	Interstate			Other State Highways		
FY 2001 District	Number of Signs	Replacement Cost	Average Cost	Number of Signs	Replacement Cost	Average Cost
Crawfordsville	127	$9,085	$72	2,212	$137,824	$62
Ft. Wayne	0	$0	$0	1,684	$119,277	$71
Greenfield	21	$2,009	$96	3,832	$337,873	$88
LaPorte	31	$3,937	$127	2,251	$141,542	$63
Seymour	76	$8,846	$116	1,356	$88,682	$65
Vincennes	88	$9,810	$111	3,252	$209,046	$64
Total	343	$33,687	$98	14,587	$1,034,244	$71

Total Replacement for All Districts		
Number of Signs	Replacement Cost	Average Cost
14,930	$1,067,931	$72

Table 1-2: INDOT Sign Maintenance Costs for 2001

	Interstate			Other State Highways		
FY 2001 District	Number of Signs	Maintenance Cost	Average Cost	Number of Signs	Maintenance Cost	Average Cost
Crawfordsville	254	$18,170	$72	4,423	$275,648	$62
Ft. Wayne	499	$24,437	$49	3,951	$273,111	$69
Greenfield	969	$54,064	$56	2,797	$153,250	$55
LaPorte	82	$9,216	$112	5,850	$373,548	$64
Seymour	606	$37,110	$61	9,812	$658,029	$67
Vincennes	169	$9,209	$54	4,673	$250,284	$54
Total	2,579	$152,206	$59	31,505	$1,983,870	$63

Total Maintenance for All Districts		
Number of Signs	Maintenance Cost	Average Cost
34,084	$2,136,076	$63

1.1. Report Motivation

Due to the introduction of proposed minimum retroreflectivity standards by the FHWA the State of Indiana needed three assessments on the signage of the state.

- The first assessment is what proportion of signs on the state’s highways and interstates would be below the proposed minimum retroreflectivity values. This would be achieved by taking a sample of signs from rural and urban areas in different parts of Indiana and determine what percentage of the samples would need to be replaced and apply that to the entire state.

- The second assessment is on INDOT’s current statewide replacement program for the interstate and state highways and determines whether or not the current ten year cycle is adequate or if the cycle needs to be shortened or if it can be extended. If the current replacement cycle needs to be shortened then the costs for maintaining signage above the minimum retroreflectivity values on the state’s interstates and highways will increase as the cycle is shortened. However, if the current cycle can be extended then the state will be able to save money over the current sign replacement cycle.

- The third assessment is to determine if there are any regional differences in retroreflectivity performance due to environmental conditions in different parts of the state.

1.2. Report Overview

The following chapter reviews research on past projects done on sign retroreflectivity. It discusses the limitations of those projects and why our research was necessary for the state of Indiana. The report then discusses the procedure used to collect the data for this study as well as what measurements were taken and what was done with the data.

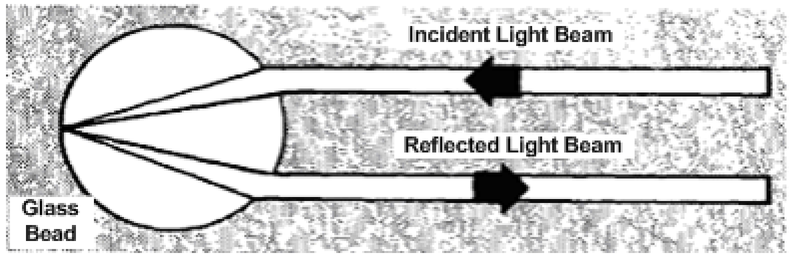
The report then discusses the analyses that were done on the data collected from the field and discusses the findings from each of them. The report concludes with a summary of the findings from the analyses with respect to the proposed FHWA retroreflectivity minimums, the proposed 4 to 1 white to red ratio, and the current Indiana Department of Transportation replacement cycle for traffic signs.

CHAPTER 2. LITERATURE REVIEW

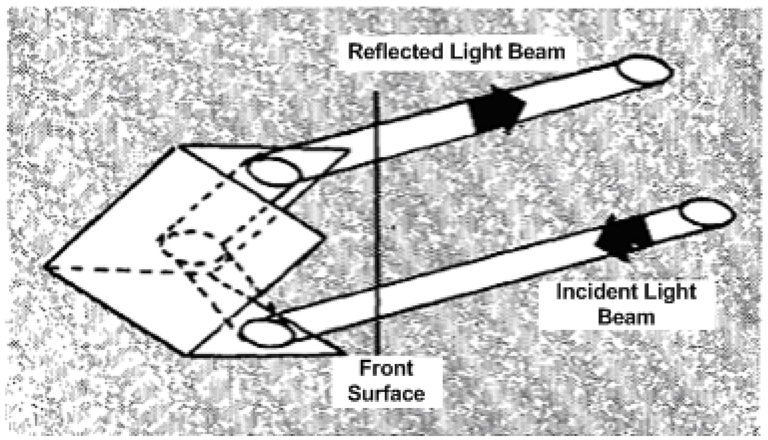
This chapter discusses the principles of retroreflectivity that make retroreflective materials possible and the factors that determine what retroreflectivity level the motorists see when a sign is used on a highway. The chapter also includes a discussion of the most commonly used sheetings and the principles behind how they work and are manufactured. Also discussed in this chapter is how different internal and external factors affect a sign's retroreflectivity. The proposed minimums, where they came from and the most current changes are also included. Finally, the chapter concludes with a summary of previous research findings and limitations.

2.1. Principles of Retroreflectivity

The basic principle of retroreflection is that the light coming from a source (e.g. headlights) is reflected back in the direction of the light source. This is achieved through the use of spherical reflectors (micro-sized glass beads) or cube corner reflectors (micro-sized prisms) as shown in Figure 2-1. The light source, which is usually the headlamps of a vehicle, sends light to the reflectors. This light is measured in candela or, its English equivalent candlepower. The intensity of the light that hits the sign surface is known as the illuminance and is measured in lux or foot-candles in English units. Luminance is known as the light that is returned to the observer and is what the motorists actually see when vehicle headlamps hit a sign face. Luminance is measured in candelas per square meter or square foot.



a) Spherical Reflector



b) Cube Corner Reflector

Figure 2-1: Common Types of Reflectors (McGee and Paniati, 1998)

The retroreflectivity of a sign is determined by the coefficient of retroreflection. The coefficient of retroreflection is the amount of light that comes out of the material per the amount of light that is coming from the source and is denoted in most cases by R_A. The R_A value is expressed in candelas per lux per square meter ($cd/lx/m^2$) or candelas per foot-candle per square foot ($cd/fc/ft^2$) in English units. The higher the R_A value the brighter the retroreflective material appears to observers.

Sheeting materials are always described by the context of its angularity, which is defined by the entrance and observation angles. These two angles are diagramed in Figure 2-2. The entrance angle is the angle between where the light beam strikes the surface of the sign and line coming perpendicular from the sign surface. The observation angle is the angle between the incoming light beam and the reflected light beam as motorists see it. These angles change as the distance between the vehicle and the sign changes. These angles are a function of the location of the sign, the vehicle, and the height of the driver's eye with respect to the headlamps. The location of the sign and vehicle determines the entrance angle while the height of the driver's eye with respect to the headlamps determines the observation angle (McGee and Paniati).

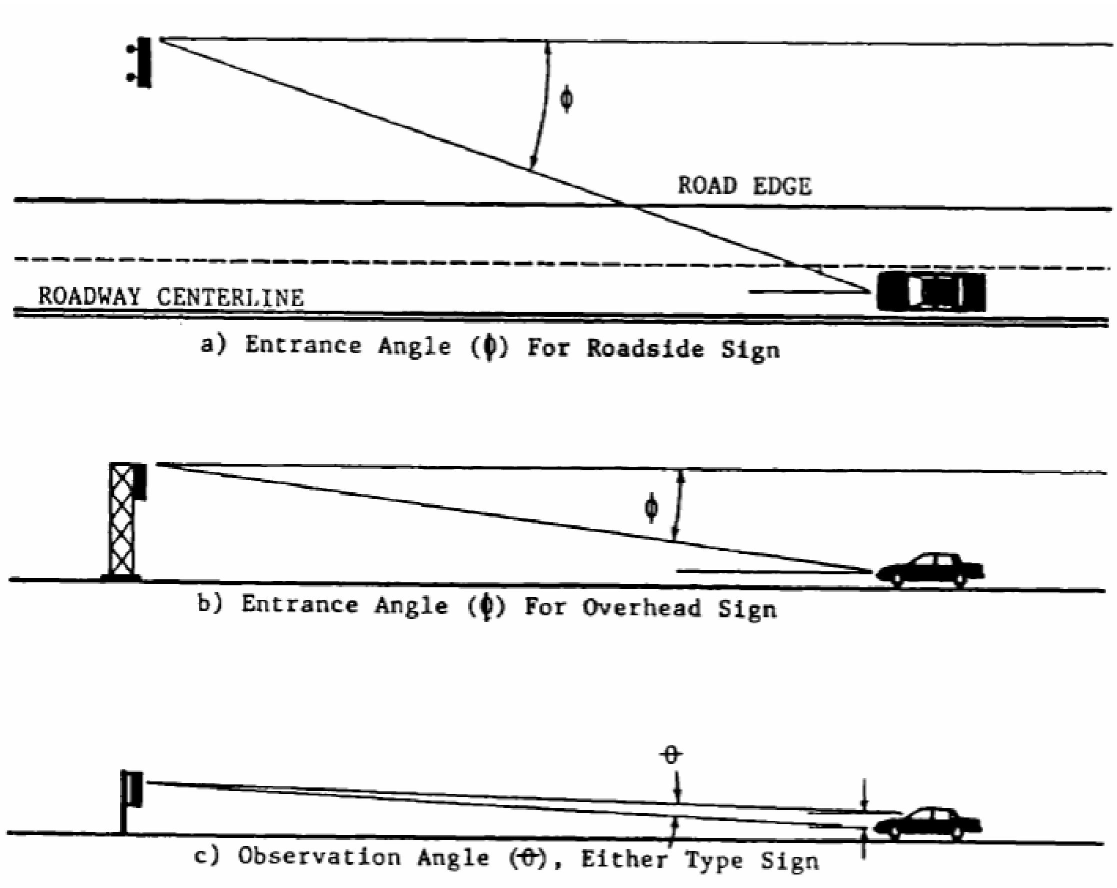


Figure 2-2: Illustration of Entrance and Observation Angles Under Actual Conditions (McGee and Paniati, 1998)

McGee and Paniati also discuss that R_A is sensitive to changes of the entrance and observation angles. They report that the R_A is much less sensitive to the entrance angle except at large angles. Also for ASTM Type I, II and III sheeting there is not a substantial change in the R_A until the entrance angle exceeds 20 degrees and in some materials there is not a significant change until the entrance angle exceeds 30 degrees. However, contrary to the entrance angle slight changes in the observation angle can have a significant impact on the R_A. Because the distance between the driver's eye and the headlamps is fixed, every time the distance between the observer and sign is doubled the required observation angle is cut in half. Because of its high degree of sensitivity the observation angle is the most important factor when calculating R_A.

Also discussed by McGee and Paniati is why the minimum retroreflectance is done with two observation angles and two entrance angles for each type of sheeting and color. The two observation angles of +0.2 and +0.5 degrees refers to viewing distance of 500 ft (162 m) and 200 ft (61m) respectively. These angles assume that the driver's eyes are 21 in (0.5 m) above the headlights. The two entrance angles are –4 and +30 degrees. The –4 degree angle is intended for signs that are too close to the edge of roadway but the face is oriented away from the perpendicular to avoid specular reflection which occurs at a 0 degree entrance angle. The +30 degree angle is considered the widest angle that would occur between the driver and a sign that needs to be seen.

2.2. Types of Retroreflective Materials

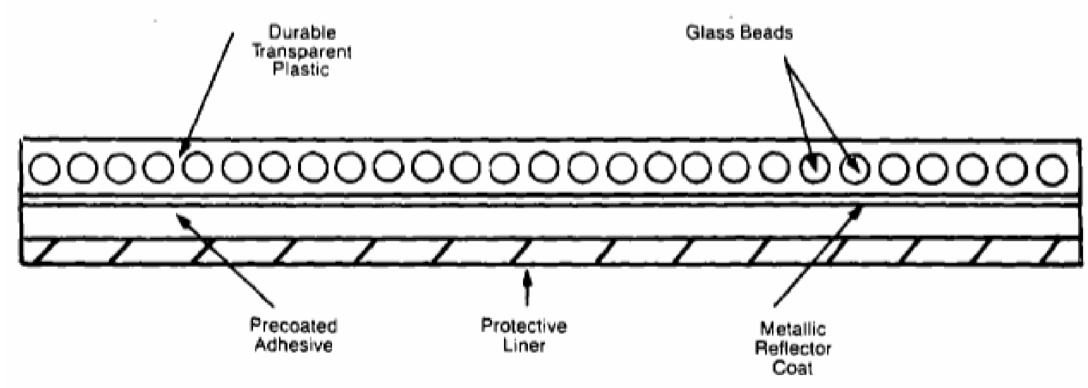
The ability for a sheeting material to reflect light is done with one of two principles, spherical reflection or prismatic reflection. Spherical reflection is achieved by using spheres or glass beads in which the incoming light is bent to the focal point of the sphere. At the focal point of the sphere there is a reflecting surface which reflects the light back out of the sphere, after being bent again at the surface, to the source. Prismatic or cube-corner reflection is achieved by using the reflecting surfaces of a prism to reflect the incoming light back to its source. Both of these principles are used to design retroreflective sheeting.

The three basic types of retroreflective materials are enclosed glass beads, encapsulated glass beads, and prismatic. The enclosed glass bead material (Figure 2-3a) uses small glass beads that are imbedded into a layer of transparent plastic. The reflecting surface used is a metallic shield that is placed behind the plastic. Encapsulated glass bead material (Figure 2-3b) uses glass beads placed on top of a metallic reflection shield and protected by transparent plastic sheet. The plastic sheet is supported slightly above the beads leaving space between the beads and the plastic. This space, which is filled with air, improves the retroreflectivity of the material. Prismatic material (Figure 2-3c) consists of small cube corners inserted into a transparent plastic film.

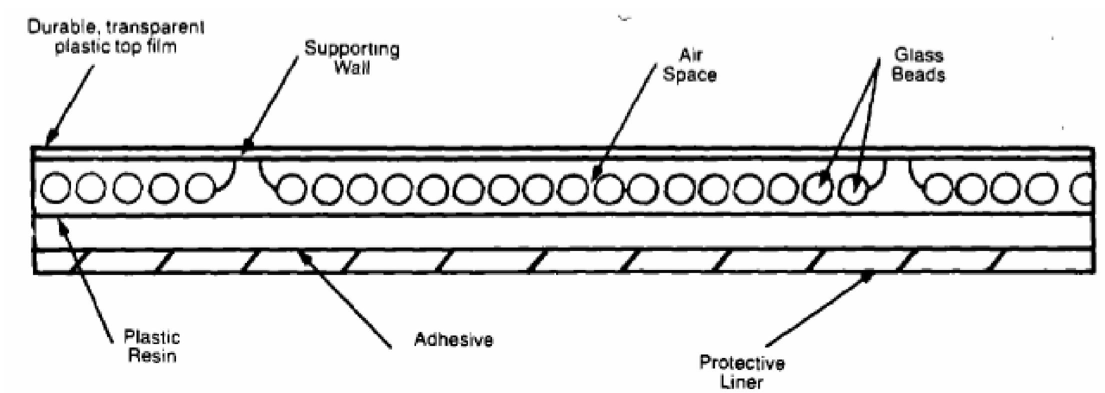
Over the past decade industry has been developing different types of retroreflective sheeting materials based on either glass beads or prisms to reflect light. As newer products have been developed the classification has been changed and expanded. The American Society for Testing and Materials (ASTM) is considered to be the most recognized source for specifications on retroreflective materials. Found in the ASTM Standard Specification for Retroreflective Sheeting for Traffic Control, D 4956-93 there are six classes of retroreflective sheeting material. Of the six defined classes the following four relate to highway signing (McGee and Paniati, 1998):

- Type I which is a medium intensity retroreflective sheeting material referred to as "engineering grade" using enclosed glass-bead sheeting.
- Type II which is a medium intensity retroreflective sheeting material referred to as "super-engineering grade" also using enclosed glass-bead sheeting.
- Type III which is a high-intensity retroreflective sheeting using encapsulated glass-bead retroreflective sheeting.
- Type IV which is a high-intensity retroreflective sheeting using non-metallized microprismatic retroreflective material.

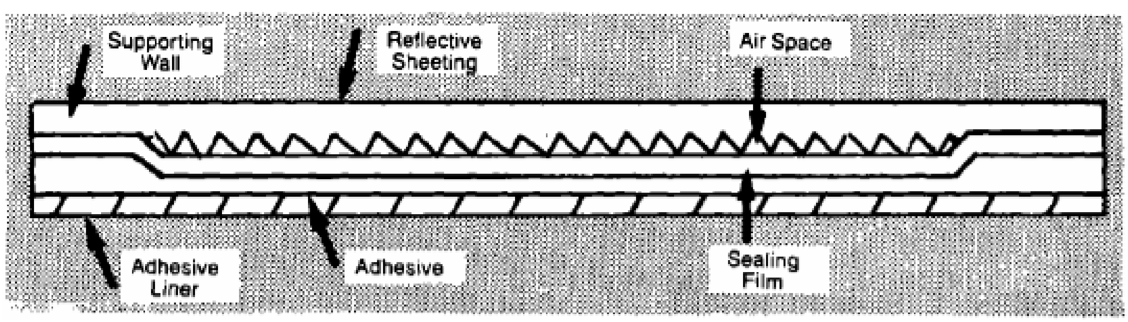
The main difference between the Type I, II and III sheetings is their basic construction and R_A. The basic construction of these sheeting materials is illustrated in Figure 2-3. Super-engineering grade (Type II) sheeting has about double the retroreflectivity of engineering grade (Type I) sheeting. Super-engineering grade sheeting differs from engineering grade sheeting because of the quality of the enclosed glass-beads used in the manufacturing of the material. The high-intensity (Types III & IV) sheetings have between 3 and 4 times more retroreflectivity than the engineering grade sheetings (Flintsch, 1993).



a) Enclosed Lens Sheeting



b) Encapsulated Lens Sheeting



c) Cube Corner Sheeting

Figure 2-3: Physical Composition of the Three Main Types of Retroreflective Sheeting (McGee and Paniati, 1998)

2.3. Factors Affecting Retroreflectivity

The retroreflectivity of a sign is the light that is reflected back to the source by the sheeting used to make the sign. The retroreflectivity can be affected by internal and external effects such as the type of sheeting used in the sign and the color of the sheeting. There are other factors that may affect the retroreflectivity of a sign as well. These factors include orientation of the sign face, amount of dirt build up on the sign, and the age of the sheeting material. Headlamps used by cars and trucks also can affect a sign's retroreflectivity but very little is reported in the literature on this subject.

In general the type of sheeting used and the color is based on the class of sign and the level of complexity of the sign and the surrounding area. In past research such as Wolshon and Degeyter it was noted that different sheeting types of signs had improvements in the retroreflectivities after washing. For example they found that overall Type III signs did not improve as much as Type I signs. Type III signs improved on average 24 and Type I as much as 40 percent. These results seem quite large given the results from other reports. The reason for such high numbers in this report maybe due to the small data set collected and incomplete drying after sign washing.

In contrast Black's "Deterioration of Retroreflective Traffic Signs" they found that an overall increase due to sign washing for the High Intensity (ASTM Type III) material was only 8 percent. The authors also noted that the small increase in retroreflectivity after washing maybe due to the "slippery" qualities of the Type III sheeting noted by signing personnel and thus would seem to clean better due to natural rainfall. They also noted that cleaning would give very little benefit except in the winter months when salt and dirt may stick to the sign when splashed by passing vehicles.

In either case the authors did not report for the sample of the signs analyzed where the signs were located and analysis was not done to see if there is a difference between before and after readings in rural as well as urban areas. It is speculated that pollution in urban areas may cause a sign's retroreflectivity to be lowered due to particles from exhaust as well as dirt from heavy traveled routes sticking to the face of the sign. An analysis of this kind needs to be done to be certain that the retroreflectivity of a sign is not significantly affected by urban pollution to the point where it causes signs not to meet the minimum retroreflectivity requirements.

Another factor thought to affect a sign's retroreflectivity is the orientation of the sign face to the sun. While the sun does not play an immediate role in the retroreflectivity it does however cause the red overlay used on the sign to deteriorate over time. For example it is believed that a sign facing between the south and south-west directions would deteriorate faster than a sign facing due north due to the amount of year round sun exposure and thus would have a lower retroreflectivity after fewer years than signs facing other directions. Past research has found that the orientation of the sign face has not been a good predictor in deterioration models (Black, 1992).

In Black's study the authors found that the orientation of the sign's face was not an acceptable predictor of the in-service retroreflectivity of traffic signs. The report does not go into specifics on how this determination was made that this factor was not an acceptable predictor of the retroreflectivity. However, this result does coincide with the results from Kirk's "Factors Affecting Sign Retroreflectivity" and "Performance of Traffic Sign Retroreflectivity" by Wolshon and Degeyter. In Black's article they discuss that there is not a "strong trend" between the retroreflectivity of a sign and its orientation to the sun. It is noted however that signs facing the southerly direction tended to have lower retroreflectivities especially for red signs.

In Wolshon and Degeyter's report they state that F-tests conducted on their data set did not yield a statistically significant correlation between the orientation of the sign face and its performance. Also in "Prediction of the Service Life of Warning Signs" by Awadallah he found that the orientation of the sign's face to the sun was not a significant predictor in determining the service life of a sign.

These results show that the orientation of a sign is not a significant factor in the deterioration of the sheeting. However, the darker colors such as red need to be analyzed separately to see if there is any significant deterioration of the red sheeting with the sign face orientation. From the reports and articles reviewed no analysis has been done on the darker colors to see if they fade faster with more sun exposure.

The last major factor to affect the retroreflectivity of a sign is the age of the sheeting material used in the signs. As the sheeting material ages it looses its retroreflective properties due to fading, peeling, and cracking. Due to this deterioration, it is not clear at what age the retroreflectivity of a sign falls below an acceptable level. The FHWA in cooperation with other states has developed proposed minimum retroreflectivity requirements as shown in Table A-, Table A-2, and Table A-3. These requirements are based on human factor studies as well as input from professionals in the field. These proposed minimums are to make sure that the majority of traffic signs in use on the nation's interstates and highways can be read by the majority of drivers. Given these minimums most state highway departments are trying to determine at what age does the typical sign fall below the minimum and how many signs in their jurisdiction will have to be replaced. Several studies have been done for different states and for a nation wide assessment to determine how many of their in-service signs will have to be replaced due to the proposed minimums.

From Kirk's "Factors Affecting Sign Retroreflectivity" the authors were unable to find a clear relationship between the age and the retroreflectivity of the sheeting. The reasons they cite are that they may not have gotten enough signs to make the range big enough to see the overall performance over time for the signs and the installation date of the signs they observed may not have been reliable. But given that there was no clear relationship they did note that as a sign ages "the variability of its retroreflectivity could increase." Wolshon and Degeyter noted that the "trend lines" of their sampled data was "flat." They suggested that this was due to the performance characteristics of the Type III sheeting and that it does not deteriorate as much as the Type I or II sheetings.

Currently, manufacturers typically warrant the High Intensity (ASTM Type III) sheeting for 10 years. In general it is believed that the High Intensity sheeting lasts longer than this warranty period and has retroreflectivity values above the proposed minimums. Awadallah's research shows that the effective service life of Type I and II sheeting is from 5 to 13 years with some signs lasting more than 15 years and still being adequate for use in the field. Because the effective life of the Type I and II sheeting is so long it is reasonable to assume that the high intensity (ASTM Type III) sheeting which is reported to be a better product would have an effective service life longer than that.

Chalmers' report showed that from the weathering tests conducted in Arizona most colors and sheetings "…typically exceeded the minimum requirements for the projected life of those materials." This suggests that in general most types of sheetings and colors will last longer than their warrantees specify. He also noted that 3M ASTM Type III orange and yellow sheeting had retroreflectivities twice that of the minimums after 10 years. Also the 3M ASTM Type III white signs had a retroreflectivity of about 250 after a simulated 10 years of exposure. Flintsch's telephone contacts with several traffic engineers from different states yielded the same conclusion that normally the service life of signs used in the field exceeded the life warranty given by the manufactures. If these are true then in most cases signs could be left out in the field longer thus reducing the replacement costs.

From reports done by Taori and McGee and McGee and Taori it was determined that between 5 and 5.5 percent of the nation's signs under state jurisdiction would need to be replaced due to the proposed FHWA retroreflectivity minimums. This was calculated out to be about 32 million dollars based on 1998 prices. It was also shown that the sign replacement for local jurisdictions was significantly higher and was attributed to signs being left out in the field longer and most local jurisdictions not having some sort of replacement program. Most states do in fact have some form of replacement program whether it is by visual inspection, by age or by route. Because most states do have some sort of replacement program the impact of the implementation of the retroreflectivity minimums on state budgets will probably not be that much. However, further research needs to be done on a state by state basis because of the different replacement and maintenance practices done by individual states.

Austin and Woltman's article "Evaluation of Headlamp Systems for Nighttime Safety: Their Relationship to Retroreflective Traffic Sign Performance" discusses the differences in the U.S. headlamps and the ECE (European H4) headlamps. In this article they compare the two different headlamp types on a series of signs and record the luminance from the signs. From this report it was discovered that the ECE low beam headlamps illuminate above the horizontal axis approximately one-half to one-quarter as much as the U.S. low beam headlamps. This in itself is not a problem except that the article notes that the U.S. lower beam photometrics were going to be altered to more closely correspond with the ECE headlamps. Given the date of this article more analysis would need to be done on the current and future planned headlight systems to determine if they would provide the required luminance for traffic signs.

2.4. Proposed Retroreflectivity Minimums

The current minimums proposed by the FHWA located in Table A-, Table A-2, and Table A-3 are based on human factor studies as well as input from various states and professionals from around the United States. The FHWA developed the minimums in a manner that attempted to balance values that would be needed to accommodate the highest percentage of drivers with the budget constraints on state and local jurisdictions. These values were also developed with the understanding that the retroreflectivity of a sign is only one of the factors that contributes to poor nighttime performance (McGee and Paniati, 1998).

From the FHWA summary report it was estimated that 75 to 85 percent of the driving population would be accommodated by the proposed minimum retroreflectivity values from the model used to develop them. An evaluation of a FHWA field study showed that for most signs the subjects were able to recognize them at levels lower than the model used to determine the minimums. From the study they also noticed that signs with a higher complexity were harder to identify by the older subjects. Overall the retroreflectivity minimums accommodated 90 percent of the subjects or better except for 3 signs (Federal Highway Administration, 1997).

In August of 2002 workshops were held around the country to get input from professionals on what were the latest minimums at that time. The preliminary values that were discussed in the meeting in Denver, Colorado are located in Table A-, Table A-5, and Table A-6. After these were discussed changes were made based on the input from the people who attended these workshops. As a result the latest minimums proposed by the Texas Transportation Institute (TTI) are located in Table A-8. Comparing this latest table to the previous versions the minimums have been vastly simplified. Also in these minimums a white to ratio has been added back into the minimums but has been lowered from 4 to 1 to 3 to 1. The full report with these changes will not be published until sometime in early 2003.

The proposed minimums in 2001 provided an extra requirement for signs with white or white and black legends with red backgrounds. That extra requirement was a 4 to 1 white to red ratio in which it states (Table A-2), "…if the retroreflectivity of the white material divided by the retroreflectivity of the red material is less than four, the sign should be replaced." The reason for this minimum ratio, which has recently been removed in 2002, is to make sure that there is enough contrast between the red background and the white legend so that at night it is readable by motorists because the red ink used as an overlay on traffic signs fades over time. As this ink fades the white sheeting underneath it starts to show through and will start to reflect more light. As the red fades more and more the sign overall becomes brighter and brighter making it harder for motorists to read the sign because the contrast between the white and red colors is lessened (Black, Hussain and Paniati, 1992). The picture in Figure 2-4 illustrates what happens when the red overlay deteriorates and the white sheeting shows through.

Figure 2-4: Sample Picture of Red Overlay Fading from Plattsburg, NY

Chalmers' research found that signs that were at the 4:1 ratio or slightly below it seemed to have more than adequate day and night contrast between the white and red colors. He states "…it may be advisable to review the methodology that went into determining the 4:1 ratio." The reason for this is because in his research he found that signs at or slightly below the 4:1 ratio were still adequate for use and highway departments may remove signs that are still acceptable for use in the field (Chalmers, 1999). Also from a study done by the Texas Department of Transportation they found that the stop sign they had on the course was rated as overall acceptable by the participants but was below the 4 to 1 ratio when measured.

Both of these results have raised some questions about the validity of the 4 to 1 ratio. Some have suggested that the ratio be reduced or removed altogether. In a conference in August of 2002 the 4 to 1 white to red ratio requirement had been removed. As of the August 2002 preliminary minimums the ratio has been added back in but has been reduced to 3 to 1 (Carlson, 2003). The full report on why the ratio was reduced will not be available until sometime in early 2003. However, there is a presentation of a paper based on this at the Transportation Research Board's annual conference in January 2003. The paper will be made available at the conference in which it will discuss the reasons for the changes in the white to red ratio and the proposed retroreflectivity minimums.

Based on research done by state highway departments and other authors just having the minimum requirements may not be enough to ensure that signs meet the needs of the population. Other factors such as age of the drivers, complexity of the sign's message, sign uniformity, changes in vehicle headlamps, and location of the sign will affect the retroreflectivity necessary for drivers to recognize, interpret, and react to the sign.

Olson discusses two factors that need to be considered in whether or not a traffic sign is suitable for use in the area in which it is to be posted. One factor is that if the sign is complex it may need a higher retroreflectivity so that it can be recognized and reacted to within the time necessary for a safe maneuver. The other factor is a person's age. As a person ages they need higher retroreflectivity levels in order to recognize and react to the sign. Montebello and Schroeder state that in general older drivers have more difficulty identifying traffic signs (day or night) than younger drivers. One hypothesis is that the signs are not tall enough and wide enough for the older drivers to identify the sign at the same distance as younger drivers can. As the population of the United States ages there will probably be more and more older drivers out on the nation's interstates and highways in the coming years thus the older drivers will need to be accommodated in some way to ensure their safety and the safety of other drivers. This is an interesting point and one that needs to be addressed but is out of the scope of this report.

Flintsch states that while the retroreflectivity largely affects the night visibility of a sign there are other factors that affect it as well such as the size, color, and the complexity of the area surrounding the sign. Coulomb and Michaut state that the retroreflectivity of a sign is only one of the parameters involved in its visibility. While size and color of the sign is determined by the type of roadway and type of sign the complexity of the surrounding area has to be taken into account by the installation crews. A sign that is adequate for rural areas may not be adequate for an urban area with background objects such as buildings and cars and overhead and background lighting. This background light or complexity may keep the sign from being detectable by drivers and thus the sign will have no effect. Mace and Pollack reported, "…visual complexity can be as important as brightness or contrast visibility." Their field study demonstrated that increasing the brightness of a sign could offset the visual complexity associated with recognizing and interpreting a sign. This mean that the more complex the sign or the area surrounding it the greater the retroreflectance required for drivers to be able to recognize and interpret the sign within the required time to make the necessary actions safely.

Hawkins and Carlson report results from a Texas Department of Transportation subject study. In their study crews from different TXDOT districts evaluate signs on a closed course. In this report they also state that retroreflectivity of sign is only one factor in determining if a sign is adequate for night time use. They also state that "the overall appearance and uniformity of the sign face are as important as the retroreflectivity level" meaning that how the sign appears at night is also a major factor. The study showed that there were more signs stated as being unacceptable by visual inspection then there were based on the retroreflectivity minimums. Based on this it is feasible to do night inspections because the maintenance people can do a visual analysis of signs and replace signs that may be above the minimums but are not adequate for nighttime use.

McGee and Paniati state that the proposed minimum retroreflectivity values provide a guide as to what levels signs will not be functional for the majority of the population under certain driving conditions. This does not mean, however, that the sign will not be functional for all drivers under all conditions. Signs with retroreflectivity values below the minimums should be considered for replacement. These minimum values should be used with good engineering judgment as to what the needs of the motorists are at the particular sign installation. Situations with complex visual backgrounds or messages may require higher retroreflectivity values. These may need to be accompanied with supplemental warning signs to give the motorist sufficient visibility for sign detection and recognition.

Given all the factors that affect a signs visibility and legibility the retroreflectivity minimums only address one aspect of this. In order for a traffic sign to be effective it must be placed in spot and have the correct sheeting as to allow for the majority of drivers to be able to read and interpret the sign throughout its expected life. While the minimum retroreflectivities can assure that the majority of signs will meet the majority of drivers needs special consideration may need to be given to signs placed in visually complex areas or with complex messages. Also nighttime visual inspections should be done on in-service signs to make sure that they not only meet the retroreflectivity minimums but also are legible to the majority of drivers.

2.5. Concluding Remarks

Overall the research in the past has been adequate for their respective scopes of work but left some questions to be answered. For example the effect of the sun on the retroreflectivity was not really explored to its fullest in any of the reports discussed here. For the most part the data was either not available to be analyzed or the analysis was not done with a large enough sample size. This question needs to be answered to determine whether or not the azimuth does have a significant impact on the retroreflectivity of traffic signs. Also left open was whether or not there was a significant improvement in a sign’s retroreflectivity after cleaning the sign. For the most part the research stated that it was an improvement but not a very large one for the ASTM Type III sheeting. There was no substantial statistical analysis done on the effects of sign cleaning and this issue needs to be addressed.

Also discussed is the aging of the sheeting and how the sheeting looses its retroreflectivity over time. ASTM Type III sheeting is believed to last longer than the warranties given by the manufactures. Because the retroreflectivities are staying above the proposed minimums it may be possible to leave signs out in the field longer thus saving highway and local jurisdictions resources. However, data collection and analysis needs to be done in order to determine how long signs can be left in service before falling below the proposed retroreflectivity minimums.

Another issue discussed in some of the research is other factors affecting the visibility and comprehension of traffic signs. As discussed in some of the research the retroreflectivity of a traffic sign is only one aspect of the overall visibility of the sign. Other factors must be considered such as the complexity of the sign as well as the surrounding area before deciding on the type of sheeting to use, the size of the sign as well as the legend, and the location of installation.

CHAPTER 3. DATA COLLECTION

This chapter discusses the methods used to collect data for this study and where data collection was done. Locations in the state of Indiana were chosen with emphasis on taking samples of older signs. The majority of the data collection took place in central and northwestern Indiana from July of 2001 until May 2002. Data collection was done on typical days with no rain or snow or extreme temperatures. Overall we collected over 2200 samples of signs about 500 of which were decommissioned signs from Crawfordsville.

3.1. Procedure for Collecting Sign Data

Data collection procedures started with a visual observation of the traffic sign. The sign was inspected for an installation date and to insure that date was not too new (i.e. only a few months to one year old). If a sign had no installation date or the date was not determinable then the sign was not sampled. A picture of a typical installation sticker used on recent installations is shown in Figure 3-1. Once the sign was determined to be ok for sampling several measurements and observations were taken of and around the signs.

First, the distance from the edge of the travel lane to the middle of the sign (i.e. sign post) was measured to the nearest inch as shown in Figure 3-2. While taking this measurement the tape measure was held as level and tight as possible so that it was reading perpendicular to the sign post and so there was no excess slack which would throw the measurement off. Next the distance from the roadway level to the bottom of the sign was measured to the nearest inch as shown in Figure 3-3. If the sign was installed on an embankment then the distance was taken from the level of the roadway to the bottom of the sign to make sure that the distance measured was the actual distance between the roadway and the sign. Next the size of the sign face was measured to the nearest inch. For rectangular and square signs the measurement was done on the bottom edge of the sign and for triangular signs the distance was measured down the diagonal edge of the sign. An example measurement of a stop sign face is in Figure 3-4. Next, a handheld global positioning satellite (GPS) receiver (Figure 3-5) was used to record the latitude and longitude of the sign installation. The GPS receiver was also used to record the direction the sign faced or azimuth which is the compass direction the sign faces. Finally, other information such as the date of installation of the sign, a description of the surrounding area, the direction of travel the sign pertained to, the speed limit of the roadway, and any visible damage to or deterioration of the sign.

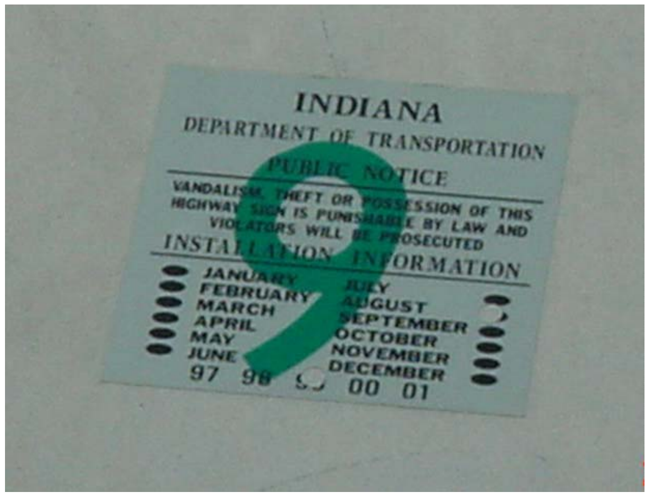


Figure 3-1: INDOT Example Sign Installation Date Sticker. Installed in August 1999

Figure 3-2: Example Distance from Roadway Measurement

Figure 3-3: Example Sign Height Measurement

Figure 3-4: Example Sign Size Measurement

Figure 3-5: Picture of Handheld GPS Receiver

The next series of measurements was done on the sign itself using a portable retroreflectometer which takes retroreflectivity readings of sheeting used on a traffic sign. The model used in the study is the Advanced Retro Technologies Sign Master 920 SEL model (ART 920 SEL) as pictured in Figure 3-6. This is a newer model than what most state departments currently use to take retroreflectivity readings of signs. The major benefit of this model over the old 820 is the ability to switch the colors being measured on the fly without having to use calibration caps. The older 820 model you have to use caps with different sheetings with known retroreflectivities in order to calibrate the machine to the specified color you want to take readings on whereas the 920 SEL just needs a turn of a dial to change colors. The benefit of this change is convenience because the person using it just has to change a dial setting instead of having to carry different color caps and have to recalibrate the machine. Another notable change is the ability for the 920 SEL to be able to use a GPS attachment and take location reading while taking retroreflectivity readings and stores the data internally and can be downloaded. This was not used for this study because it was thought that it would be cumbersome to try and keep up with which sign and GPS readings stored go with the sign's other measurements.

Figure 3-6: ART Sign Master 920 SEL used in Data Collection

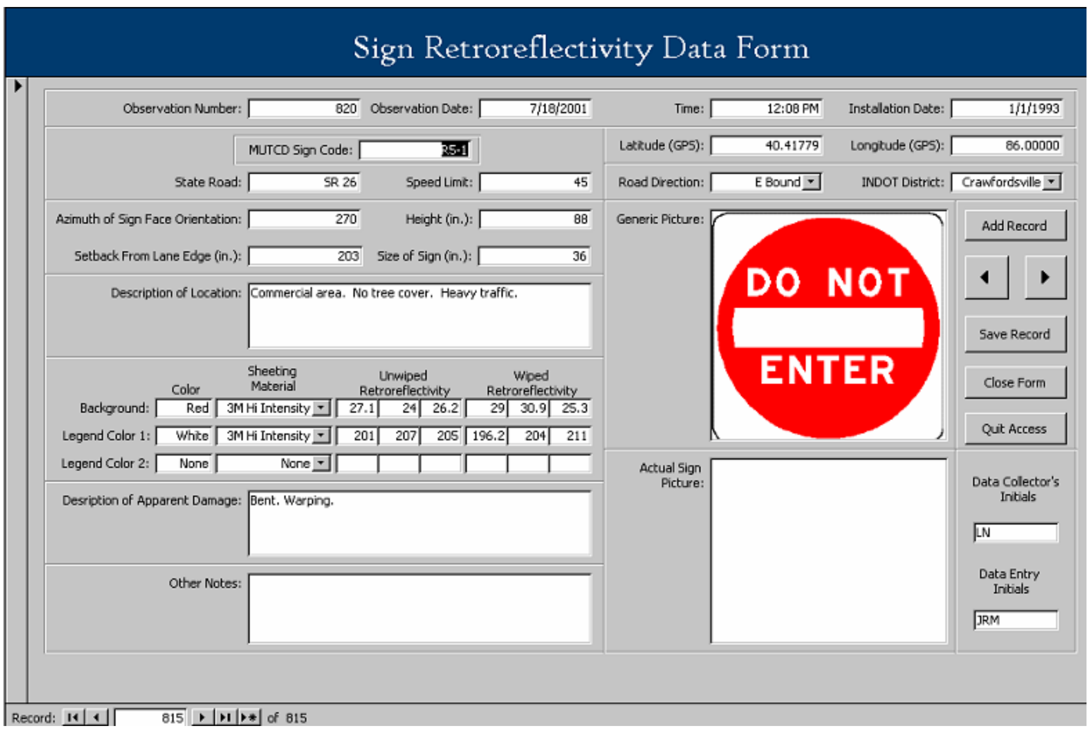
For each sign three readings were taken on each sheeting color and then the sign was wiped with a dry mop sponge (Figure 3-7) and then three more readings were taken in the same places as before. For example, a stop sign would require a total of 12 readings on the sign face. Three readings each on the white and red colors and then three more readings on each color after the sign face had been wiped. For signs that were mounted too high to be reached by hand the ART 920 SEL has an extension pole (Figure 3-8) which allowed the retroreflectivity readings to be taken on these signs.

Figure 3-7: Picture of Dry Mop used to Wipe Signs

Figure 3-8: Picture of ART 920 with Extension Pole

The reason for wiping the signs was to be able to capture changes in the retroreflectivity readings due the removal of dirt and other materials from the sign face. A dry mop sponge was chosen to be used because it was for one easier and faster to use a dry mop than use a wet mop in which you have to wait for the sign face to dry. The second reason was that it was assumed that the natural cleaning ability of rain and other weather elements kept the sign face fairly clean and the mop was used to remove dirt off the sign face that had just recently gotten on the sign. Any signs with noticeable damage or vandalism were noted when the retroreflectivity readings were taken.

All of the data was recorded on a field data collection sheet and then was taken back to a lab and entered into a database. A sample picture of the database input form is shown in Figure 3-9. Once the data was recorded into the database then the analyses on the data collected could be done as well as keep track of the number of samples taken overall as well as in what district. The field collection sheets were saved and stored for future reference in case there was a discrepancy with the data or there was a user error when the data was entered into the database.


Sign Retroreflectivity Data Form

Observation Number: 820 Observation Date: 7/18/2001 Time: 12:08 PM Installation Date: 1/1/1993

MUTCD Sign Code: R5-1 Latitude (GPS): 40.41779 Longitude (GPS): 86.00000

State Road: SR 26 Speed Limit: 45 Road Direction: E Bound INDOT District: Crawfordsville

Azimuth of Sign Face Orientation: 270 Height (in.): 88 Generic Picture:

Setback From Lane Edge (in.): 203 Size of Sign (in.): 36

Description of Location: Commercial area. No tree cover. Heavy traffic.

	Color	Sheeting Material	Unwiped Retroreflectivity			Wiped Retroreflectivity		
Background:	Red	3M Hi Intensity	27.1	24	26.2	29	30.9	25.3
Legend Color 1:	White	3M Hi Intensity	201	207	205	196.2	204	211
Legend Color 2:	None	None						

Desription of Apparent Damage: Bent. Warping.

Other Notes:

Actual Sign Picture:

Add Record | Save Record | Close Form | Quit Access

Data Collector's Initials: LN

Data Entry Initials: JRM

Record: 815 of 815

Figure 3-9: Sample Database Input Form

3.2. Geographic Locations of Data Collection

In general data collection was done on routes that had signs close to 10 years old and were about to be replaced by the district. However, as data collection went on routes with older signs were harder to find due to a lack of bookkeeping or the older signs were scattered along the routes with newer signs due to the different replacement policies that the different INDOT districts have. The data collection ranged from rural to very urbanized areas. We collected in rural farming areas throughout middle Indiana as well as major industrial sections such as the Gary, Indiana area to try and capture every aspect of the state and also to see if there were any differences in the signs from the different areas. In all we collected over 2200 sign samples of which over 1700 were from in-service signs.

Data collection began in the Crawfordsville district at the beginning of this study in June of 2001. The first set of data collection was down at the Crawfordsville DOT bonepile where decommissioned signs are brought to be sent for recycling. Pictures of the bone pile are located in Figure 3-10 and Figure 3-11. This data was used in the preliminary stages of this study to try and get a grasp on what is happening to traffic signs around Indiana. However, the location of these signs could not be determined because the signs are not marked where they came from when they are removed. This data was analyzed and reported on in 2001 by Luke Nuber. After this was done the field data collection began shortly thereafter. Field data collection started around Purdue University and West Lafayette, IN. and then quickly spread to Lafayette, IN. As routes around these cities were finished data collection moved out into the outlying rural towns. As the routes with older signs, around 10 years old, were exhausted the data collection moved into the Greenfield and Laporte Districts.

Figure 3-10: Picture of Crawfordsville Bonepile

Figure 3-11: Picture of Sorted Signs Measured from the Crawfordsville Bonepile

Very few data points were collected in Greenfield due to mostly a lack of time and the focus shifting to routes in the Laporte district near and around Gary, Indiana. A little over 100 signs were collected in the Greenfield district. All of the signs sampled were around the Muncie, IN. area near downtown. After the short data collection period in the Greenfield district data collection began in the Laporte district.

Data collection in the Laporte district began in the Winamac, IN. area. From there it moved up to and around the Gary, IN. area and ended south of Gary. The reason for collection in the Gary area was to get signs from an industrial area to determine if pollution from heavy traffic and/or industry affected the retroreflectivity readings of the signs. Data collection in this district began in December 2001 and continued until the data collection was stopped in May of 2002.

3.2.1. Crawfordsville District Locations

Data collection began around the Lafayette/West Lafayette Area and then moved outward through Crawfordsville. A full view of the entire Crawfordsville district is in Figure 3-12. Data collection locations are marked on the maps following for the Lafayette/West Lafayette area (Figure 3-13) as well as other routes in the Fowler (Figure 3-14) and Frankfort (Figure 3-15) sub districts. The black boxes indicate data collection locations and the description is the limits of the data collection.

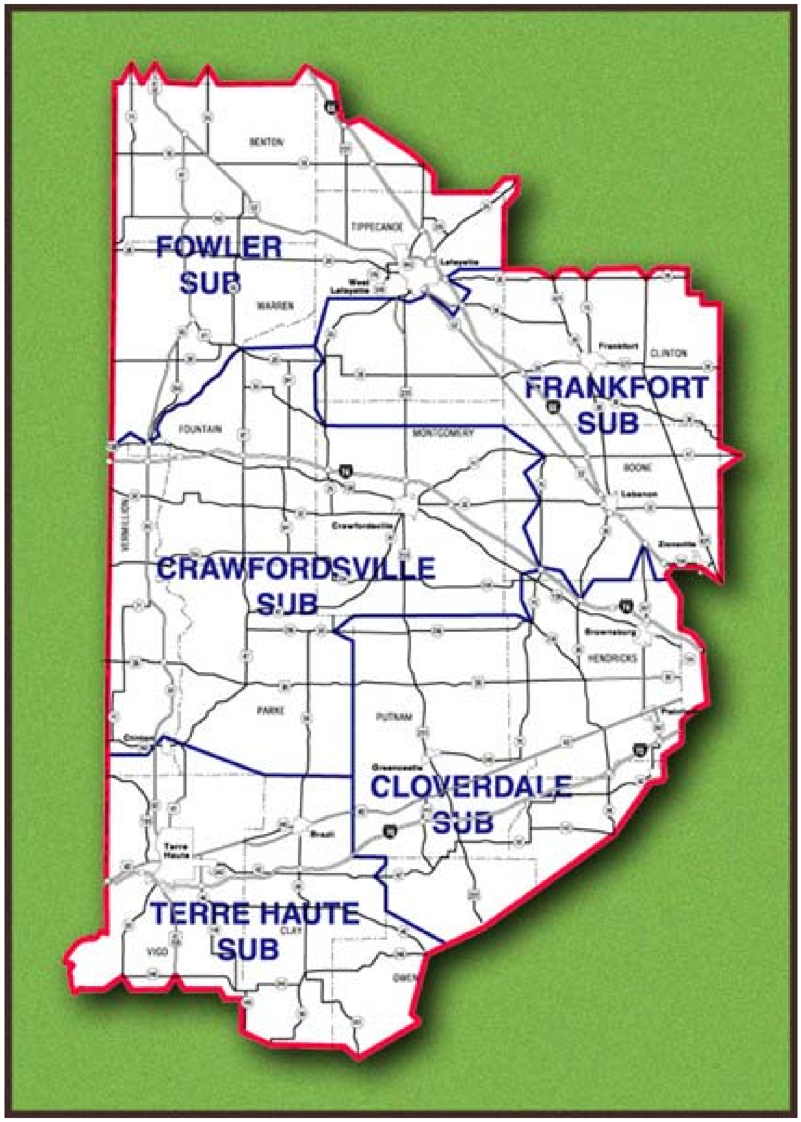


Figure 3-12: Crawfordsville District Overview

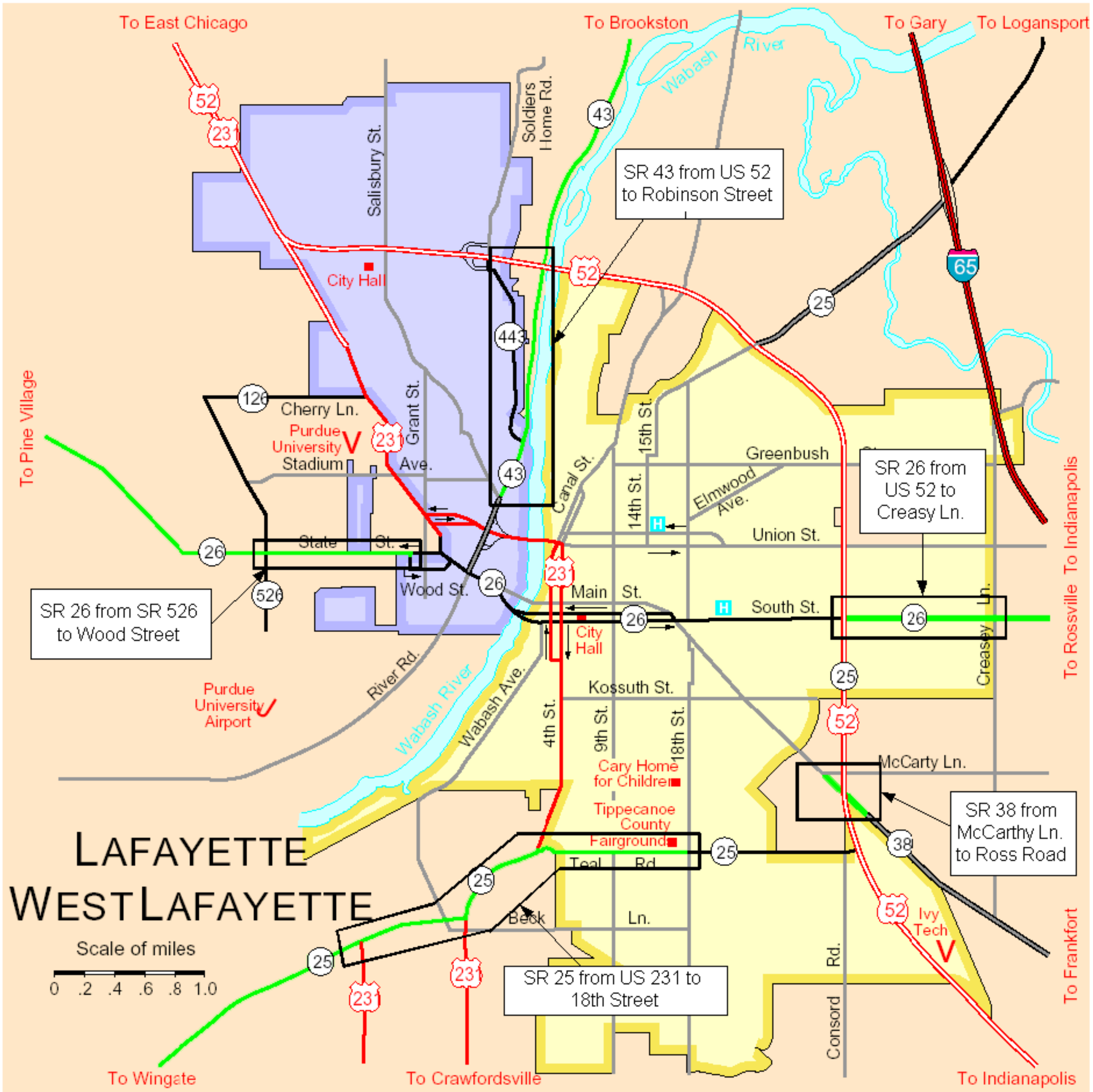


Figure 3-13: Data Collection Locations in Lafayette/West Lafayette

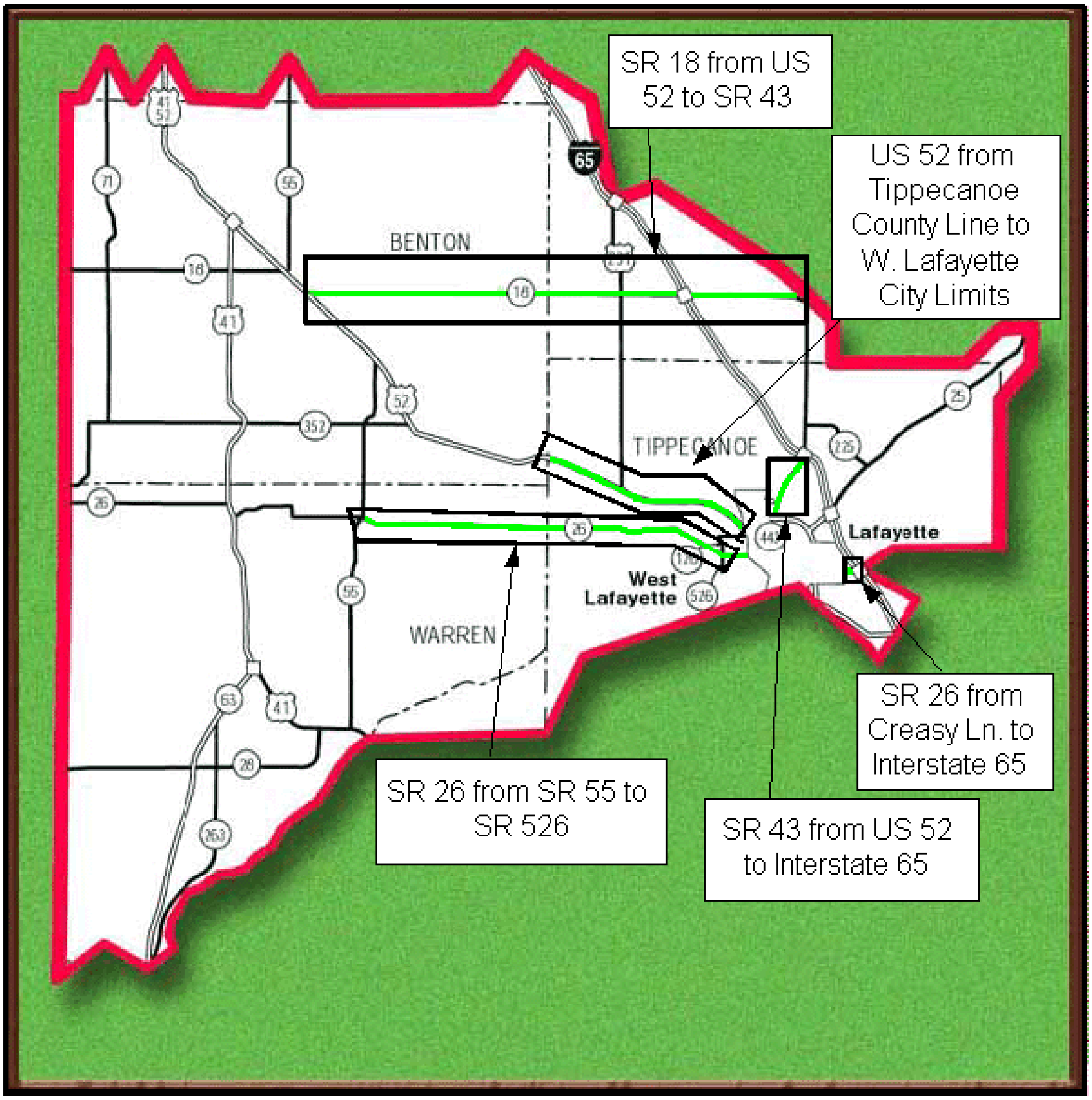


Figure 3-14: Data Collection Locations in the Fowler Sub District

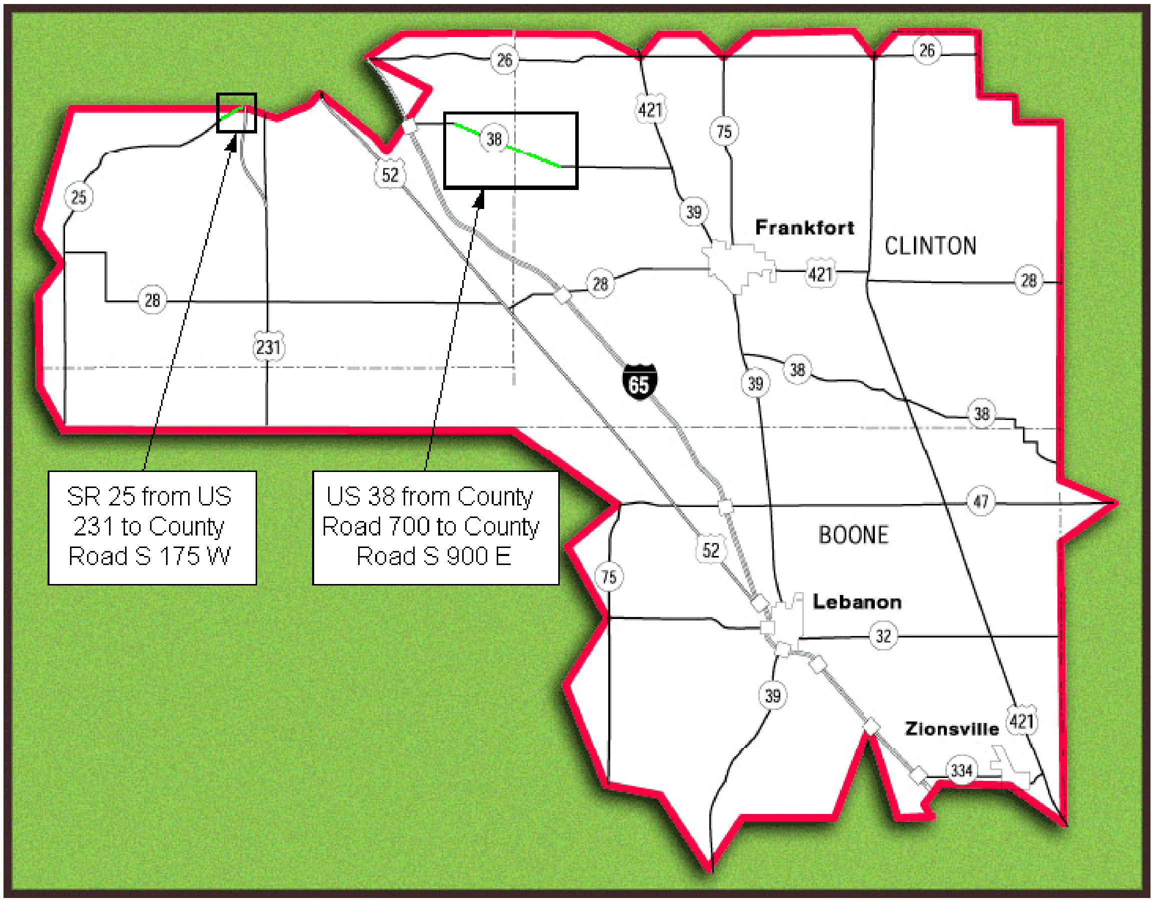


Figure 3-15: Data Collection Locations in the Frankfort Sub District

3.2.2. Greenfield District Locations

Data collection did not last long in the Greenfield District due to a lack of time and more emphasis being put on the Laporte area. The only data collected in this district was mostly around the Muncie, IN area in the Albany (Figure 3-17) sub district and a little in Greenfield (Figure 3-18) sub district. A map of the entire Greenfield district is shown in Figure 3-16. The black boxes indicate data collection locations and the description is the limits of the data collection.

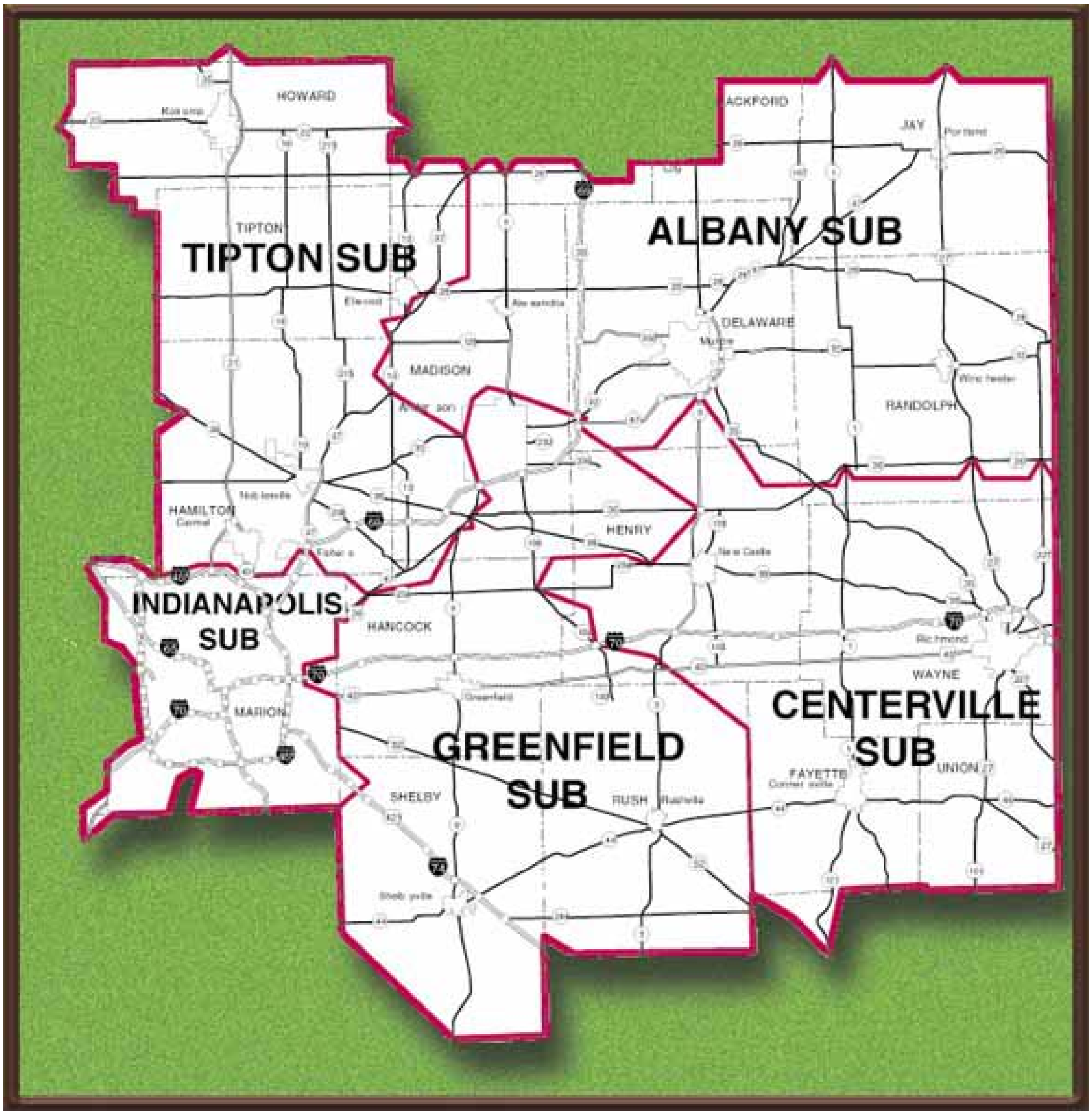


Figure 3-16: Greenfield District Overview

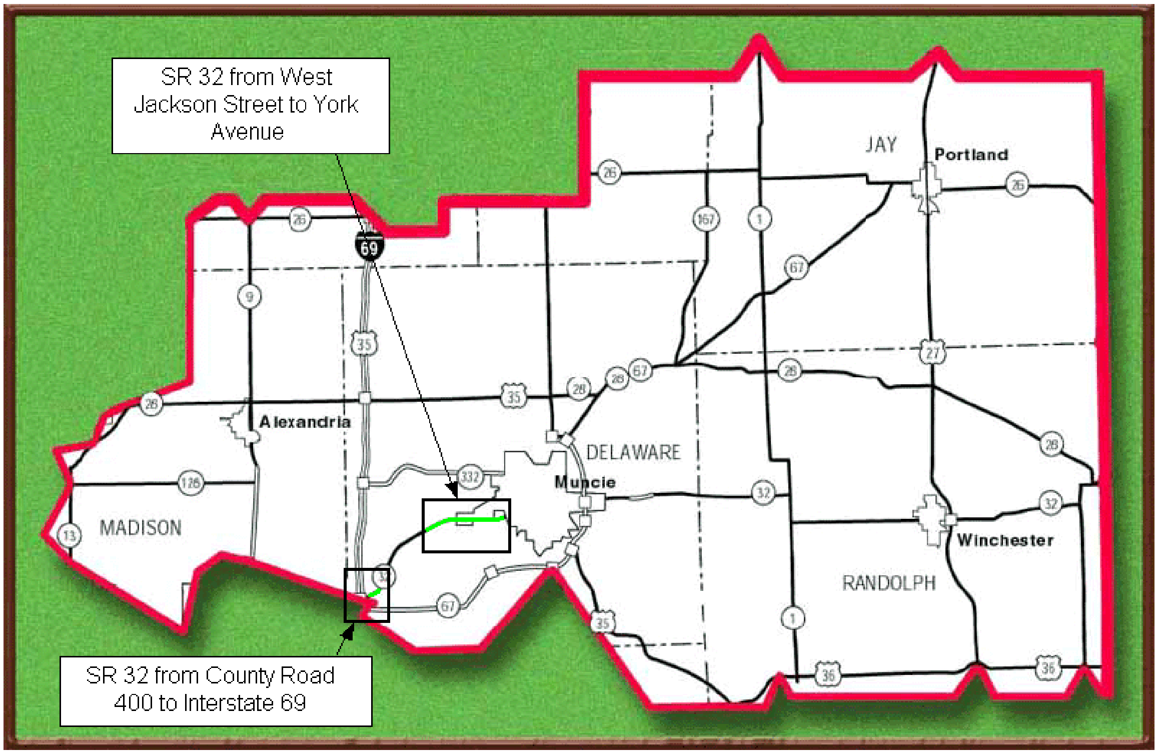


Figure 3-17: Data Collection Locations in the Albany Sub District

Figure 3-18: Data Collection Locations in the Greenfield Sub District

3.2.3. Laporte District Locations

Data collection in the Laporte District (Figure 3-19) began in the Winamac sub district (Figure 3-20) around the town of Winamac, IN. The data collection then moved up to the Gary (Figure 3-21) sub district. The data collection finally ended in May 2002 in the Rensselaer sub district (Figure 3-22) along US 41. The black boxes indicate data collection locations and the description is the limits of the data collection.

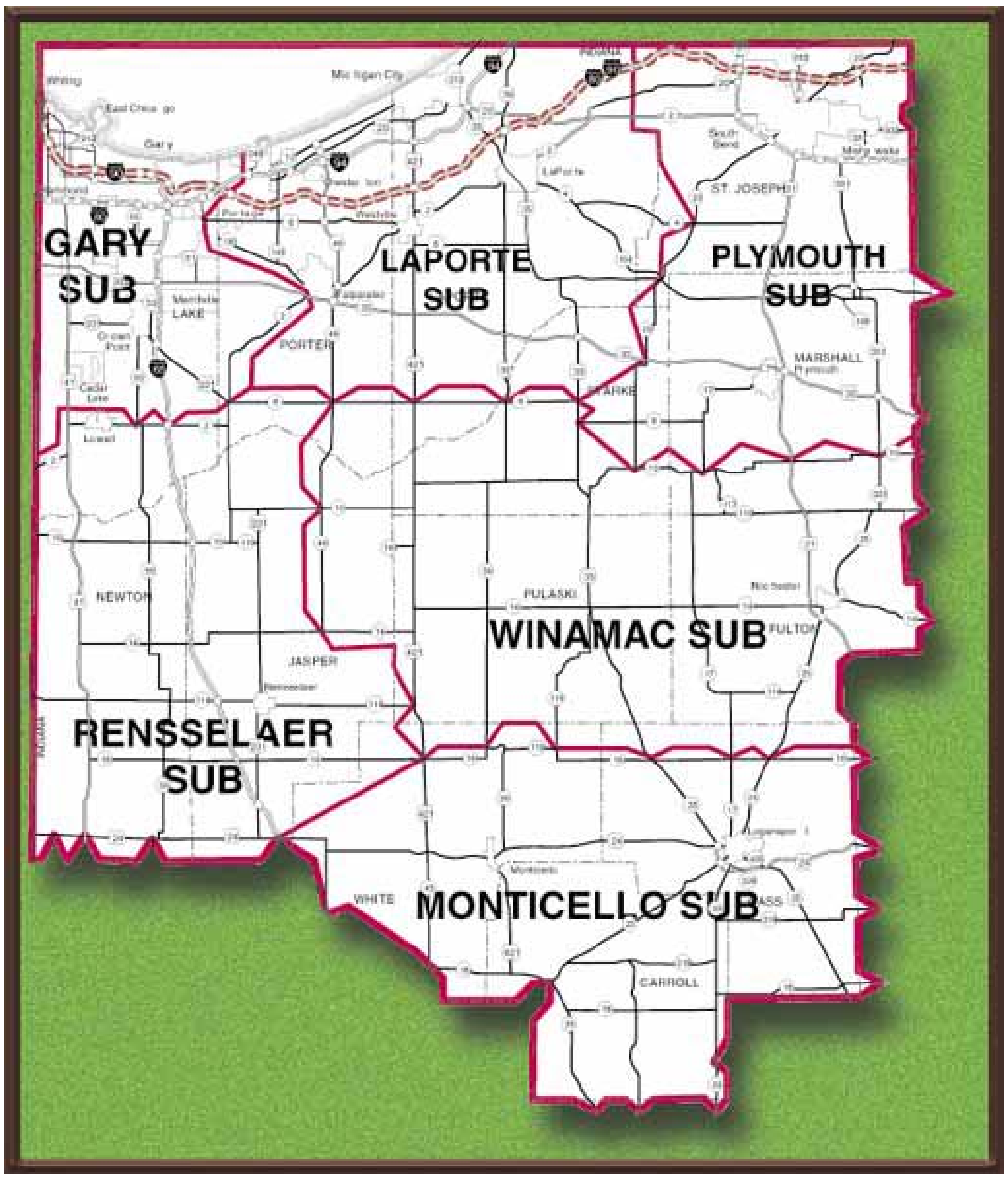


Figure 3-19: Laporte District Overview

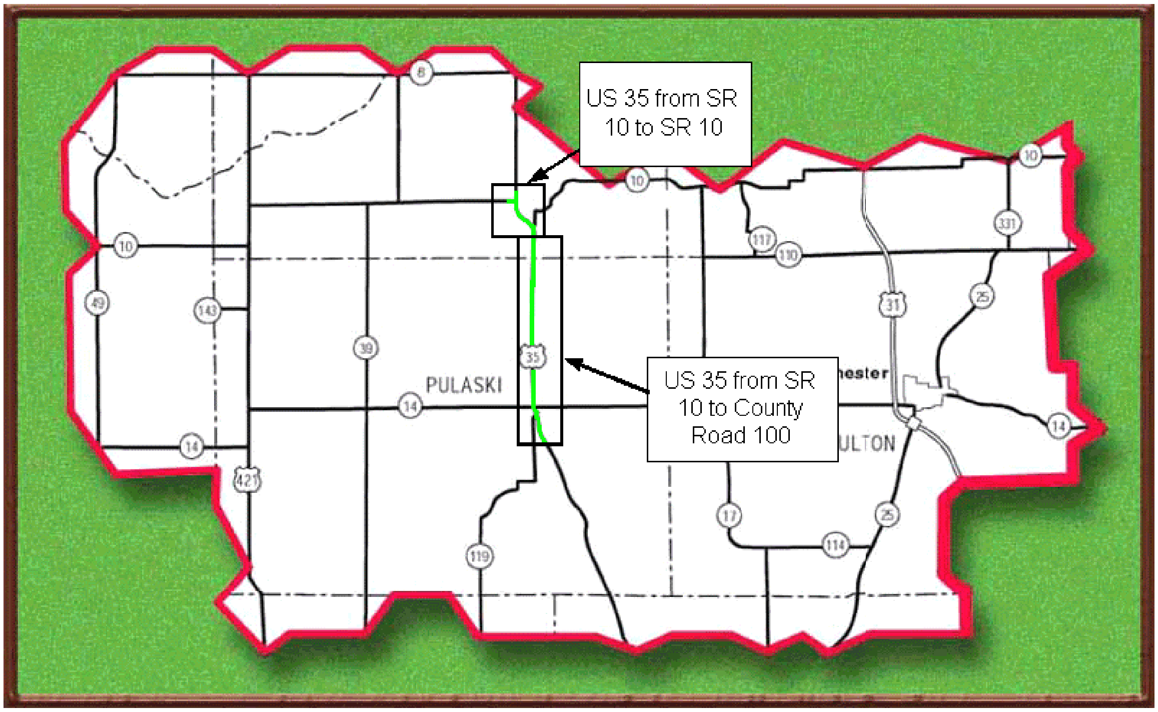


Figure 3-20: Data Collection Locations in the Winamac Sub District

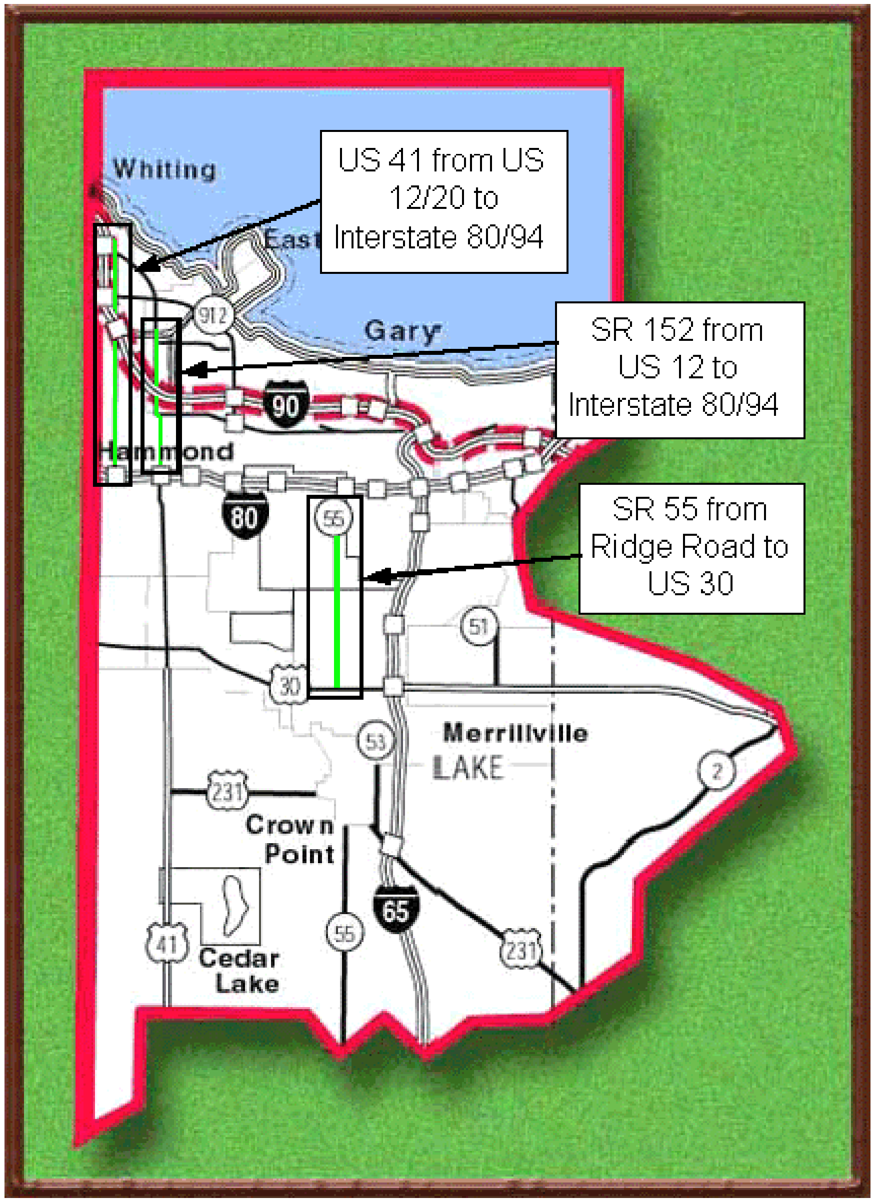


Figure 3-21: Data Collection Locations in the Gary Sub District

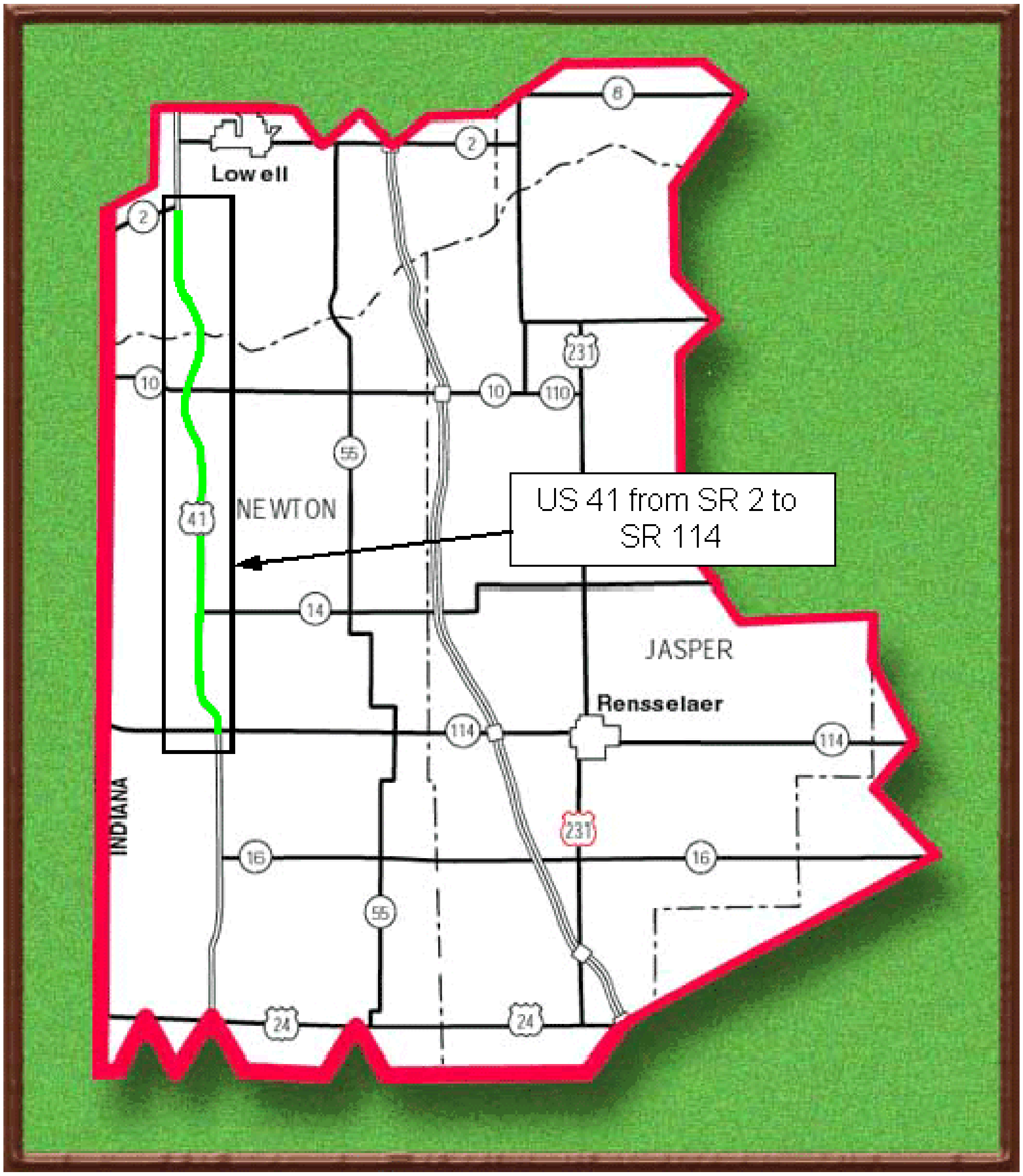


Figure 3-22: Data Collection Locations in the Rensselaer Sub District

CHAPTER 4. DATA ANALYSIS

This chapter discusses the analyses done on the data collected from in-service signs in Indiana. It discusses what data was used in the analyses, the analyses done to determine if the retroreflectivity of sheeting can be predicted using the age, whether or not a wiped sign has a significantly higher retroreflectivity than an unwiped sign, if the orientation of the sign face affects the retroreflectivity, how red and white signs perform relative to the proposed 4 to 1 retroreflectivity ratio, and how the retroreflectivity readings vary on a sign as well as from machine to machine.

4.1. Data Used in the Analysis

When this study was started the initial data collection was done on signs taken out of service. These signs were taken from a "bonepile" located at the Crawfordsville District DOT garage. From this "bonepile" a total of 550 signs were collected. After the "bonepile" at the Crawfordsville DOT garage was depleted data collection started on the in-service signs along the state and US highways in Indiana. A total of 1613 signs were collected from in-service locations around Indiana as shown in the previous chapter.

The data collected from the "bonepile" was used in a paper (Nuber, 2001) submitted to the Transportation Research Board (TRB) annual conference for discussion and input from professionals in the transportation industry. One of the main arguments voiced by the people who attended the session where this paper was presented was that the signs from the "bonepile" were damaged as they were removed and transported and thus not a representative population of the signs in the field. The counter argument for this was that using these signs would be more conservative because these signs would be older, around 10 years of age, and thus give a more conservative result on the expected in-service life of the average sign along the state and US highways in Indiana.

For this report, however, only data collected from the in-service signs with ASTM Type III sheeting were used in the data analyses. A total of 1341 samples were used in the analyses that follow. For the analyses done in this chapter the retroreflectivity readings taken from the different colors were averaged together to get one retroreflectivity for each color on the sign. An example of the readings done on a stop sign is illustrated in Figure 4-1. In this figure you can see that there are 3 readings done on each color. Readings 1, 2 and 3 for the red are taken and then averaged together and the same is done for the white. Then the readings are repeated in the same place after the sign has been wiped.

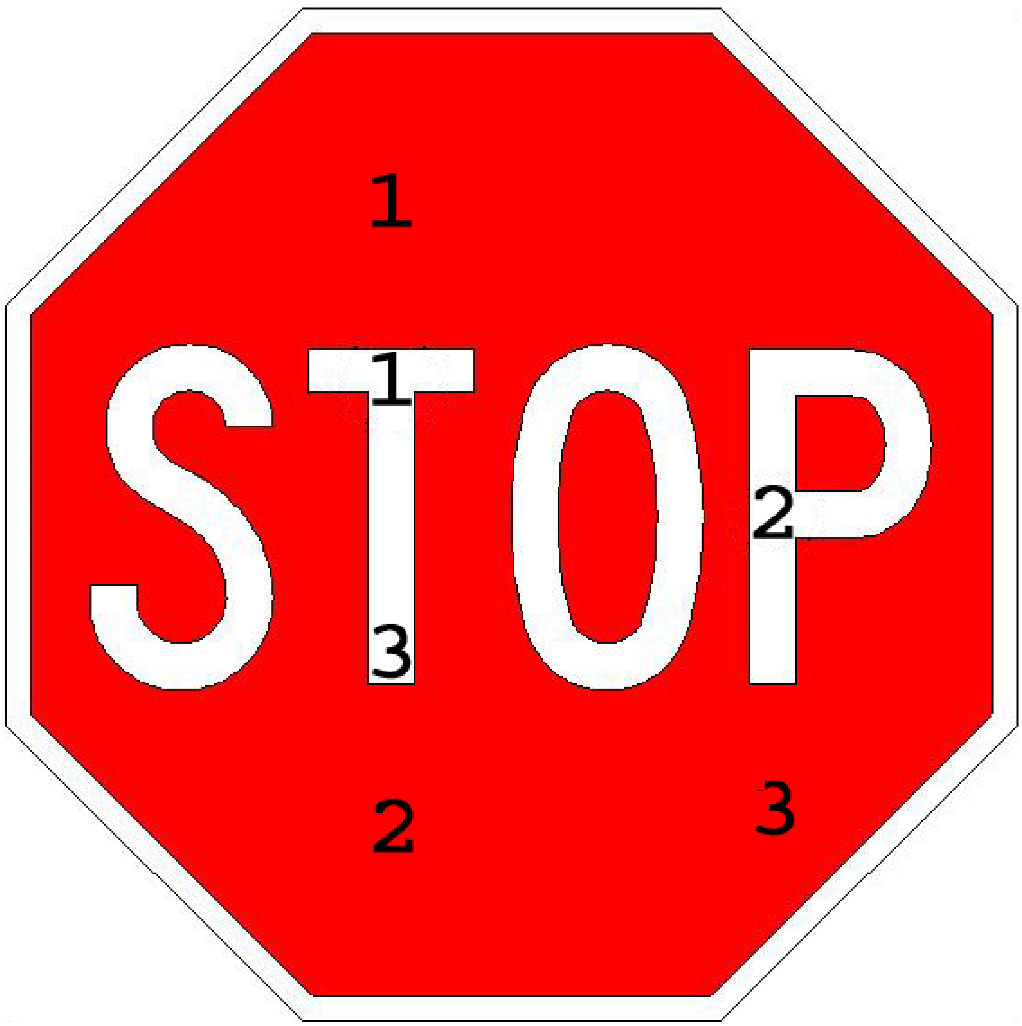


Figure 4-1: Location of Retroreflectivity Readings for a Stop Sign

4.2. Sheeting Age Analysis

From the literature review reported in the previous chapter there were some conflicts whether or not the age of the sheeting could be used in determining the retroreflectivity by the use of a trend line. Some of the previous research has been able to use the age in determining the retroreflectivity and some have not. For this reason the age analysis was done on the data collected from the in-service signs. The age analysis is broken down into 3 sections one for each major sheeting color (red, white, and yellow).

4.2.1. Red Sheeting Age Analysis

Overall red is thought to be the sheeting most affected by weathering due to the nature of the red color itself. Over time the red ink used in the overlaying of traffic signs looses its color. As you can see from the trend line in Figure 4-2 the red color does lose its retroreflectivity as the sheeting ages. There is a very distinct downward trend. However there is no real predictability of a signs average retroreflectivity as shown by the R^2 value. It shows that there are about a 32 percent correlation between the age and the average retroreflectivity. The reason this is so low is probably due to the variability of the readings as the sheeting gets older. From the graph in Figure 4-2 you can see that range of average retroreflectivity values as the sheeting ages does increase.

The dotted line represents the proposed retroreflectivity minimums as shown in Table A-2 and Table A-6. As you can see there are only 4 data points that fall below this line. These points are detailed in Table B-1 with pictures of the signs in Figure B-1. These 4 signs are about 1 percent of the data collected from in-service signs with red backgrounds. It is also interesting to note that these 4 signs are about 10 years of age or older. There are signs that were sampled that are older than these 4 and still have average retroreflectivities well above the proposed minimums.

Another set of analyses was done to see if the number of retroreflectivity minimum violators changed when using the minimum values from both the unwiped and wiped readings taken from the signs in the field. Instead of using the average retroreflectivities these graphs use the minimum of the 3 readings

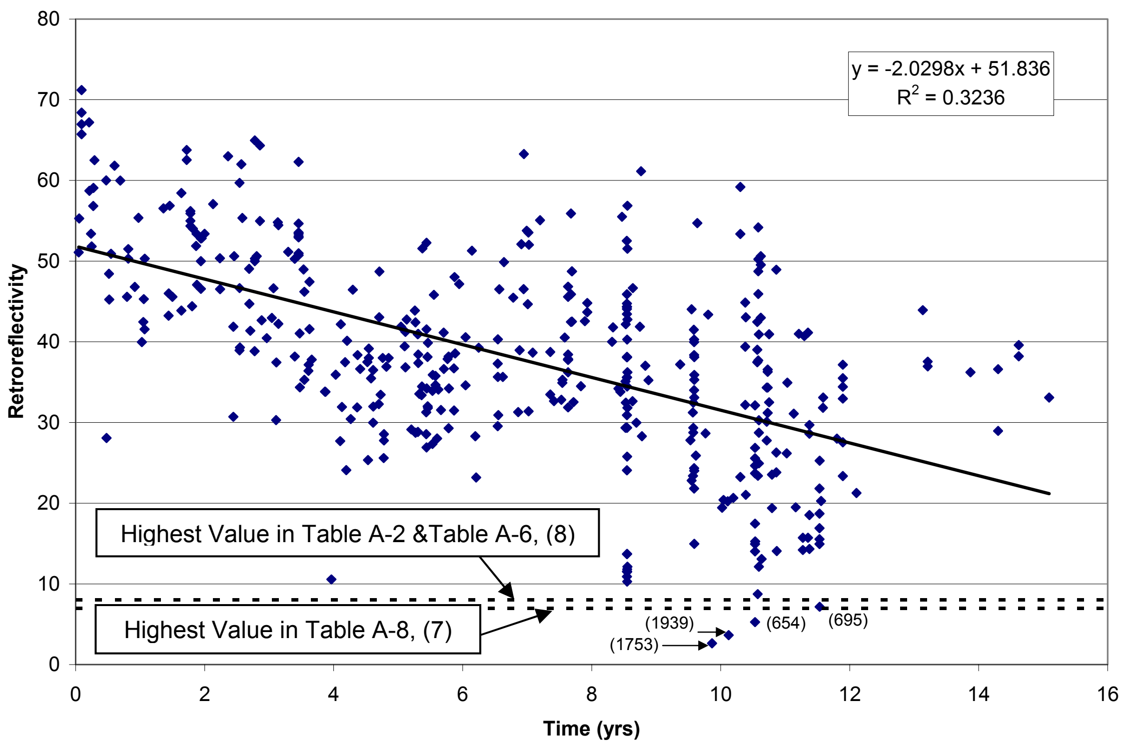


Figure 4-2: Red ASTM Type III Average Unwiped Background Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 415)

taken for both the unwiped and wiped readings. The graph of the minimum unwiped retroreflectivity readings versus the age is located in Figure 4-3. The graph of the minimum wiped retroreflectivity readings versus the age is located in Figure 4-4.

In Figure 4-3 you can see that there is the same downward trend and it is similar to the trend shown in Figure 4-2. One of the two differences between these two graphs is the variability of the retroreflectivity readings between signs in the same age group. You can see that the variability is more in this graph as compared to the previous because the R^2 value is lower which means that there is not as much of a correlation between the age and the minimum unwiped retroreflectivity. The correlation of this graph is about 30 percent whereas the correlation of the graph of the average retroreflectivities is 32 percent.

The second difference between the average retroreflectivity and the minimum unwiped retroreflectivity is the number of signs that violate the proposed retroreflectivity minimums. As you can see in Figure 4-3 there are now 6 signs that violate the proposed retroreflectivity minimums as compared to just 4 in Figure 4-2. This difference is largely due to effect averaging has on a set of readings. Averaging the retroreflectivity readings taken from the sign masks the variability found on that sign. For example if a sign has a "dead" spot where the sheeting has decayed faster then the rest of the sign and the other readings are taken on parts of the sign where it has not decayed then averaging the readings together will essentially hide or cover up the one bad reading taken. This is the reason that there are 2 more signs that do not meet the proposed retroreflectivity minimums.

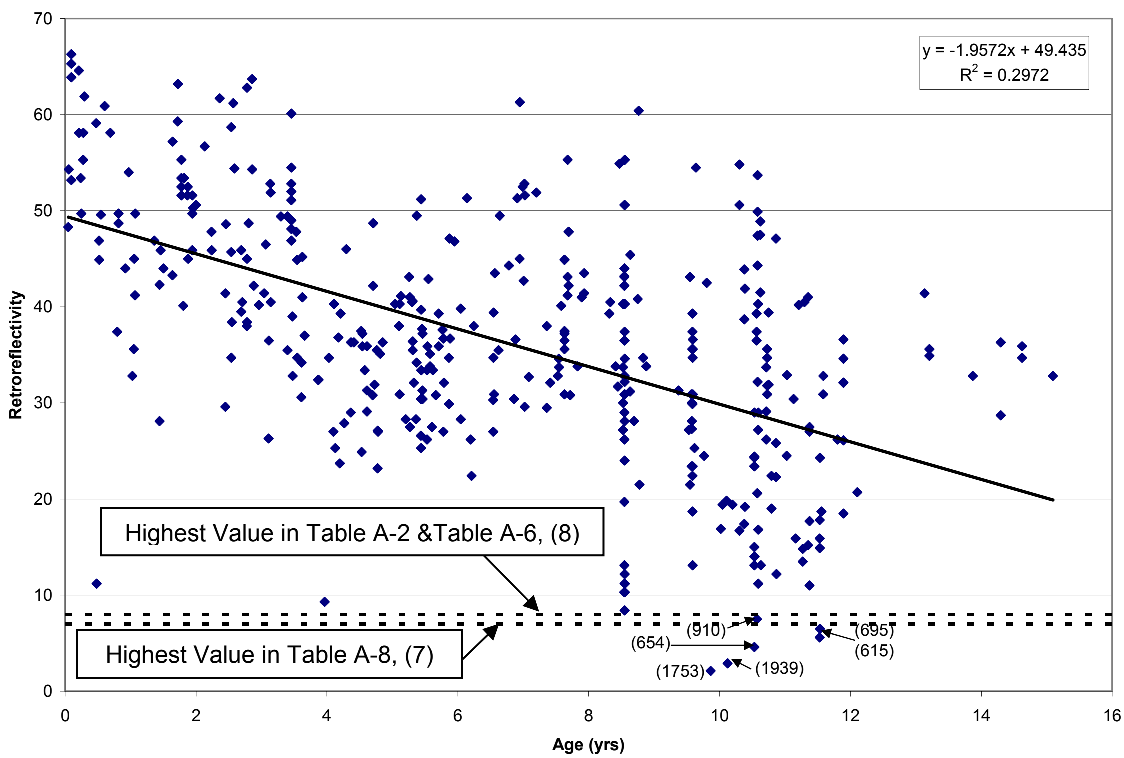


Figure 4-3: Red ASTM Type III Minimum Unwiped Background Color Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 415)

Even though there are a couple more signs not meeting the proposed minimums these 6 signs only account for about 1.5 percent of the total red background color signs sampled in Indiana. Because of this it can be said that the vast majority of the signs in use are above the proposed retroreflectivity minimums. The retroreflectivity readings taken for the signs that violate the proposed minimums shown in Figure 4-3 are located in Table B-2.

The last analysis done for the red sheeting age analysis is a graph on the minimum wiped retroreflectivity readings versus age. This graph takes the minimum of the wiped readings instead of the average of the wiped readings. As you can see there is the same downward trend as the previous two graphs show. The correlation between the minimum wiped value and the age is about 30 percent which is about the same as the graph with the minimum unwiped retroreflectivities (Figure 4-3). Because the correlation is about the same for the two graphs it can be said that there is really no difference between the wiped and the unwiped readings taken from the same sign. Also the variability is about the same for both of these graphs which also shows that there is really no difference between the wiped and unwiped readings.

On the graph in Figure 4-4 you can see that there are 5 signs which violate the proposed retroreflectivity minimums. These 5 signs count for about 1.2 percent of the total samples taken on signs with red backgrounds. This is a very small percentage and from this it can be said, as in the previous 2 analyses, that the vast majority of the signs in the field are above the proposed minimum retroreflectivities. The retroreflectivity readings for the signs that violate the proposed minimums shown in Figure 4-4 are located in Table B-3.

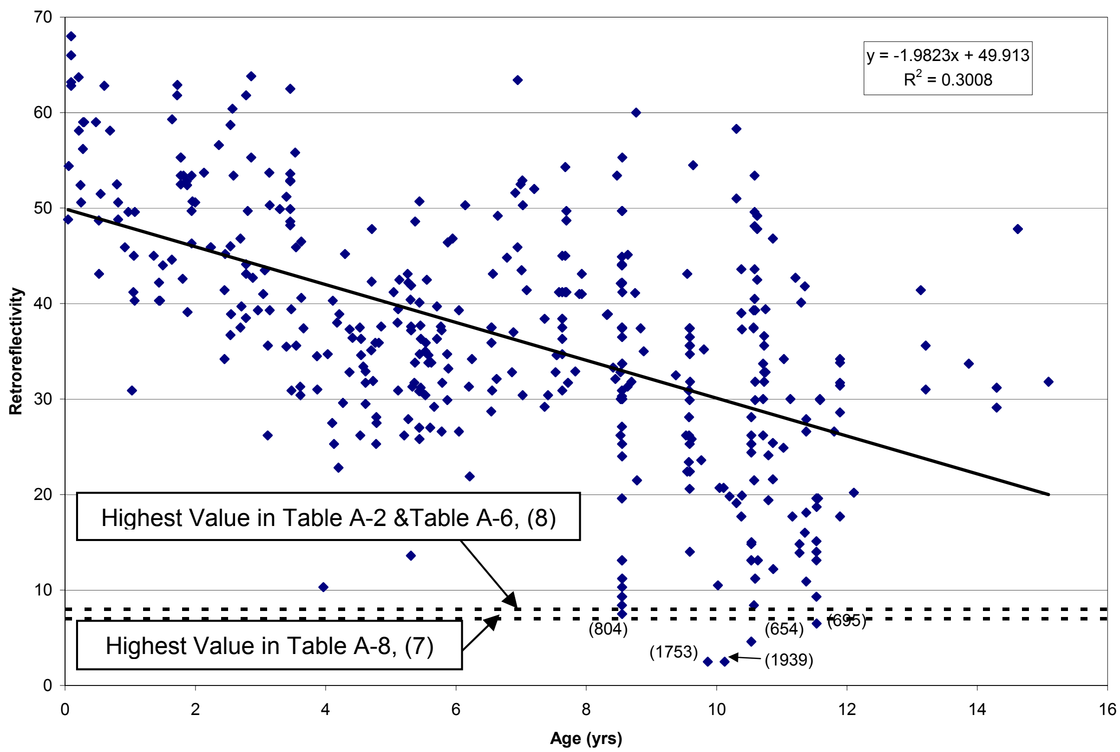


Figure 4-4: Red ASTM Type III Minimum Wiped Background Color Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 415)

4.2.2. White Sheeting Age Analysis

White sheeting by far is the most used sheeting for signing highways and interstates. The reason this is so is because white is used in all regulatory signs which are the majority of signs used. Because of this the number of data points collected for white background signs is 683 which is 30 percent more than the red samples and almost 3 times more than the yellow samples. From the graph shown in Figure 4-5 you can see that the majority of samples collected fall between 0 and 10 years of age with a good amount of samples older than 10 years as compared to the number of red samples. Also you can see that the trend line is basically flat meaning that there really is no apparent downward trend in the retroreflectivity as in the case of the red samples. The R^2 value of 0.015 shown on the graph means that there is just about no correlation between the average unwiped retroreflectivity and the age. This suggests that the white sheeting is not affected by the elements a will last well beyond the 10 year warranty offered by the vendor.

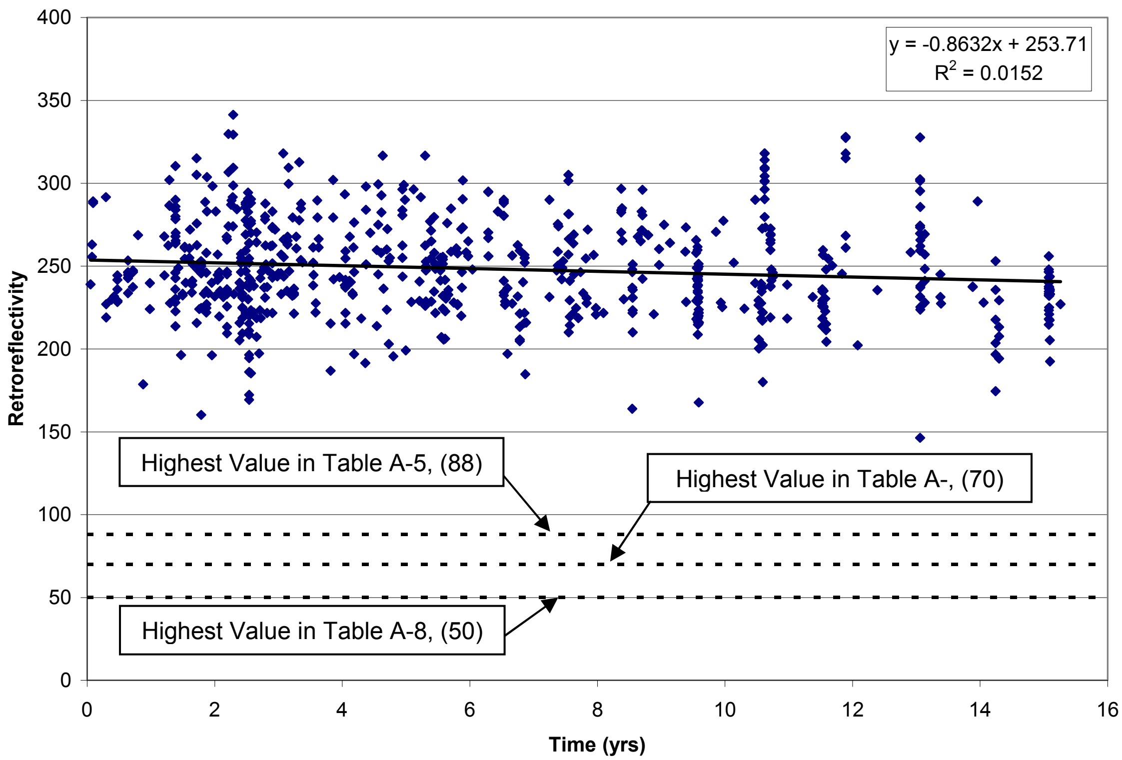


Figure 4-5: White ASTM Type III Average Unwiped Background Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 683)

The two dotted lines represent the proposed minimums as shown in Table A-, Table A-5, and Table A-8. The most interesting aspect of the graph in Figure 4-5 is the fact that there are no signs which fall below either of the proposed minimums. From the 683 samples collected not one sign has an average retroreflectivity of less than 100. Even signs that are 15 years of age have average retroreflectivities over 150. These results are probably due to the construction of the 3M ASTM Type III sheeting (Figure 2-3b). Given this performance seen in the field it is possible that signs made with this material could be left out in the field longer than their warranties cover and longer than the current 10 year replacement cycle done by INDOT.

The same set of analyses was done on the white samples as was done on the red samples. To see if there was a masking effect, as there was in the red sample, two more graphs were done to see how the minimum readings taken from each of the white samples would affect the compliance of the of the signs in the sample with the proposed retroreflectivity minimums.

The graph in Figure 4-6 shows the plot of the minimum unwiped retroreflectivity reading versus the age for signs with a white background. As you can see by this graph there is more of a downward trend then there was in the previous one. The reason for this trend is it that, as stated before, there is an averaging effect which covers up variability of the readings on the sign face due to “dead” spots.

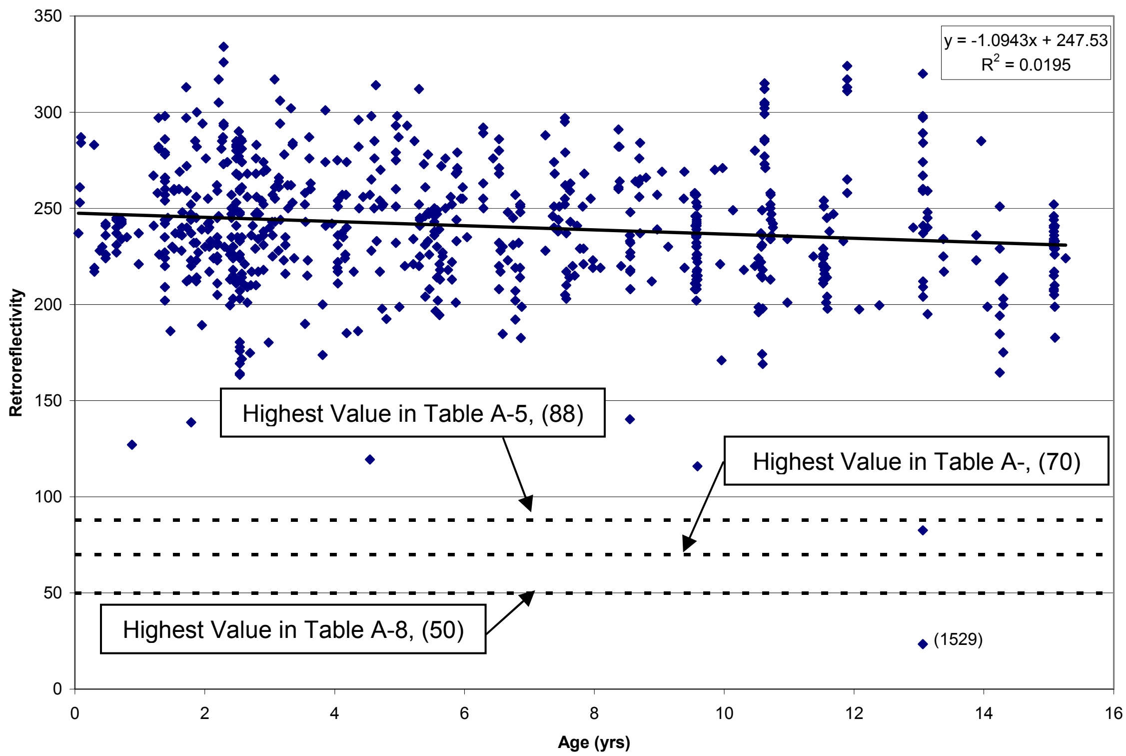


Figure 4-6: White ASTM Type III Minimum Unwiped Background Color Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 683)

Also from the graph in Figure 4-6 there is a sign that is now below the proposed minimums. The retroreflectivity readings for this sign are located in Table B-4. These readings show that there was a dead spot on the sign which caused the sign to fall below the proposed minimums. Also one can see that the vast majority of the signs sampled are still well above the proposed retroreflectivity minimums.

With this analysis there is only a correlation of about 2 percent between the age and the minimum sampled retroreflectivity which means that there is no link between the age of the sheeting and the retroreflectivity. This suggests signs with the 3M ASTM Type III sheetings could be left out in the field longer than most DOT's currently allow thus allowing some fiscal savings in the form of sheeting cost and labor for fabrication and installation.

The last analysis done on signs with white backgrounds was a plot of the minimum wiped retroreflectivity versus the age. This graph is located in Figure 4-8. As with the graph in Figure 4-6 there is a slight downward trend. This is due to the effect that averaging has on the data collected as discussed before. There is a slightly greater correlation between the minimum wiped retroreflectivity and the age. This correlation is only about 3.6 percent and is not really much thus there is really no relationship between the age and the retroreflectivity of the sign. Because of this is it plausible that signs made from 3M white ASTM Type III material could be left out in the field longer then they currently are.

There also appears to be no difference between the unwiped and wiped graphs. There may be some small benefit to wiping the signs clean of dirt but it is not significant enough to show up in this graph. Because there is really no notable difference between the wiped and unwiped graphs it would be safe to say that wiping really does not have a significant effect on the retroreflectivity readings of the sign because the overall graph was not changed.

There is also one sign which violates the proposed minimums and that is the same point as in the previous graph (ID #1529). The measurements for this sign are located in Table B-5 and a picture of the sign is located in Figure 4-7. As you can see the reason this sign violates the minimum retroreflectivity is because of a “dead” spot on the sign. Dead spots such as these would be very hard to detect by using a retroreflectometer not to mention the expenses associated with doing hand readings on signs. The best way to catch these types of signs would be to do night inspections with standard headlights because dead spots will not reflect much light and would appear as a dark portion of the sign.

Figure 4-7: Picture of Sign #1529

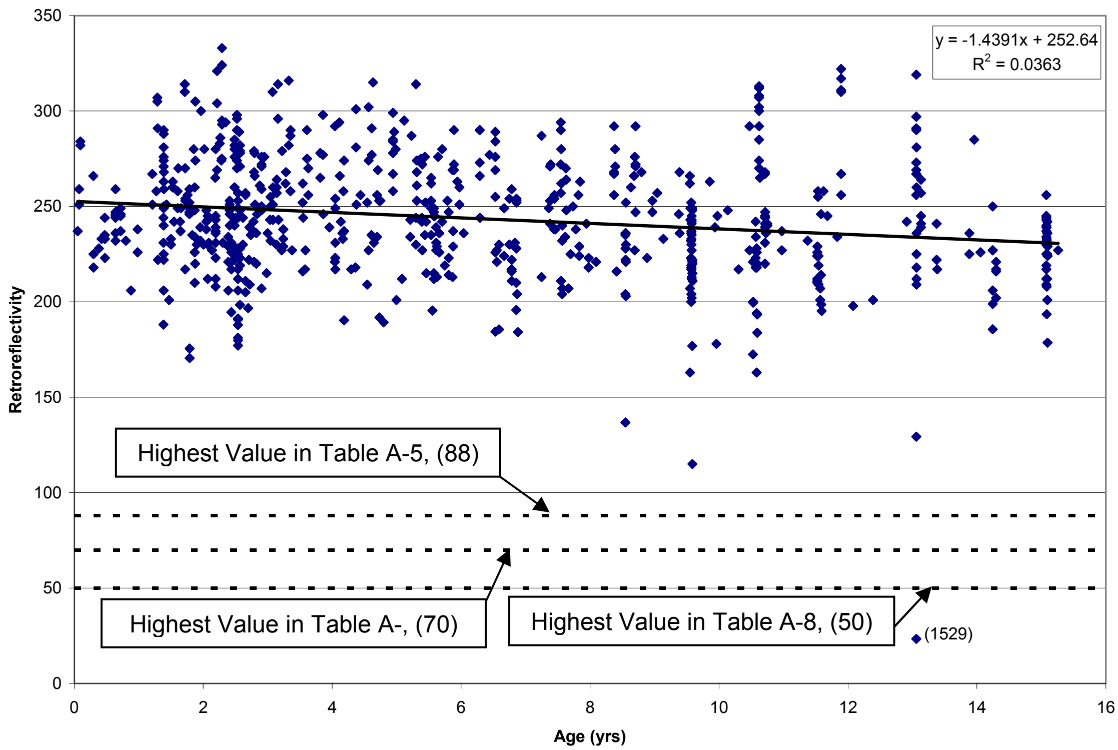


Figure 4-8: White ASTM Type III Minimum Wiped Background Color Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 683)

4.2.3. Yellow Sheeting Age Analysis

Age analysis was done the same on the signs with yellow background as red and white. The first graph located in Figure 4-9 shows the average unwiped retroreflectivity versus the age of the sign. From the trend line on the graph you can see that there is an apparent downward trend as the age of the sheeting increases. This downward trend is not as much as in the case of the signs with red backgrounds but is more so than the signs with white backgrounds. The correlation between the average retroreflectivity is about 19 percent which means there is some correlation but not enough to be able to predict the average retroreflectivity given an age.

The two dotted lines on the graph in Figure 4-9 show the proposed retroreflectivity minimums as listed in Table A-3, Table A-, and Table A-8. You can see that only 3 points violate the proposed 2001 minimums and these points are older than 16 years. Pictures and descriptions of these 3 signs are located in Figure B-2. There are two more points which violate the preliminary 2002 minimums bringing the total number of points which violate the minimums up to 5 which is about 2.1 percent of the entire yellow sample. Given the age of these signs it appears that the sheeting on these signs probably just deteriorated accounting for the fall below the proposed minimums. There are other signs in the sample that are of the same age which are way above the proposed minimums. All of these factors give a good reason to allow the signs made with 3M ASTM Type III yellow sheeting to remain in the field longer than the current 10 year cycle used by INDOT.

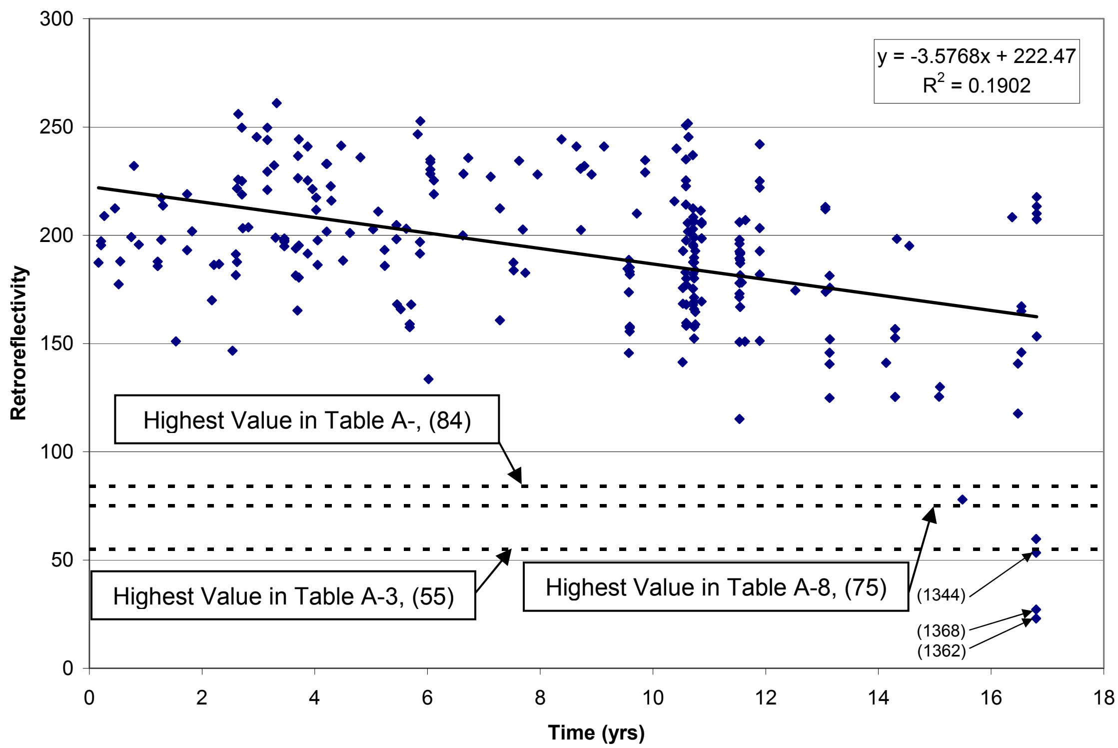


Figure 4-9: Yellow ASTM Type III Average Unwiped Background Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 243)

The next analysis done on the yellow background data is the minimum unwiped retroreflectivity versus age. The plot of the minimum unwiped retroreflectivity is located in Figure 4-10. From this graph you can see that there is still a downward trend in the data points but it is actually slightly less than in Figure 4-9. The reason for this is that there may not be as much of a covering up effect on the yellow signs as there is on the white signs.

There are still the same number of signs that violate the proposed minimums meaning that the minimum unwiped retroreflectivity as seen in the previous graph is near the average retroreflectivity for that sign. The retroreflectivity readings for the violators are located in Table

B-7. As you can see from this table the signs have pretty low minimum retroreflectivities which is synonymous with the deterioration of the yellow sheeting.

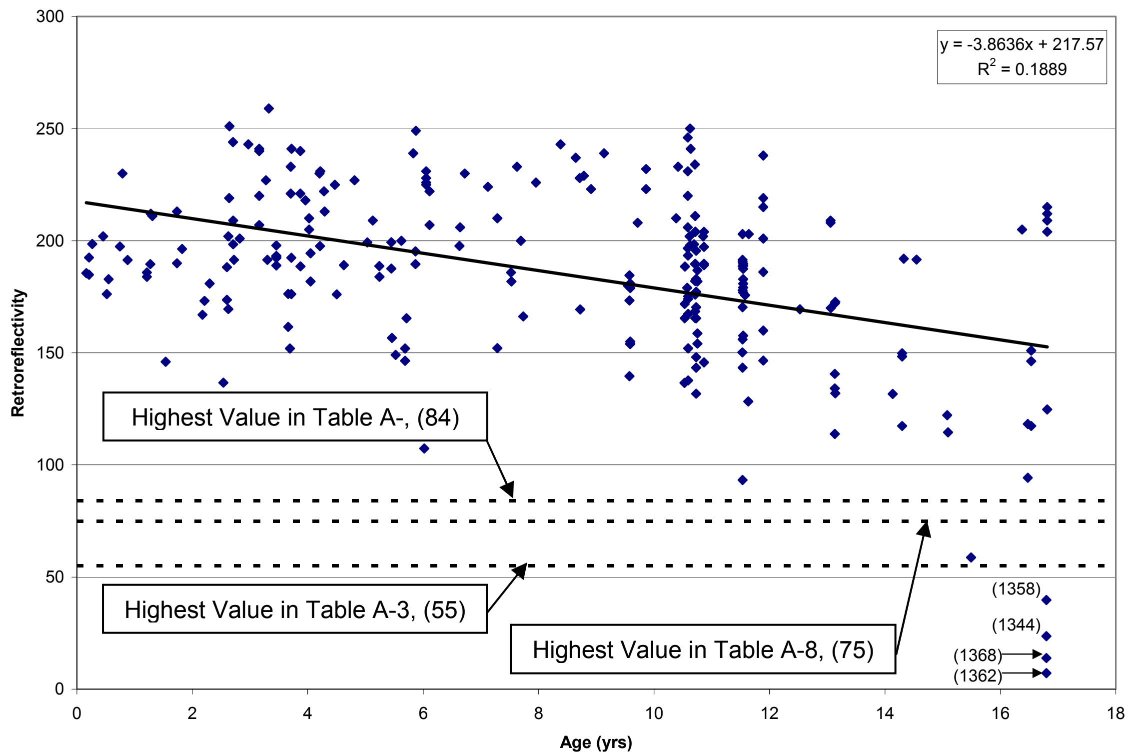


Figure 4-10: Yellow ASTM Type III Minimum Unwiped Background Color Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 243)

Given that the number of violators remained the same, the trend really did not change that much, and that the majority of the signs sampled are well above the minimums it would be plausible to leave the 3M yellow ASTM Type III sheeting signs out in the field longer than they currently are. T

The last analysis done on the yellow background sign sample is the minimum wiped retroreflectivity versus the age. The plot of this, located in Figure 4-11, shows that same downward trend as seen in the previous two graphs. The correlation in this graph is about 10 percent which is around the same as the other two as well. Overall there is not really that much of a change between the unwiped and wiped graphs. This is because there is not much change in the wiped retroreflectivity readings from the unwiped ones.

The same 5 samples as in the previous two graphs are still violating the proposed minimums. The retroreflectivity readings for these signs can be found in Table B-8. As you can see in this table the signs had poor retroreflectivity readings overall meaning that the sheeting had deteriorated pretty badly probably because they had been in the field for such a long time.

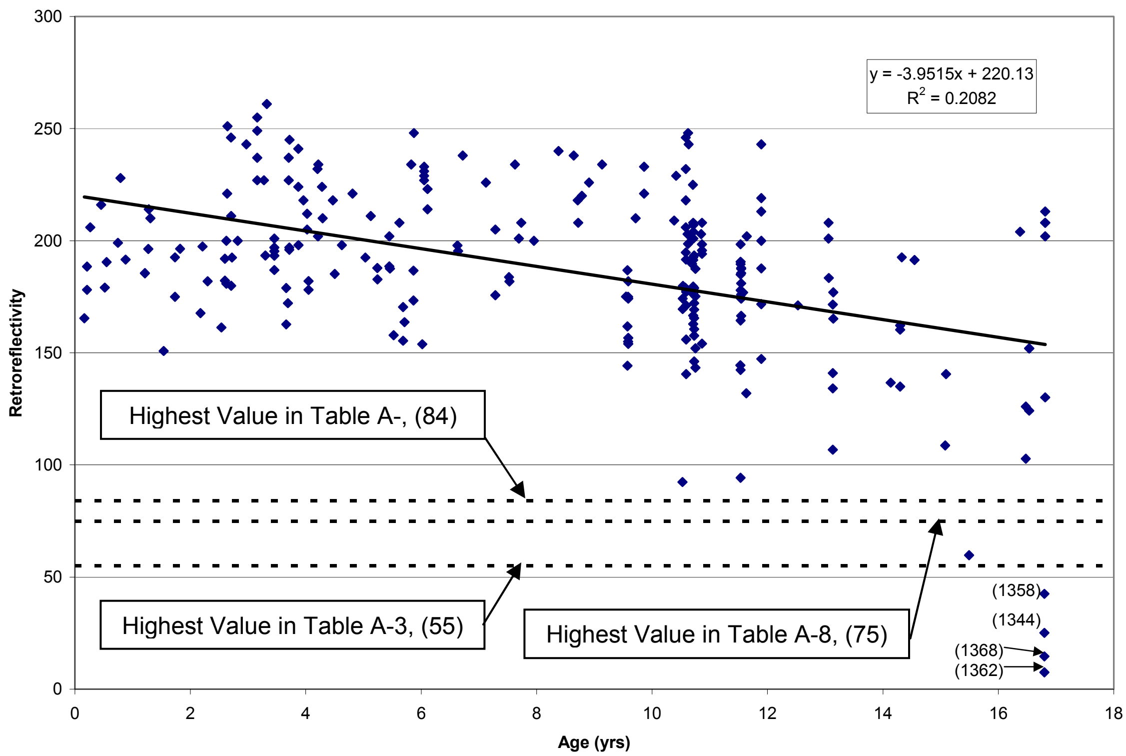


Figure 4-11: Yellow ASTM Type III Minimum Wiped Background Color Retroreflectivity versus Time Excluding the Crawfordsville Bonepile (n = 243)

From the analysis of the age of the signs the following things can be concluded. First, there really is no way to precisely predict the retroreflectivity of a sign given its age. The reason is that the variability of readings among signs of the same age is just too great to get a good prediction of the retroreflectivity. Second, overall the signs sampled preformed very well. Of the 1341 samples analyzed only 11 samples fell below any of the proposed minimums. This accounts for about 0.8 percent of the entire sample. Because this is so small it probably means that the vast majority of signs in the field will meet the proposed retroreflectivity minimums. Third, from the graphs of the unwiped minimum retroreflectivity versus age and wiped retroreflectivity versus age you can conclude that there is really no difference between the wiped and unwiped readings. These graphs, in all cases, had roughly the same slopes as well as the same number of points that violated the proposed retroreflectivity minimums which means that these graphs are basically the same. Finally, given the trends of the red samples taken, signs with red sheetings should not be left in service any longer than the current 10-year cycle. However, the signs sampled with white and yellow backgrounds could be left in service longer due to their observed performance.

4.3. Unwiped Versus Wiped Analysis

The next analysis done is the unwiped versus wiped retroreflectivity readings. This analysis is done to determine if there is a statistical difference between wiped and unwiped average background and legend 1 retroreflectivity readings on the same sign sampled. The test used is the T-test which uses the sample size, mean, and variation values of the unwiped and wiped retroreflectivities for the colors red, white, and yellow. The value obtained is the t-stat which is then compared to a normal probability curve with at a 95 percent confidence interval. There were two analyses done by district on the data set. The first was comparing the unwiped and wiped average retroreflectivity readings in the Crawfordsville and Greenfield Districts. The second analysis was done on the Laporte district. The t-test tables are broken down into 3 sections by color and in each section broken down by age group.

The analysis done on the Crawfordsville and Greenfield Districts is located in Table 4-4. From this analysis you can see that the mean for the wiped and the mean for the unwiped in each section are about the same. This is backed up by the t-stat which shows that none of the means between the wiped and unwiped are statistically different. This means that there is no significant improvement of the retroreflectivities due to wiping of the sign.

The analysis done on the Laporte District (an area with significant industrial activity and low air quality), located in Table 4-5, has a different result than the previous table. For the background colors red and yellow there is no statistical difference between the wiped and unwiped means. However, this is not the case for the white background color. When all of the ages are combined into one group there is a statistical difference between the mean of the wiped and unwiped retroreflectivities. This means that there is a significant improvement in the retroreflectivity after a sign has been wiped. The reason that this is true is because the 0 to 5 year and 5 to 10 year difference between wiped and unwiped retroreflectivities is almost statistically different. Because these two categories account for most of the sample once they are combined it causes the difference to be significant. However, this does raise a question on whether or not newer signs made with white sheeting are affected more by dirt and grime than older signs because as a whole the white signs have a different retroreflectivity after they are wiped but in 5 year groups they are not. Although there is a significant difference, in reality this difference is so small in relationship to the proposed minimums that it is not relevant.

Table 4-4: T-test table of Wiped versus Unwiped for Background and Legend 1 colors for the Crawfordsville and Greenfield Districts Excluding the Crawfordsville Bonepile

ASTM Type III		Crawfordsville & Greenfield					
Color	**Age (Years)**	**n**	**Mean W**	**Mean UW**	**Var W**	**Var UW**	**t-stat**
RED	**All**	225	39.2	39.1	211.9	214.6	0.09
	0-5	77	48.9	48.6	123.0	127.9	0.18
	5-10	91	35.0	34.7	117.7	118.8	0.20
	10-15	56	33.0	33.2	298.1	309.0	-0.05
WHITE	**All**	442	233.2	231.9	734.4	751.5	0.68
	0-5	173	237.4	236.3	475.1	445.0	0.46
	5-10	155	225.5	223.5	476.1	519.9	0.77
	10-15	114	237.5	236.6	1366.6	1398.7	0.19
YELLOW	**All**	139	192.6	192.3	509.5	540.8	0.09
	0-5	37	203.1	202.7	247.2	262.4	0.09
	5-10	30	191.7	191.2	554.6	607.0	0.07
	10-15	72	187.5	187.4	554.7	588.8	0.03

Table 4-5: T-test table of Wiped versus Unwiped for Background and Legend 1 colors for the Laporte District

ASTM Type III		Laporte					
Color	**Age (Years)**	**n**	**Mean W**	**Mean UW**	**Var W**	**Var UW**	**t-stat**
RED	**All**	147	38.3	37.8	122.5	117.8	0.43
	0-5	47	41.8	41.1	87.3	86.3	0.37
	5-10	68	38.6	38.3	117.2	116.8	0.12
	10-15	32	32.6	31.6	141.6	117.9	0.35
WHITE	**All**	402	262.1	258.0	989.7	1110.1	**1.78**
	0-5	175	268.5	263.5	801.6	955.6	1.58
	5-10	158	258.8	255.2	623.2	715.7	1.23
	10-15	69	253.2	250.4	2133.3	2293.5	0.34
YELLOW	**All**	56	224.3	222.3	614.1	663.6	0.41
	0-5	20	236.3	233.5	439.2	391.0	0.43
	5-10	20	228.2	225.4	255.2	461.5	0.46
	10-15	17	193.7	193.8	740.1	831.5	-0.01

4.4. Retroreflectivity and Azimuth Analysis

The azimuth analysis was performed on the data collected in the field and is split into three sections by color (red, white, and yellow). The graphs in this section are broken down by 5 year age groups to try and keep the graphs smaller as well as group the data points in a reasonable manner. T-tests on the orientation of the sign face and the retroreflectivity were only done on the red sheeting because it is hypothesized that the red ink fades more rapidly on the southern facing signs than on signs facing other directions. All the analyses done in this section are with the average unwiped retroreflectivity readings of the signs.

4.4.1. Red Sheeting Retroreflectivity and Age Azimuth Analysis

The red ink that is used to overlay signs fades over time. As this red ink fades more of the white background sheeting shows through and the red actual starts to reflect more and more light as discussed in chapter 2 and shown in Figure 2-4. It is theorized that sun exposure has a significant impact on the red ink and causes it to fade more rapidly than it otherwise would. In order to evaluate if there is such an effect, plots of the average retroreflectivity versus the azimuth were made. Also a t-test was done on different facing signs to determine if there was a statistical difference between signs facing different directions.

The graphs in Figure 4-12, Figure 4-13, and Figure 4-14 are broken up into 5 year age groups. From these graphs you can see that there is no clear trend for signs around the 180 degree marker having lower retroreflectivities than the others. In Figure 4-12 you can see there are more signs with high retroreflectivities on and near the 180 degree marker but this is not true for the other two graphs. The reason for this is that signs with red overlays are replaced more frequently due to fading since they are more easily noticed than white or yellow background signs and therefore there are not as many older signs as newer ones. It is also important to note that of the 4 signs that violate the proposed minimums 3 of them are located at or near 180 degrees. The dotted line represents the proposed retroreflectivity minimums as shown in Table A-2, Table A-6, and Table A-8. Overall from these graphs one can not determine that anyone direction fades significantly more quickly than another. Another interesting aspect is the number of data points located on the cardinal directions. Since Indiana roadways were built on a grid type of system the signs usually face one of the primary directions. This explains why the majority of the data is located in one of the cardinal directions.

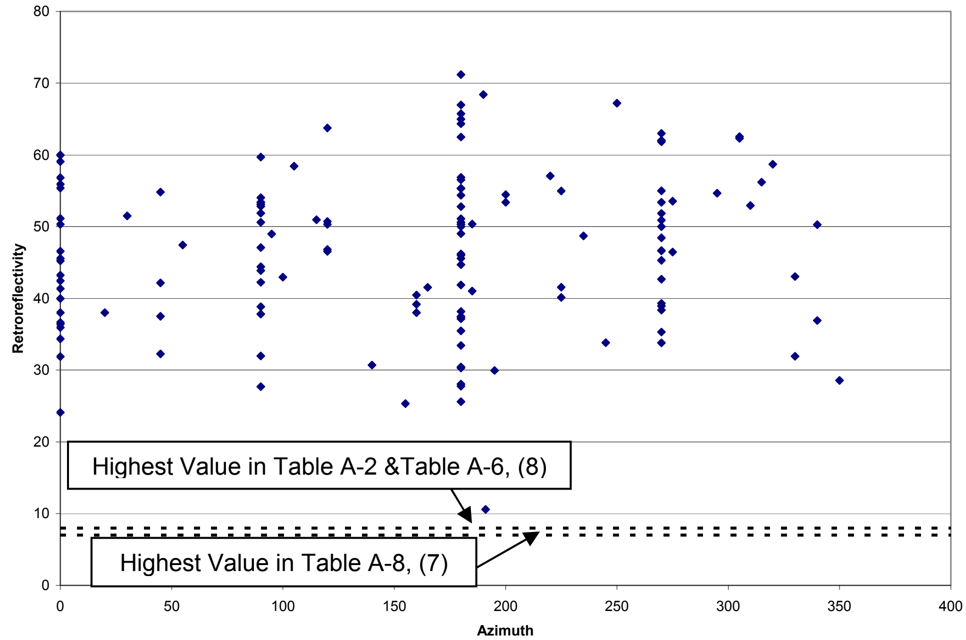


Figure 4-12: Red ASTM Type III Background Retroreflectivity versus Azimuth for Age 0 – 5 years Excluding the Crawfordsville Bonepile (n = 139)

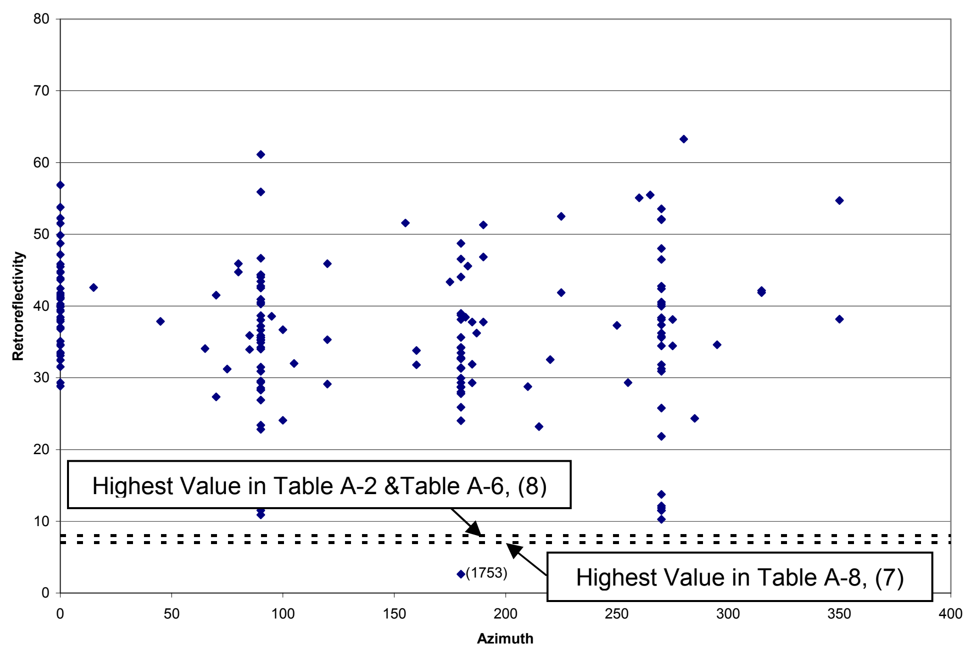


Figure 4-13: Red ASTM Type III Background Retroreflectivity versus Azimuth for Age 5 – 10 years Excluding the Crawfordsville Bonepile (n = 179)

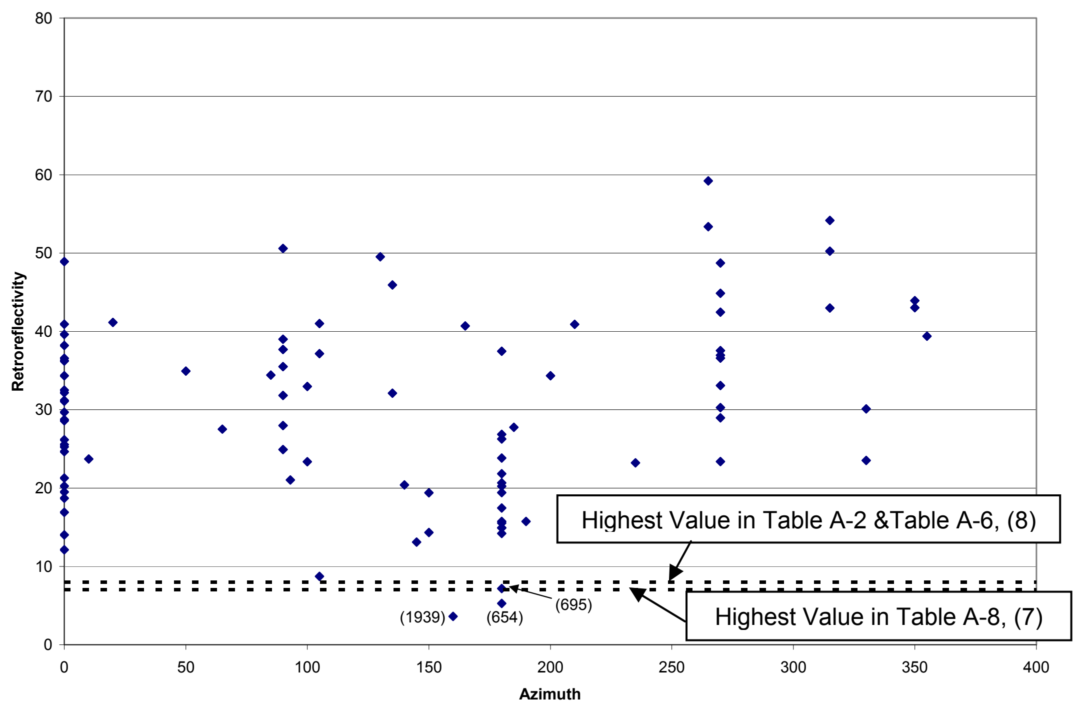


Figure 4-14: Red ASTM Type III Background Retroreflectivity versus Azimuth for Age 10 – 15 years Excluding the Crawfordsville Bonepile (n = 97)

The other set of analyses done on signs with red backgrounds was a t-test on each of the average retroreflectivity of the cardinal directions. In order to accomplish this 90 degree bins were made which include the cardinal direction and 45 degrees on either side. For example to test the south facing signs against the north facing signs all the signs from an azimuth of 135 to 225 degrees were included for the south facing signs and all signs from and azimuth of 315 to 45 degrees were included for the north facing signs. The south facing signs were tested against the north, east, and west facing signs as shown in Table 4-6, Table 4-7, and Table 4-8.

As you can see from Table 4-6, Table 4-7, and Table 4-8, none of the directions came out significantly different from the south facing signs meaning that there is no statistically significant difference in average retroreflectivities between each of the directions. This means that for this sample there is no significant statistical evidence to suggest red signs facing south do fade faster than red signs facing any other direction. One interesting point to look at is in the variance for each of the comparisons. Even though there is really not any statistical difference there appears to be more variability among readings for the south facing signs than for the others. This could be due to different process of overlaying the sign with the red ink as well as the thickness of the red ink layer applied. In order to be able to determine why the variability is more for signs facing south some research would need to be done on the processes of overlaying signs.

Table 4-6: T-test table of Unwiped Red ASTM Type III Background Color for Azimuth 135 - 225 versus Azimuth 315 – 45 Excluding the Crawfordsville Bonepile

Age	n1	n2	Mean1	Mean2	Variance1	Variance2	t-stat
All	119	114	36.1	38.4	217.9	105.6	0.23
0-5	50	35	45.6	43.8	172.1	96.7	0.48
5-10	42	44	35.1	40.8	84.4	46.6	-0.14
10-15	27	34	20.2	29.8	94.3	85.5	-0.30

Table 4-7: T-test table of Unwiped Red ASTM Type III Background Color for Azimuth 135 - 225 versus Azimuth 45 – 135 Excluding the Crawfordsville Bonepile

Age	n1	n2	Mean1	Mean2	Variance1	Variance2	t-stat
All	119	98	36.1	38.1	217.9	124.2	0.88
0-5	50	26	45.6	48.1	172.1	65.3	0.73
5-10	42	53	35.1	34.8	84.4	96.4	-0.58
10-15	27	19	20.2	33.5	94.3	102.5	0.27

Table 4-8: T-test table of Unwiped Red ASTM Type III Background Color for Azimuth 135 - 225 versus Azimuth 225 – 315 Excluding the Crawfordsville Bonepile

Age	n1	n2	Mean1	Mean2	Variance1	Variance2	t-stat
All	119	84	36.1	41.0	217.9	183.6	1.21
0-5	50	28	45.6	50.1	172.1	89.1	0.65
5-10	42	39	35.1	35.5	84.4	180.4	0.10
10-15	27	17	20.2	38.9	94.3	150.4	0.28

4.4.2. White Sheeting Retroreflectivity and Azimuth Analysis

The next azimuth analysis was done on sheeting with a white background. These signs are the regulatory signs and by far the biggest group of data collected. The plots of the average unwiped retroreflectivity are located in Figure 4-15, Figure 4-16, Figure 4-17, and Figure 4-18. The dotted lines represent the proposed minimums as stated in Table A-, Table A-5, and Table A-8. As you can see from the graphs the orientation of the sign face does not appear to affect its average retroreflectivity. As shown before in Figure 4-5 samples over 15 years old still have average retroreflectivities well above the proposed retroreflectivity minimums. There are no samples which fall below the proposed minimums probably due to the way the ASTM Type III white sheeting performs.

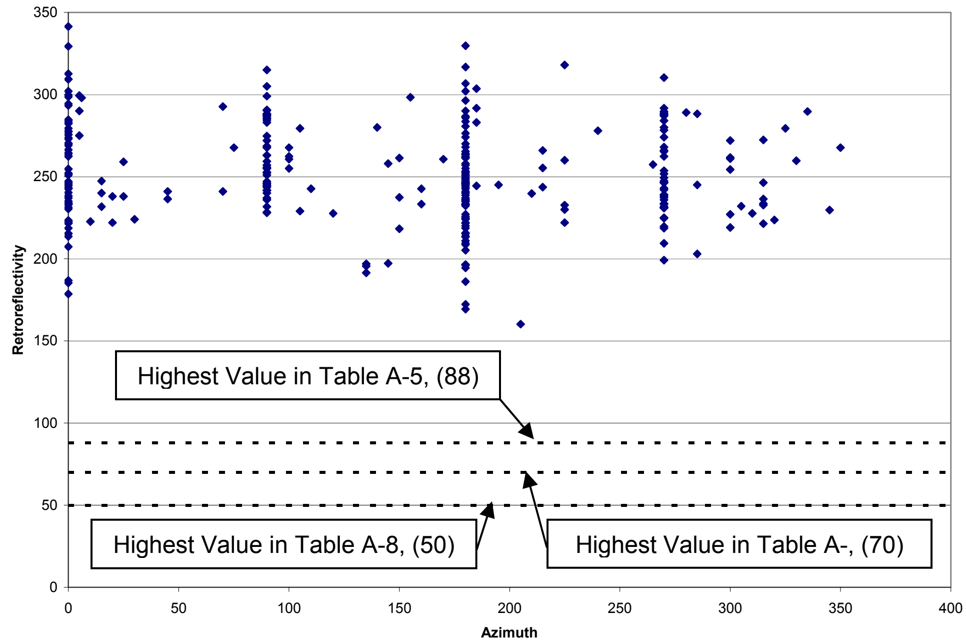


Figure 4-15: White ASTM Type III Background Retroreflectivity versus Azimuth for Age 0 – 5 years Excluding the Crawfordsville Bonepile (n = 332)

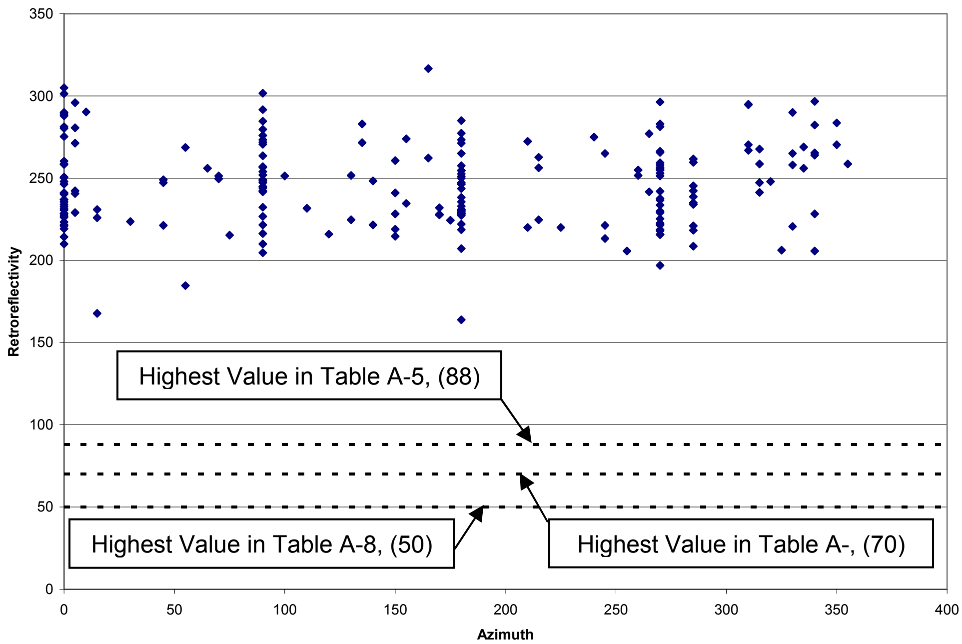


Figure 4-16: White ASTM Type III Background Retroreflectivity versus Azimuth for Age 5 – 10 years Excluding the Crawfordsville Bonepile (n = 212)

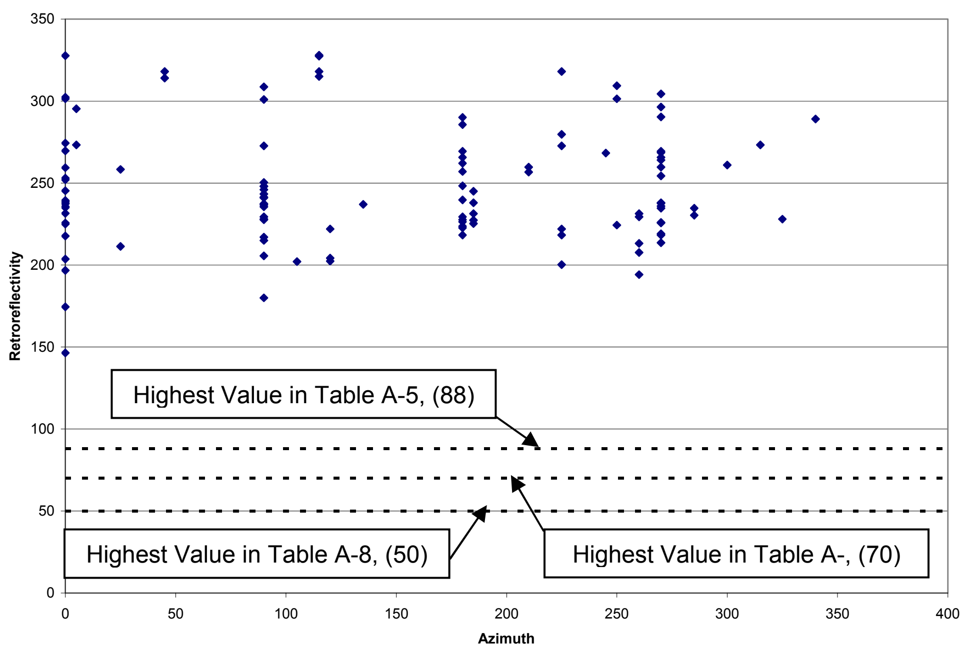


Figure 4-17: White ASTM Type III Background Retroreflectivity versus Azimuth for Age 10 – 15 years Excluding the Crawfordsville Bonepile (n = 118)

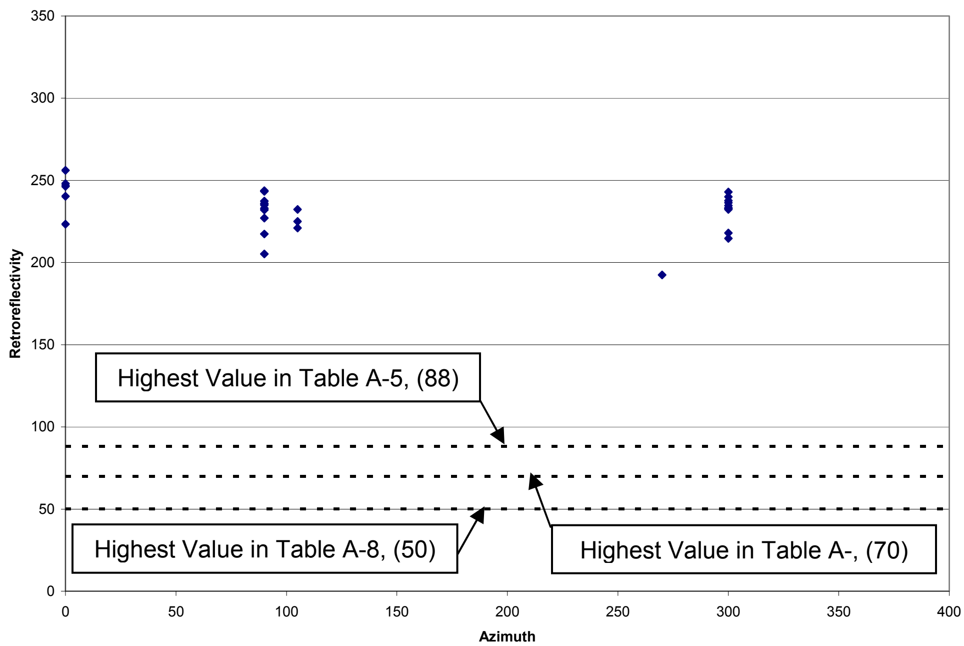


Figure 4-18: White ASTM Type III Background Retroreflectivity versus Azimuth for Age 15+ years Excluding the Crawfordsville Bonepile (n = 31)

4.4.3. Yellow Sheeting Retroreflectivity and Azimuth Analysis

The last azimuth analysis done was on the yellow sheetings. Located in Figure 4-19, Figure 4-20, Figure 4-21, and Figure 4-22 are the graphs of the average unwiped retroreflectivities versus the azimuth. These graphs are broken down into 5 year age groups. The dotted lines on the graphs represent the proposed retroreflectivity minimums located in Table A-3, Table A-, and Table A-8. From these graphs you can see that there is no obvious effect of the sign orientation on the average retroreflectivity. The data is pretty evenly distributed over the entire graph in each case except for the 15 and older graph. In this graph you can see that the average retroreflectivity of the signs has decreased a good amount. Also there are 3 proposed minimum violators in this graph. From all accounts the reason that these signs have such low retroreflectivities is because the sheeting is just too old. For the most part all of these signs have developed dead spots over the majority of face of the sign. A good visual comparison of this is the picture of older signs located in Figure 4-23 with the picture of a new no passing sign located in Figure 4-24. The signs in Figure 4-23 have dead spots which show up at night as dark or black spots on the sign. The newer sign (Figure 4-24) does not have these dead spots.

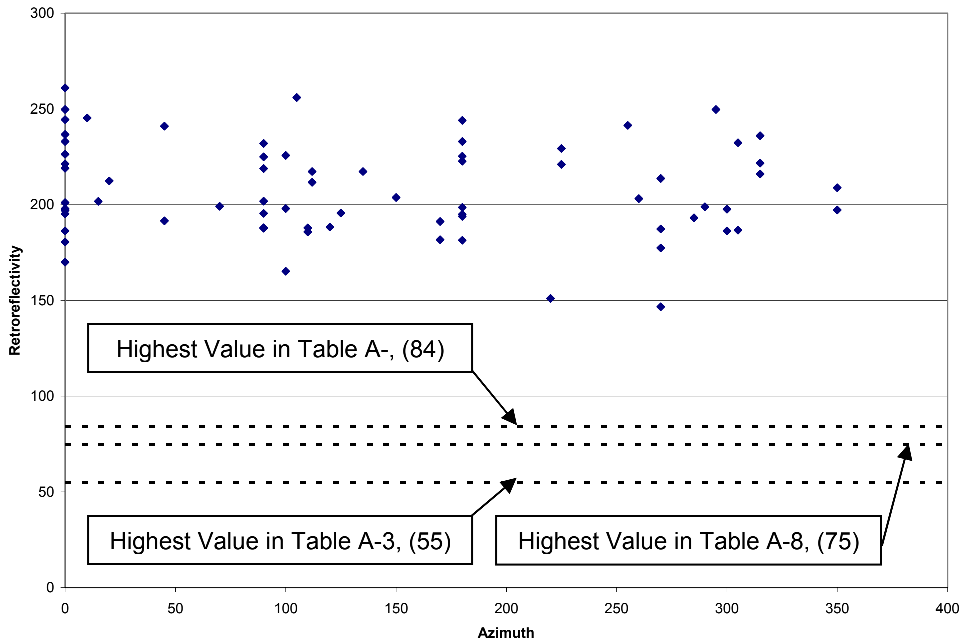


Figure 4-19: Yellow ASTM Type III Background Retroreflectivity versus Azimuth for Age 0 - 5 years Excluding the Crawfordsville Bonepile (n = 72)

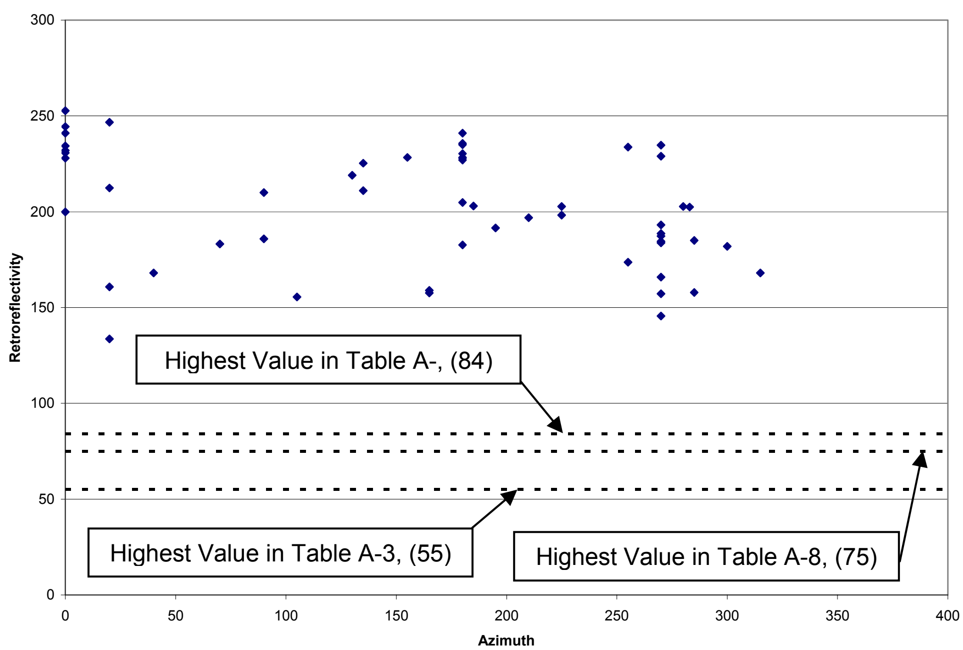


Figure 4-20: Yellow ASTM Type III Background Retroreflectivity versus Azimuth for Age 5 - 10 years Excluding the Crawfordsville Bonepile (n = 55)

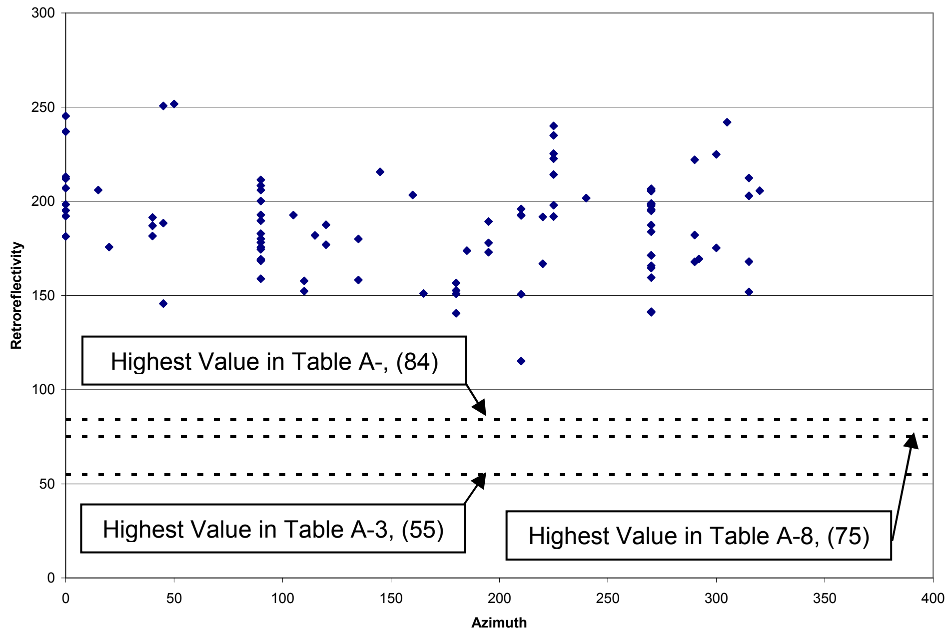


Figure 4-21: Yellow ASTM Type III Background Retroreflectivity versus Azimuth for Age 10 - 15 years Excluding the Crawfordsville Bonepile (n = 98)

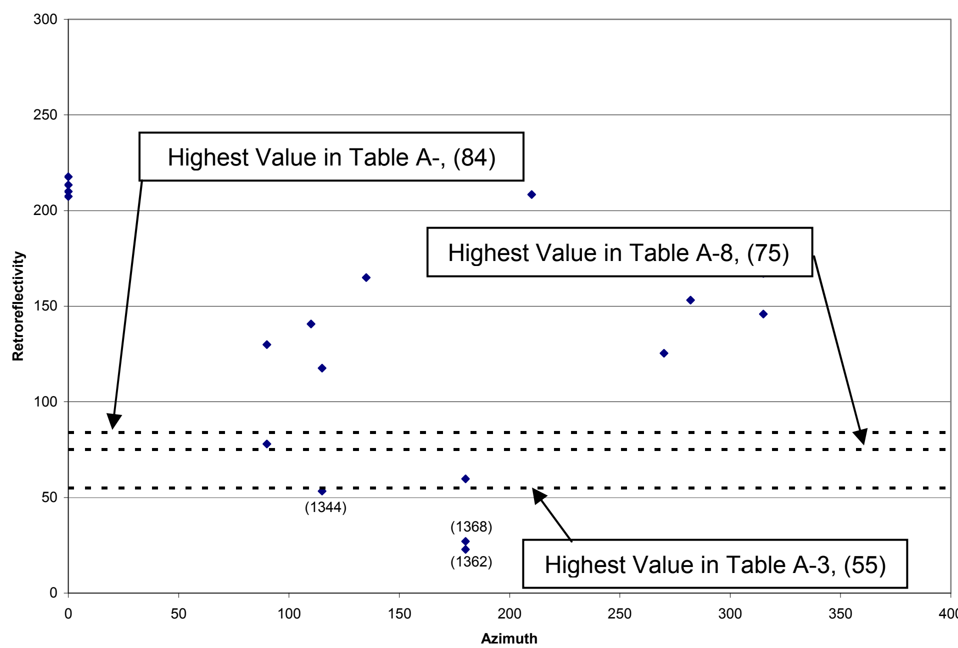


Figure 4-22: Yellow ASTM Type III Background Retroreflectivity versus Azimuth for Age 15+ years Excluding the Crawfordsville Bonepile (n = 18)

Figure 4-23: Simulated Night Picture of Old No Passing Zone Signs

Figure 4-24: Night Picture of a New No Passing Zone Sign Installed July 2001

In all cases the orientation of the sign face does not significantly affect the average retroreflectivity of a sign. However, there is an apparent variability in the retroreflectivity readings for red signs facing in the southern direction. In all cases no signs violated the proposed minimums that were from 0 to 10 years of age. In the case of yellow signs no sign violated the proposed minimums that were less than 15 years of age and for white no signs violated the proposed minimums. Given these results it is safe to assume that the orientation of the sign face does not play a major role in deterioration of the sign face. Also it is plausible that white and yellow signs could be left out longer than they currently are because of their performance in the field.

4.5. 4 to 1 White to Red Ratio Analysis

The 4 to 1 ratio for red and white signs was included in the 2001 proposed minimums as shown in Table A-2. This ratio was put into place to make sure that red and white signs had enough internal contrast so they could be seen at night. Overtime the red overlay used on white signs fades and eventually starts to reflect more light than it is supposed to (Figure 2-4). This ratio was added so that this effect could be captured in a quantitative form. When the retroreflectivity readings on the red start to increase the sign looses the contrast that makes it readable at night because the red is reflecting more light than it should and the face of the sign starts to white out. The authors of the minimums shown in Table A-2 wanted to make sure that signs did not reach this point so they added the 4 to 1 ratio.

In order to see how the signs collected in the field performed to this ratio graphs were done on the data set with and without the Crawfordsville bonepile. The first analysis was done on the data set with out the bonepile to see how signs in the field performed with respect to their age as well as the 4 to 1 ratio. There are two graphs of the same set of data. One is the entire graph with the outliers Figure 4-25 (non-cropped) and Figure 4-26 is the same graph with the outliers removed (cropped) so that a closer view of the data could be obtained. In the graph in Figure 4-25 you can see that there are signs with ratios better than 20 up to almost 100. The reason for these points is that the red retroreflectivity reading is very low and the white retroreflectivity reading is very high. A detailed description of signs with white to red ratios over 20 is located in Table B-9. In all cases where the ratio was above 20 the red retroreflectivity reading is near or below the proposed red retroreflectivity minimums as shown in Table A-2, Table A-6, and Table A-8.

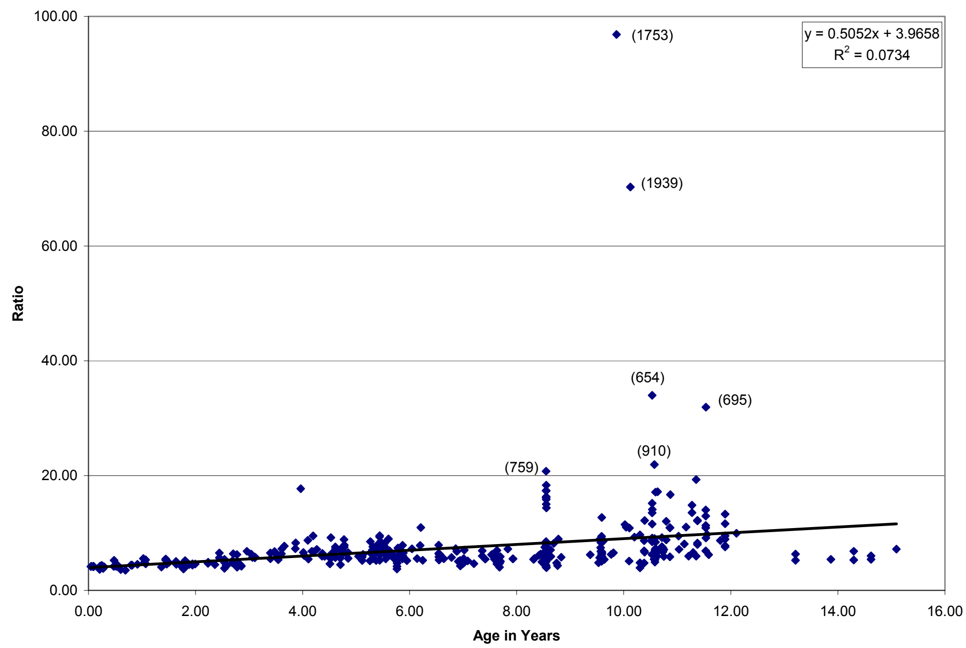


Figure 4-25: Red/White ASTM Type III Ratio versus Age for Unwiped Signs Excluding the Crawfordsville Bonepile (non-cropped) (n = 422)

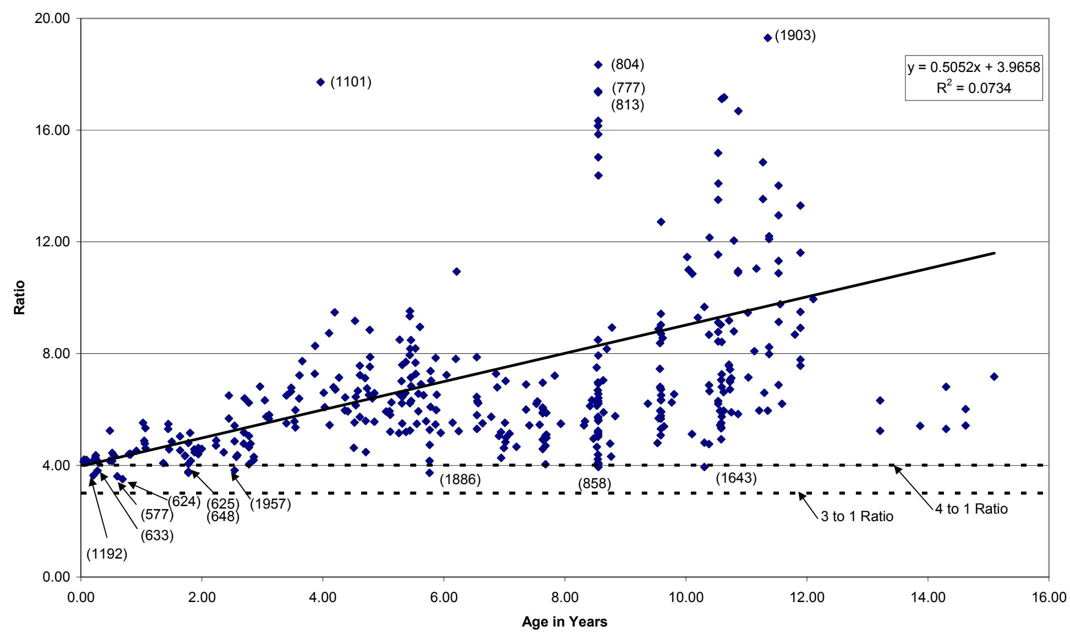


Figure 4-26: Red/White ASTM Type III Ratio versus Age for Unwiped Signs Excluding the Crawfordsville Bonepile (cropped) (n = 422)

In the graph in Figure 4-26 you can see that there is an increasing trend in the white to red ratios. The reason for this trend again is due to the red ink fading over time but the white sheeting performing so well that as the red overlay fades and loses retroreflectivity the white sheeting is not fading thus causing the ratio of white divided by red to increase as the sign ages. The ratio violators are numbered with their sign number on the graph. As you can see most of the violators are between 0 and 3 years of age. The reason for this is thought to be that the red ink used was overlaid too thick thus causing the red retroreflectivity readings to be very low. A list of the retroreflectivity readings for the 4 to1 ratio violators is located in Table B-10. In all cases of signs failing the proposed 4 to 1 ratio the retroreflectivity readings of the red and white retroreflectivities are above the proposed minimums but the red retroreflectivity is too high and the white retroreflectivity is not high enough.

Similar graphs were done on the data including the samples taken from the Crawfordsville bonepile. These graphs are located in Figure B-6 and Figure B-7. In most cases these graphs have the same results except that all of the 4 to 1 ratio violators are located out past 8 years of age. The same reasoning holds for why these signs violate the 4 to 1 ratio as well as why there are signs with ratios greater than 20. For the sample of signs taken in the field that violated the 4 to 1 ratio and had ratios greater than 20, pictures are available in Figure B-3, Figure B-4, and Figure B-5.

Signs that violated the 4 to 1 ratio were removed from the field for closer observation. Since the 4 to 1 ratio has been changed to 3 to 1 in latest version of the proposed retroreflectivity minimums (Table A-8Table A-6) all of the signs sampled will pass the 3 to 1 ratio as most of these signs where technical violations, had a ratio of exactly 4 or slightly below 4, of the 4 to 1 ratio. Also there is some variation in the readings done by different retroreflectometers. A comparison of the readings taken in the field with readings taken from different retroreflectometers is discussed in section 4.7 along with a discussion of how that impacted the 4 to 1 ratio.

Overall the vast majority of the signs observed in the field were above the 4 to 1 ratio. Of the 422 ratios analyzed only 10 signs fell below the 4 to 1 ratio accounting for about 2.4 percent of the entire sample. Because this amount is so small the vast majority of signs would meet the proposed 4 to 1 ratio and over 99 percent of the signs should meet the newest 3 to 1 ratio under normal circumstances.

4.6. Retroreflectivity Range Analysis

The analysis of the range of the retroreflectivity readings shows how the retroreflectivity readings vary over the entire face of a sign. For the most part the retroreflectivity readings from the sign are within 5 to 10 percent of each other. However signs can loose beads from the sheeting causing dead spots in the sign thus causing the uniformity of the sign face to decrease and could cause visibility problems. In order to see this for each of the colors the analysis was done on each of the main colors (red, white, and yellow). For each of the colors a plot of the retroreflectivity range versus the age of the sign was done for both the wiped and unwiped readings. Any signs with high ranges were noted on the graph.

4.6.1. Red Retroreflectivity Range Analysis

The graph of the range of the wiped and unwiped retroreflectivities is located in Figure 4-27. In this graph there is a concentrated section of ranges which are below 10. You can also see that there are some signs with pretty high ranges. Descriptions of the signs with high unwiped and wiped retroreflectivity ranges are located in Table B-11 and Table B-12. As you can see for the most part there really is no visible pattern in the ranges as a sign ages. There are only a few signs with high ranges from 0 to 2 years old as well as 10 years or older. This means that the uniformity of the sign face is for the most part staying the same as the sign ages which means that the sheeting is staying intact. Because the majority of the sign faces are retaining their uniformity as they age the average retroreflectivity taken from a few readings is enough to determine the overall retroreflectivity of the sign face for use in these analyses.

Another interesting point this graph shows is that there is really no significant difference between the wiped and unwiped points. If there would have been a significant difference between the wiped and unwiped ranges then the wiped ranges should be lower then the unwiped but this is not the case as they are about he same excluding some outliers. This suggests that there is no apparent benefit from wiping the sign faces because the uniformity of the sign face has not changed that much to have a major impact on the range of the retroreflectivity readings from the same sign.

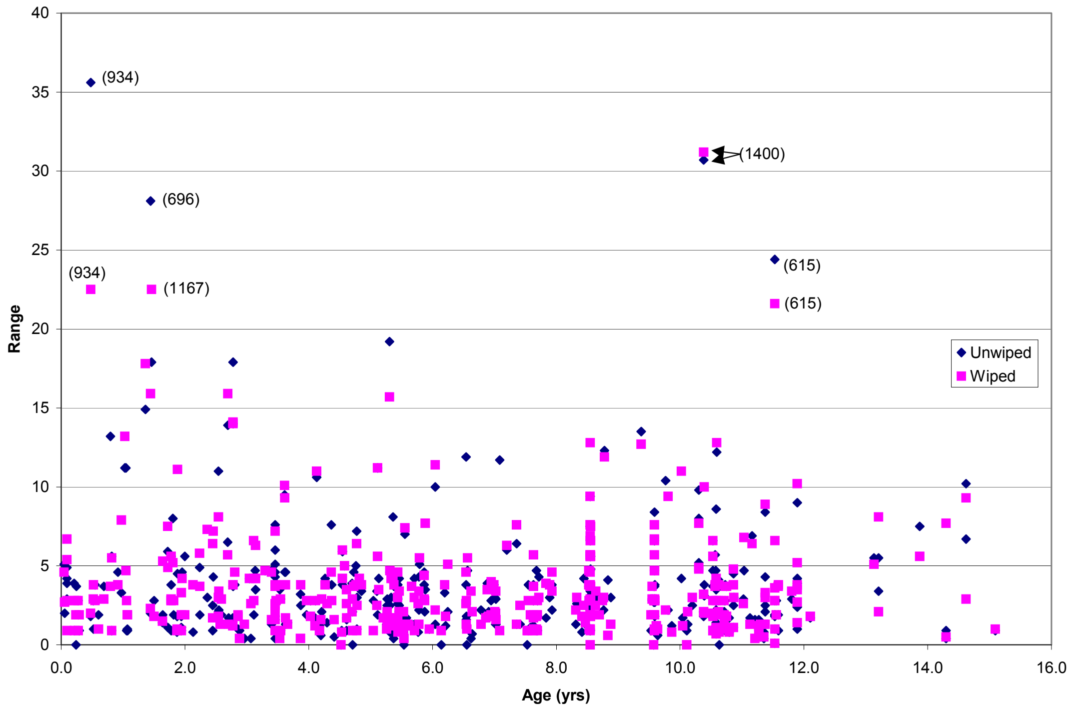


Figure 4-27: Red ASTM Type III Unwiped and Wiped Background Retroreflectivity Range versus Age Excluding the Crawfordsville Bonepile

4.6.2. White Retroreflectivity Range Analysis

The graph for the ranges of the wiped and unwiped retroreflectivities for the white background samples is located in Figure 4-28. From this graph you can see that the white ranges are quite a bit larger but the majority of them are below 50. There are only a few of the signs that have wiped and unwiped retroreflectivity ranges above 50. These points are described in more detail in Table B-13 and Table B-14. Because of the scale of the graph it is hard to accurately see how the retroreflectivity range of the signs change over time but for the most part it appears that the range stays pretty much constant as the signs get older.

As in the previous graph the wiped and unwiped ranges are not very much different. This means that there is really no major benefit from wiping the signs because the range is really not changed as whole very much. However for some of the signs that have high ranges their range is reduced when they are wiped. This could possibly mean that in the case of white signs wiping could increase the consistency of a small percentage of signs.

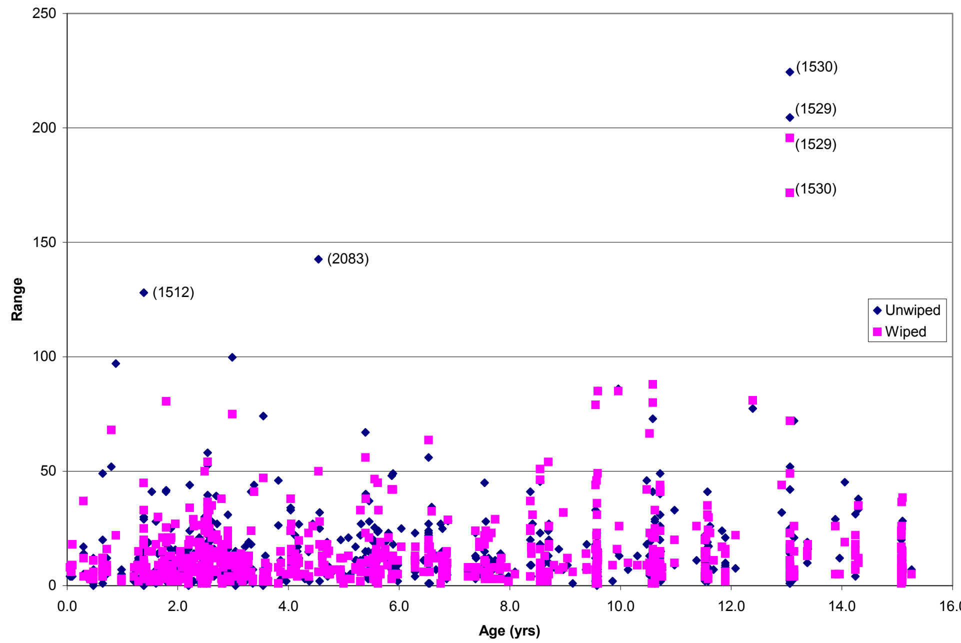


Figure 4-28: White ASTM Type III Unwiped and Wiped Background Retroreflectivity Range versus Age Excluding the Crawfordsville Bonepile

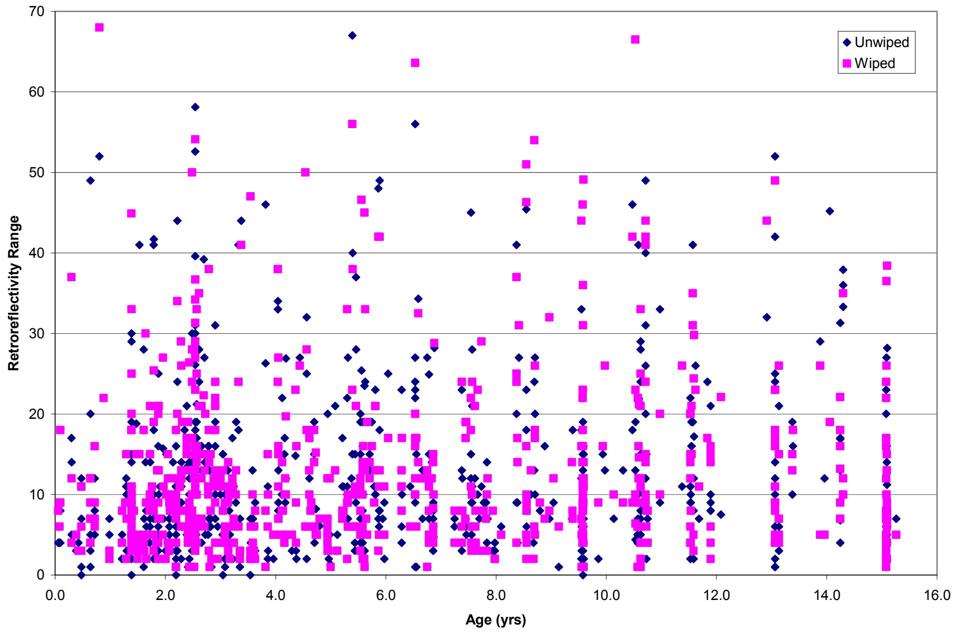


Figure 4-29: White ASTM Type III Unwiped and Wiped Background Retroreflectivity Range versus Age Excluding the Crawfordsville Bonepile (Cropped at 70)

4.6.3. Yellow Retroreflectivity Range Analysis

The last set of data analyzed for the range was the yellow background color. As you can see from the graph in Figure 4-30 the range of retroreflectivity readings are similar to white. All but a few of the signs have ranges less than 50 and the majority have retroreflectivity ranges less than 30. The list of the signs with the highest unwiped and wiped retroreflectivity ranges is located in Table B-15 and Table B-16. Also you can see form this graph is that there is not really a relationship between the retroreflectivity ranges and the age of the sign. However just about all of the signs that are over 15 years of age have high retroreflectivity ranges. This is probably due to the sheeting used to make the sign deteriorating significantly and developing dead spots.

As in the previous two graphs there is really not much of a difference between the wiped and unwiped ranges. This also suggests that there is really no benefit from wiping the yellow signs because there is no major improvement in the retroreflectivity ranges.

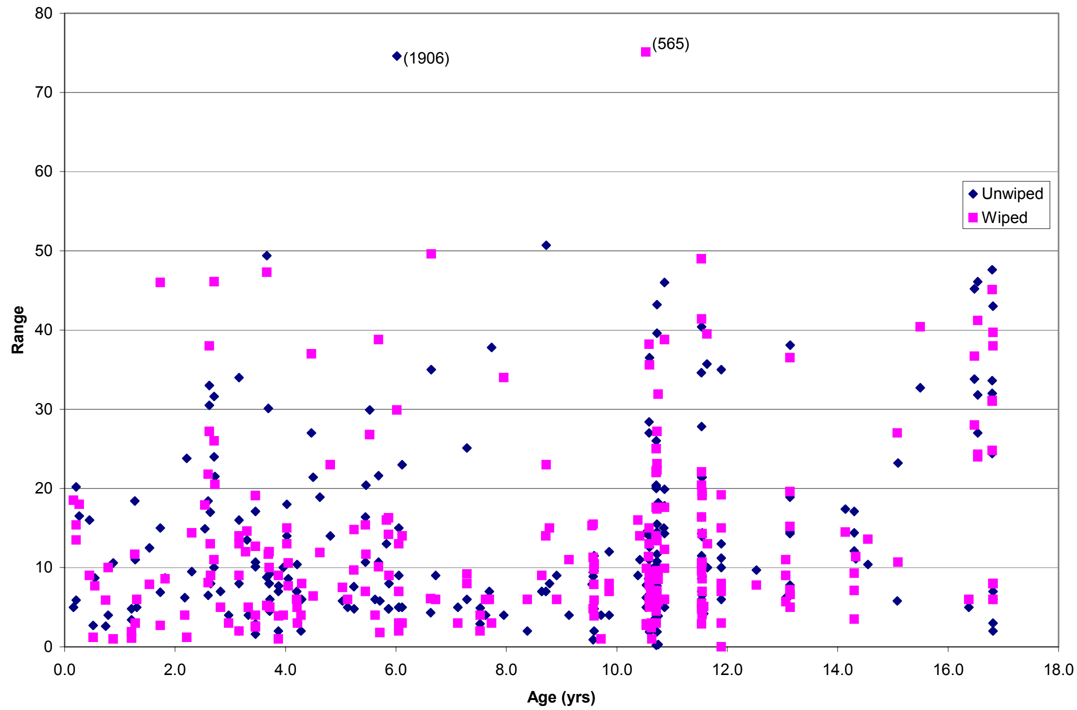


Figure 4-30: Yellow ASTM Type III Unwiped and Wiped Background Retroreflectivity Range versus Age Excluding the Crawfordsville Bonepile

4.7. Retroreflectometer Reading Variability

This section discusses the variability of the different retroreflectometers used in this study. All of the data collected in the field was done using an Advance Retro Technologies 920 (ART 920 SEL) retroreflectometer. However there were some issues with the retroreflectometers due to battery charge or the machine not working properly. In order to fix these problems the retroreflectometer had to be sent back to the manufacturer for repair. During the time that the main retroreflectometer was sent back a loaner had to be used. This loner was assumed to be calibrated and would take the same measurements as the other retroreflectometer with little variation. The same model retroreflectometer (ART 920 SEL) was used for the entire data collection process.

Later in the project we contacted 3M for some sample sheeting to test the retroreflectometer used in the field on new sheeting. 3M sent us 2 sample stop signs made of ASTM Type III sheeting also known as high intensity sheeting. Before 3M sent the sheeting they tested it using an in house retroreflectometer (ART 820). 3M also sent with the sample sheeting retroreflectivity ranges for both the red and white colors on the samples. The reason 3M gave us ranges was because there is some variability among the readings because it is almost impossible to take measurements from the same point every time. These ranges were then compared to the measurements taken using the ART 920 retroreflectometer to see how this model compared to the one used by 3M. Included in Table 4-9 are the readings of the sample sheeting using the ART 920 retroreflectometer. Using the ART 920 we came up with average retroreflectivities for the red sheeting of 44 to 46 and for the white sheeting 271 to 278. The ranges from 3M were 35 to 40 for the sample red sheeting and 305 to 310 for the sample white sheeting. The readings for the red are a little above the range but the readings for the white are low. The reason for this is that the different machines are calibrated using different methods. However, for the samples taken the ART 920 is consistently reading lower than the 3M retroreflectometer.

Because it was found that the retroreflectometer used to take all of the field measurements was reading lower than what the retroreflectivity of the sheeting actually was on the sample sheeting the signs that violated the proposed retroreflectivity as well as the 4 to 1 ratio as shown in section 2 of this chapter and Table B-10 were removed from service and brought in for some testing. In Table 4-9 the signs that violated the proposed retroreflectivity minimums as well as the 4 to 1 white to red ratio are listed with their original in-field measurement, measurements done using a loaner machine from 3M similar to the one used to test the sample materials, and measurements using the ART 920 but taken in August of 2002. This table is a summary table of the measurements taken. The raw measurements are located in Table B-17, Table B-18, and Table B-19.

In the summary table and in the raw data tables you can see that for the majority of the signs tested using the ART 920 had lower retroreflectivities for the white and about the same measurements for the red. This indicates that the ART 920 is consistently reading lower for the white readings than the machine borrowed from 3M. Another interesting point about these tables is that the ratios for the signs taken using the 3M machine do not violate the 4 to 1 ratio. Some of the signs taken with the ART 920 do violate the 4 to 1 ratio in the original field measurements but do not when their measurements were taken again in August. In all cases signs that violated the proposed minimums for the red sheeting did not pass the minimums when measurements were taken with the 3M machine or the ART 920.

Overall there is some difference between the 920 retroreflectometer and the older machine as used by 3M. However there is no major difference between the readings taken by the different ART 920 retroreflectometers. In most cases the ART 920 is reading around the same readings as the older retroreflectometer or below. Because the ART 920 is reading lower than what the sheeting actually is we are getting more conservative retroreflectivity values than the older retroreflectometers. Although we would like to see perfect agreement between measuring devices, we do not believe these discrepancies had an adverse impact because the readings are within 10 percent of the other 920 readings and are lower than the readings given by the 820 retroreflectometer.

Table 4-9: Comparison of retroreflectivity readings of 3M samples and removed signs using the ART 920 and the ART 820 retroreflectometers

		ART 920 in Field			820 in Lab 08/12/02			ART 920 in Lab 08/22/02		
Sign #	**Color**	**Average**	**W:R Ratio**	**4:1 Violator**	**Average**	**W:R Ratio**	**4:1 Violator**	**Average**	**W:R Ratio**	**4:1 Violator**
Sample 1	Red	44	6.2	No	48	6.7	No	44	6.2	No
	White	276			325			276		
Sample 2	Red	46	6.0	No	48	6.8	No	44	6.2	No
	White	278			324			271		
577	Red	62	3.6	Yes	80	4.0	No	77	3.7	Yes
	White	223			322			282		
624	Red	60	3.5	Yes	67	4.1	No	68	3.7	Yes
	White	210			277			253		
625	Red	56	3.8	Yes	67	4.7	No	63	4.3	No
	White	211			315			271		
633	Red	59	3.8	Yes	69	4.4	No	68	3.9	Yes
	White	223			301			267		
648	Red	54	3.7	Yes	67	4.7	No	64	4.2	No
	White	203			314			270		
654	Red	5	34.0	No	6	49.8	No	3	68.8	No
	White	179			274			238		
759	Red	11	20.8	No	9	30.7	No	8	32.6	No
	White	226			276			247		
910	Red	9	30.2	No	10	31.5	No	8	33.5	No
	White	264			309			268		
1192	Red	67	3.6	Yes	70	4.2	No	68	3.8	Yes
	White	244			292			254		
1362	Yellow	23	N/A	N/A	36	N/A	N/A	24	N/A	N/A
	Black	-			-			-		
1368	Yellow	27	N/A	N/A	49	N/A	N/A	41	N/A	N/A
	Black	-			-			-		
1643	Red	59	3.9	Yes	57	4.4	No	58	3.9	Yes
	White	233			251			224		
1753	Red	3	96.8	No	4	72.4	No	2	133.9	No
	White	255			304			254		
1939	Red	4	70.3	No	5	54.5	No	4	67.8	No
	White	255			289			244		
1957	Red	60	3.8	Yes	64	4.7	No	60	4.4	No
	White	228			302			261		

4.8. Concluding Remarks

This chapter discussed the data analyses done on the ASTM Type III sheeting data collected in the field. From these analyses we found that the vast majority of the signs analyzed in the field are above the proposed retroreflectivity minimums. Out of all the data analyzed only 7 of the signs fell below the most conservative retroreflectivity minimum for any of the colors. Also the vast majority of the red and white signs have white to red ratios above the recently removed 4 to 1 ratio.

Also in this chapter it was shown that wiping a sign does not significantly affect the retroreflectivity of the sheeting or the range of retroreflectivity readings from the same sign. Also from the analyses we found that taking the average of the retroreflectivity readings does cover up if a sign has a dead spot but for the most part the averages do represent the overall retroreflectivity of the sign fairly well.

It was initially thought that red signs facing the southern direction would loose retroreflectivity faster than signs facing other directions. However, this was not supported by the t-tests done on the data.

It was also thought that as a sign ages it looses significant retroreflectivity. However this is generally not true as there is no real link between the age and the retroreflectivity readings of white and yellow. There is a much more apparent downward trend in the retroreflectivity of red signs as the signs age. This trend is not very strong as there was only a 33 percent correlation between the age and the average retroreflectivity of the sign. However from this analysis it was found that the majority of signs that had white and yellow backgrounds kept retroreflectivity levels above the proposed minimums out past 15 years of age. Because of this it is possible that these signs could be left out in the field longer than they currently are and could save INDOT money in life cycle costs.

Finally in this chapter it was determined that there are some differences between the ART 920 and ART 820 retroreflectometers used to collect the data in the field. However in all cases the ART 920 had retroreflectivity readings at or below the older model meaning that the readings taken using the ART 920 are more conservative.

CHAPTER 5. CONCLUSIONS & RECOMMENDATIONS

This chapter includes summary results of the findings from this study. The chapter also discusses how the findings relate to the proposed FHWA retroreflectivity minimums and if Indiana will be in compliance with the minimums when they are put in place. This chapter also discusses the 4 to 1 ratio that was in the 2001 proposed minimums but has been removed in the preliminary 2002 minimums. Finally, this chapter discusses INDOT's current replacement procedure and if and how the current replacement procedures can be changed to meet the proposed minimums as well as save the state of Indiana money in life cycle costs.

5.1. Proposed FHWA Retroreflectivity Minimums

Given the data analyses performed on the data collected from the field the vast majority of the signs are expected to meet the proposed retroreflectivity minimums with no change in the current replacement policy. Given that a very small percentage of the sample taken violated the most conservative minimums for each of the color categories over 98% of the signs in the field under normal circumstances should not only meet but exceed the proposed retroreflectivity minimums for any speed or size sign. In the proposed minimums are different requirements for different size and speeds for each color group. We have found that this needlessly complicates field inspection because the majority of the signs pass the most conservative minimums for each of the color groups regardless of sign size or posted speed. This result is similar to the results found in Nuber and Bullock's study done on the data collected from the Crawfordsville Bonepile (Nuber, 2001). In that study they found that only 4% of the signs sampled fell below the most conservative minimums for each of the color groups.

5.2. White to Red Ratio Requirement

As of October 2002 this requirement as stated in the 2001 proposed retroreflectivity minimums located in Table A-2 has been reduced. The reason for the reduction is not yet known as the report from the Texas Transportation Institute is still under review and will not be published until the annual meeting of the Transportation Research Board in January 2003. In this draft report published in October the white to red ratio has been reduced from 4 to 1 to 3 to 1. This change in the ratio does not impact this study because the vast majority of the red and white signs passed the 4 to 1 ratio and all of the signs sampled pass the proposed 3 to 1 ratio.

The majority of the signs with red backgrounds and white legends will meet the 4 to 1 ratio requirement. The main reason is that the performance of the brand new white ASTM Type III sheeting is so good that for the most part the retroreflectivity does not change as the sign ages. The only color that really will change in these signs is the red overlay because it fades over time. The 4 to 1 ratio is there to keep the signs from losing too much of the internal contrast which makes the sign visible at night. However, from this analysis it was shown that most of the signs met the 4 to 1 ratio. This ratio is a good idea but we think that the ratio, while still in effect, was too high. The majority of the signs that were sampled that failed the 4 to 1 ratio did so due to being right at the 4 to 1 or slightly below. Of the signs removed from the field due to ratio violations, as shown in Table B-10, most were at or below the 4 to 1 ratio and from visual tests done on the signs they performed well. Any changes to the ratio that are less than 4 to 1 will not affect the compliance of signs in the State of Indiana. However, if the ratio is ever increased above this 4 to 1 ratio then the data will have to be reanalyzed to see what percentage of signs would violate the higher ratio. If the newly proposed 3 to 1 ratio is instituted over 99 percent of the sign population in the state should meet this requirement given the observed performance of the sampled signs.

5.3. INDOT Sign Replacement Procedures

Currently INDOT districts replace traffic signs in a ten year cycle. This is done using one of two methods. The first is done by replacing signs as sections of highways and interstates are repaved. The other is done based on inspection of the signs age. Both of these methods have their pros and cons but the replacement due to inspection is the best way to go as far as safety and cost is concerned. From the research done on this subject we feel that the best way to check a sign for replacement is to use a night observation technique. This allows trained personnel to travel at night time when the signs are most needed and make sure that they are adequate for use in the field. Unlike using a retroreflectometer at night one can see the how the entire face of the sign performs and be able to catch dead spots on the sign face. Also unlike using a retroreflectometer this method is not as cost or labor intensive.

It is also possible to be able to save the state of Indiana money in terms of cost and labor of replacing signs that have reached the 10 year limit. From the analyses done it is possible that the life cycle of traffic signs with white and yellow backgrounds can be safely extended for at least two years to 12 years. The reason for this is the performance that we are seeing from the yellow and white sheeting (Figure 4-9 and Figure 4-5). There were signs sampled which had retroreflectivity minimums way above the proposed minimums and were 13 to 15 years of age. If signs are performing this well this far into their life then it is possible to leave the signs out for 12 years or possibly even longer. Red, however, should not be left out in the field for longer than 10 years because the red coloring at that point has faded too much and the internal contrast of the sign starts to become an issue. The sign may still have a white to red ratio greater than the required ratio but if the white sheeting on the sign retains most of its retroreflectivity then the red may have a high enough retroreflectivity to cause the sign to white out and not be adequate for night time use.

It is possible to leave the yellow and white sheetings out longer than they currently are saving the state money in sheeting costs. It may also be possible to leave signs with white and yellow backgrounds out in the field longer than 12 years after the 12-year cycle has been implemented and analyzed.

5.4. Estimated Sheeting and Labor Cost Savings

Because of the proposed extension in the life cycle of signs with white and yellow backgrounds there will be a savings in both material and labor costs from this increase. The cost estimate for just signs with white and yellow backgrounds is tricky because the major cost of the sheeting is not the color but the size of the sign. The size of the sign determines how much sheeting you use. In order to come up with an estimate certain assumptions had to be made. There were 9918 yellow and white background signs replaced in 2001 with 99,180 white and yellow signs will be replaced over a 10 year cycle assuming replace 1/10th of the signs are replaced every year. The cost analysis performed shown in Table 5-1 shows $214,548 spent in 2001 on materials replacing white and yellow background signs. Assuming this is an average yearly replacement cost and an average number of signs replaced each year the cost comes out to $214,548 every year replacing 1/10th of the white and yellow background signs in the state or $1.7 million present worth for a ten year cycle assuming a 4.5% interest rate and no inflation.

Interest Rate: 4.5% (No Inflation)
Estimated Annual Cost (Table 5-1): $214,548

Estimated Present Worth: PW = $214,548 (P/A, 10, 4.5%) = $1,697,658

We now assume that the same number of signs will be replaced in a 12-year cycle as in a 10-year cycle so there is really no change in the number of signs replaced overall just a decrease in the number of signs replaced each year. To be exact it is 1/12th of the signs instead of 1/10th. Using this assumption and the present worth it is assumed that the overall cost will not change in a 12-year cycle meaning that it will cost the same for a 10-year replacement cycle as it would for a 12-year replacement cycle. Using the present worth an annual cost of $186,176 was estimated for a 12-year cycle. Taking the estimated yearly cost for a 12-year cycle and subtracting the estimated yearly cost for a 10-year cycle there is a difference of $28,372. The difference in these costs is the annual savings of the 12-year cycle over the 10-year cycle for signs with white and yellow backgrounds.

Estimated Annual Cost (10-Year Cycle): $214,548
Estimated Annual Cost (12-Year Cycle): A = $1,697,658 (A/P, 12, 4.5%) = $186,176
Difference Between Annual Costs: $28,372

The other factor in the cost savings is the labor costs. From the summary table in Table 1-1 there were 14,930 signs replaced at a labor cost of $1,067,931. Using the same assumptions as before on the number of signs replaced and the overall cost being constant it was estimated that it costs $736,017 annually in labor to replace signs with white and yellow backgrounds and $5,823,895 over the entire 10-year cycle.

Interest Rate: 4.5% (No Inflation)
Estimated Annual Cost: $736,017
Estimated Present Worth: PW = $736,017 (P/A, 10, 4.5%) = $5,823,895

Estimated Annual Cost (10-Year Cycle): $736,017
Estimated Annual Cost (12-Year Cycle): A = $5,823,895 (A/P, 12, 4.5%) = $638,684
Difference Between Annual Costs: $97,333

From these results it is estimated that $28,372 in material costs and $97,333 in labor costs would be saved annual by implementing a 12-year cycle on signs with white and yellow backgrounds. This results in an estimated $125,705 in overall annual savings in using the 12-year cycle over the current 10-year cycle.

Table 5-1: Estimated Yearly Material Replacement Cost for White and Yellow Signs

Estimated Yearly White and Yellow Background Sign Material Cost								
Sign Size	12"	15"	18"	24"	30"	36"	48"	Total
Percentage of Yellow and White Signs from Data Sample	0.00%	0.00%	14.71%	38.49%	8.42%	33.58%	4.80%	100.00%
Estimated White and Yellow Signs Replaced in 2001	0	0	1514	3960	867	3456	494	10290
Sheeting Cost per ft^2	$1.66	$1.66	$1.66	$1.66	$1.66	$1.66	$1.66	N/A
Average ft^2 per sign	1.00	1.56	2.25	4.00	6.25	9.00	16.00	N/A
Average Sheeting Cost per Sign	$1.66	$2.59	$3.74	$6.64	$10.38	$14.94	$26.56	N/A
Estimated Sheeting Cost for New Signs in 2001	$0	$0	$5,654	$26,295	$8,991	$51,625	$13,111	$105,677
Alum. Backing Type	080	080	110	110	110	125	125	N/A
Cost per ft^2	$1.31	$1.31	$1.41	$1.41	$1.41	$1.90	$1.90	N/A
Average ft^2 per sign	1.00	1.56	2.25	4.00	6.25	9.00	16.00	N/A
Average Cost per Sign	$1.31	$2.05	$3.17	$5.64	$8.81	$17.10	$30.40	N/A
Estimated Alum. Backing Cost for New Signs in 2001	$0	$0	$4,803	$22,335	$7,637	$59,089	$15,007	$108,871
Estimated Yearly Sign Replacement Material Cost	$0	$0	$10,457	$48,630	$16,628	$110,715	$28,118	**$214,548**

LIST OF REFERENCES

LIST OF REFERENCES

ASTM Standards on Color and Appearance Measurement, American Society for Testing and Materials. Philadelphia, Pennslyvannia, Forth Edition 1994.

Austin, RL., Woltman, HL., "Evaluation of Headlamp Systems for Nighttime Safety: Their Relationship to Retroreflective Traffic Sign Performance," Transportation Research Record #1149, Transportation Research Board, Washington, DC, 1987, pp. 11-14.

Awadallah, FI., "Prediction of the Service Life of Warning Signs," Public Roads Vol. 51 Issue 4, Publisher, 1988, pp. 116-122.

Black, KL., McGee, HW., Hussain, SF., "Implementation Strategies for Sign Retroreflectivity Standards," NCHRP Report #346, Publisher, 1992.

Black, KL., Hussain, SF., Paniati, JF., "Deterioration of Retroreflective Traffic Signs," ITE Journal Vol. 62 Issue 7, Publisher, 1992, pp.16-22.

Carlson, P.J., Hawkins, H.G., Schertz, G., Mace, D. and Opiela, K., "Developing Updated Minimum In-Service Retroreflectivity Levels for Traffic Signs," Proceedings from TRB Annual Meeting, Washington, D.C., January 2003.

Chalmers, SW., "Retroreflective Sign Sheeting Issues and Considerations," Transportation Frontiers for the Next Millennium: 69th Annual Meeting of the Institute of Transportation Engineers (CD-006), Publisher, 1999.

Coulomb, M., and Michaut, G., "Reflectivity Road Signs: Visibility at Night," Transport Research Record 1093, Transportation Research Board, Washington, DC, 1986, pp. 58-65.

Federal Highway Administration., "Minimum Sign Retroreflective Guidelines. Summary Report," Research Project FHWA-RD-97-074, Federal Highway Administration, 1997.

Federal Highway Administration., Preliminary 2002 Minimum Retroreflectivity Values, Federal Highway Administration, 2002.

FHWA Safety Core Business Unit., Minimum Maintained Retroreflectivity Guideline Status, Federal Highway Administration, February, 2001.

Flintsch, GW., "Review of Retroreflective Sign Sheeting Materials, Practices, and Policies. Final Report," Research Project FHWA/AZ-SP93/04, Federal Highway Administration, 1993.

Hawkins, HG, Jr., Carlson, PJ., "Sign Retroreflectivity: Comparing Results of Nighttime Visual Inspections with Application of Minimum Retroreflectivity Values," Transportation Research Record #1754, Transportation Research Board, Washington, DC, 2001, pp. 11-20.

Kirk, AR., Hunt, EA., Brooks, EW., "Factors effecting sign retroreflectivity," Research Project OR-RD-01-09. Oregon Dept. of transportation, 2001.

Lagergren, EA., "Traffic Sign Retroreflectivity Measurements Using Human Observers. Final Report," Research Project WA-RD 140.1, Washington State Department of Transportation, 1987.

Lumia, JJ., "Mobile System for Measuring the Retroreflectance of Traffic Signs," Transportation Research Record #1247, Transportation Research Board, Washington, DC, 1989, pp. 69-78.

Mace, D., and Pollack, L., Visual Complexity and Sign Brightness in the Detection and Recognition of Traffic Signs, Institute for Research, State College, PA, 1983.

McGee, HW., and Paniati, JA., "An Implementation Guide for Minimum Retroreflectivity Requirements for Traffic Signs," Research Project FHWA-RD-97-052, Federal Highway Administration, 1998.

McGee, HW., and Taori, S., "Impacts on State and Local Agencies for Maintaining Traffic Signs within Minimum Retroreflectivity Guidelines," Research Project FHWA-RD-97-053, Federal Highway Administration, 1998.

Mercier, CR., Goodspeed, C., Simmons, CJ., Paniati, JF., "Evaluation of Proposed Minimum Retroreflectivity Requirements for Traffic Signs," Transportation Research Record #1495, Transportation Research Board, Washington, DC, 1995, pp. 57-67.

Montebello, D., and Schroeder, J., "Cost Effectiveness of Traffic Sign Materials," Research Project MN/RC-2000-12, Minnesota Department of Transportation, 2000.

Mounce, JM., and Ulberg, MA., "Impact Assessment of Revised Retroreflectivity Requirements for the State of Montana – Phase I – Final Report," Research Project FHWA/MT-95/8117-1, Federal Highway Administration, 1995.

Nuber, L., and Bullock, D., "Comparison of Observed Retroreflectivity Values with Proposed FHWA Minimums," Purdue University, 2001

Olson, PL., "Minimum Photometric Properties of Retroreflective Signs," Transportation Research Record #1247, Transportation Research Board, Washington, DC, 1989, pp. 56-68.

Panitai, JF., and Mace, DJ., "Minimum Retroreflectivity Requirements for Traffic Signs," Research Project FHWA-RD-93-077, Federal Highway Administration, 1993.

Paniati, JF., and Schwab, RN., "Research on the End of Life for Retroreflective Materials: A Progress Report, "Transportation Research Record #1316, Transportation Research Board, Washington, DC, 1991, pp. 13-17.

Taori, S., and McGee, HW., "Impacts of Maintaining Traffic Signs within Minimum Retroreflectivity Guidelines," Transportation Research Record #1650, Transportation Research Board, Washington, DC, 1998, pp. 19-27.

Wolshon, B., and Degeyter, R., "Performance of Traffic Sign Retroreflectivity," IMSA (International Municipal Signal Association) Journal Vol. 38 Issue 4, Publisher, 2000.

APPENDICIES

APPENDIX A. PROPOSED RETROREFLECTIVITY MINIMUMS

Table A-1: FHWA Recommended Retroreflectivity Minimums for Legend Color Black and/or Black and Red with Background Color White

Traffic Speed:	45 mi/h or greater			40 mi/h or less		
Sign Size:	>=48	30-36-in	<=24-in	>=48-in	30-36-in	<=24-in
I	25	35	45	20	25	30
II	30	45	55	25	30	35
III	40	55	70	30	40	45
IV & VII	50	70	90	40	50	60

All table values in $cd/lx/m^2$

Table A-2: FHWA Recommended Retroreflectivity Minimums for Legend Color White with Background Color Red

Traffic Speed:	45 mi/h or greater						40 mi/h or less					
Sign Size:	>=48-in		36-in		<=30-in		>=48-in		36-in		<=30-in	
Color:	W	R	W	R	W	R	W	R	W	R	W	R
All Signs:	35	8	45	8	50	8	25	5	30	5	35	5

All table values in $cd/lx/m^2$

Note: Since both the legend and the background of these signs is retroreflectorized a minimum maintained **contrast ratio of 4:1** has also been established. If the retroreflectivity value for either the white or red material falls below the value specified in the table or **if the retroreflectivity of the white material divided by the retroreflectivity of the red material is less than four, the sign should be replaced**.

Table A-3: FHWA Recommended Retroreflectivity Minimums for Legend Color Black with Background Color Yellow or Orange

Legend	Sign Size:	>=48-in	36-in	<=30-in
	Material Type			
Bold Symbol*	ALL	15	20	25
Fine Symbol & Word	I	20	30	35
	II	25	35	45
	III	30	45	55
	IV & VII	40	60	70

All table values in $cd/lx/m^2$

* Warning signs with bold symbols:

MUTCD Code	Sign Type	MUTCD Code	Sign Type
W1-1	Turn	W3-la	Stop Ahead
W1-2	Curve	W3-2a	Yield Ahead
W1-3	Reverse Turn	W3-3	Signal Ahead
W1-4	Reverse Curve	W4-1	Merge
W1-5	Winding Road	W4-2	Lane Reduction
W1-6	Large Arrow	W 4-3	Added Lane
W1-7	Double Head Arrow	W6-1	Divided Highway Begins
W1-8	Chevron	W6-2	Divided Highway Ends
W2-1	Cross Road	W6-3	Two-Way Traffic
W2-2	Side Road	W8-S	Slippery When Wet
W2-4	T Intersection	W 11-2	Advance Pedestrian Crossing
W2-5	Y Intersection	W 11A-2	Pedestrian Crossing
W20-7a	Flagger Ahead		

Table A-4: August 2002 Preliminary Retroreflectivity Minimums for Legend Color Black with Background Color Yellow or Orange

Position	Type	Sign Size	I	II	III	VII	VIII	IX
Right Shoulder	Text	<=36"	48	66	84	107	98	28
		>=48"	29	40	51	65	60	17
	Symbol - Bold	Any	34	47	60	76	70	20
	Symbol - Fine		*	151	192	244	224	63
All table values in cd/lx/m^2								
* Denotes a Missing Value								

Table A-5: August 2002 Preliminary Retroreflectivity Minimums for Legend Color Black and/or Black and Red with Background Color White

Size	Spd	I	II	III	VII	VIII	IX
<=24"	70	33	33	33	34	28	25
	55	39	43	43	52	38	26
	45	63	80	84	107	84	38
	35	31	45	62	77	47	19
	25	42	46	88	337	200	41
30-36"	70	27	27	27	28	23	21
	55	31	34	35	41	30	21
	45	49	61	65	82	64	29
	35	31	45	62	77	74	19
	25	42	46	88	337	200	41
>=48"	70	25	25	25	26	21	19
	55	26	29	29	34	25	17
	45	49	61	65	82	64	29
	35	31	45	62	77	74	19
	25	42	46	88	337	200	41
All table values in cd/lx/m^2							

Table A-6: August 2002 Preliminary Retroreflectivity Minimums for Legend Color White with Background Color Red

Traffic Speed	>=45 mph		<=40 mph	
Sign Size	ANY		ANY	
Portion of Sign	White	Red	White	Red
2002 Values	40	8	30	6
All table values in cd/lx/m^2				
Note: The 4:1 ratio has been removed.				

Table A-7: ASTM Retroreflectivity Requirements for New Sheeting

	Color	I	II	III	VII	VIII	IX
ASTM 4956-01a	White	70	140	250	750	700	380
	Yellow	50	100	170	560	525	285
	Orange	25	60	100	280	265	145
	Green	9	30	45	75	70	38
	Red	14	30	45	150	105	76
	Blue	4	10	20	34	42	17
	Brown	1	5	12	N/A	21	N/A
All table values in cd/lx/m^2							

Table A-8: October 2002 Preliminary Retroreflectivity Minimums (Carlson, 2003)

Sign Color	Criteria	Sheeting Type (ASTM D4956-01a) (5)					
		I	II	III	VII	VIII	IX
White on Red	See Note ①	35 // 7					
Black on Orange or Yellow	See Note ②	*	50				
	See Note ③	*	75				
Black on White		50					
White on Green	Overhead	* // 7	* // 15	* // 25	250 // 25		
	Shoulder	* // 7	120 // 15				

NOTE: Values in cells represent legend retroreflectivity // background retroreflectivity (for positive contrast signs). Units are cd/lx/m^2 measured at an observation angle of 0.2° and an entrance angle of -4.0°.

① Minimum Contrast Ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity).
② For any bold symbol sign and text signs measuring 48 inches or more.
③ For any fine symbol sign and text signs measuring less than 48 inches.
* Sheeting Type should not be used.

Bold Symbol Signs

- W1-1 – Turn
- W1-2 – Curve
- W1-3 – Reverse Turn
- W1-4 – Reverse Curve
- W1-5 – Winding Road
- W1-6 – Large Arrow (One direction)
- W1-7 – Large Arrow (Two directions)
- W1-8 – Chevron
- W1-9 – Turn & Advisory Speed
- W1-10 – Horizontal Alignment & Intersection
- W2-1 – Cross Road
- W2-2, W2-3 – Side Road
- W2-4 – T Intersection
- W2-5 – Y Intersection
- W2-6 – Circular Intersection
- W3-1a – Stop Ahead
- W3-2a – Yield Ahead
- W3-3 – Signal Ahead
- W4-3 – Added Lane
- W6-1 – Divided Highway Begins
- W6-2 – Divided Highway Ends
- W6-3 – Two-Way Traffic
- W10-1, -2, -3, -4 – Highway-Railroad Intersection Advance Warning
- W11-2 – Pedestrian Crossing
- W11-3 – Deer Crossing
- W11-4 – Cattle Crossing
- W11-5 – Farm Equipment
- W11-5p, -6p, -7p – Pointing Arrow Plaques
- W11-8 – Fire Station
- W11-10 – Truck Crossing
- W12-1 – Double Arrow

Special Case Signs

- W3-1a – Stop Ahead
  - Red retroreflectivity ≥ 7, White retroreflectivity ≥ 35
- W3-2a – Yield Ahead
  - Red retroreflectivity ≥ 7, White retroreflectivity ≥ 35
- W3-3 – Signal Ahead
  - Red retroreflectivity ≥ 7, Green retroreflectivity ≥ 7
- W14-3 – No Passing Zone
  - Use dimension B in *Standard Highway Signs*, (2002 Edition)
- W4-4p – Cross Traffic Does Not Stop
  - Use dimension A in *Standard Highway Signs*, (2002 Edition)
- W13-2, -3, -1, -5 – Ramp & Curve Speed Advisory Plaques
  - Use dimension B in *Standard Highway Signs*, (2002 Edition)

APPENDIX B. DATA ANALYSIS GRAPHS AND TABLES

Table B-1: Low Retroreflectivity for Red ASTM Type III Signs

Background Color	Observation #	Age in Yrs.	Unwiped Average	Azimuth	Sign Flagged
Red	654	10.5	5	180	Yes
	695	11.5	7	180	Replaced
	1753	9.9	3	180	Yes
	1939	10.1	4	160	Yes
Violation for Red ASTM Type III is less than or equal to a retroreflectivity of 8.					

a) Observation #1753

b) Observation #1939

c) Observation #654

d) Observation #695 has been replaced as of 04/20/2002

Figure B-1: Pictures of Low Retroreflectivity Red ASTM Type III Signs

Table B-2: Low Retroreflectivity for Unwiped Red ASTM Type III Background Color

Observation #	Age	Reading			Range
		1	2	3	
615	11.5	6	30	30	24
654	10.5	6	5	6	1
695	11.5	8	7	8	1
910	10.6	10	8	8	3
1753	9.9	2	3	3	1
1939	10.1	4	3	4	1

Table B-3: Low Retroreflectivity for Wiped Red ASTM Type III Background Color

Observation #	Age	Reading			Range
		1	2	3	
654	10.5	7	5	6	2
695	11.5	8	7	7	1
804	8.5	10	8	13	6
1753	9.9	3	3	3	1
1939	10.1	4	3	5	2

Table B-4: Low Retroreflectivity for Unwiped White ASTM Type III Background Color

Observation #	Age	Reading			Range
		1	2	3	
1529	13.1	23	188	228	205

Table B-5: Low Retroreflectivity for Wiped White ASTM Type III Background Color

Observation #	Age	Reading			Range
		1	2	3	
1529	13.1	23	183	219	196

Table B-6: Low Retroreflectivity for Yellow ASTM Type III Signs

Background Color	Observation #	Age in Yrs.	Unwiped Average	Azimuth	Sign Flagged
Yellow	1344	16.8	53	115	Replaced
	1362	16.8	23	180	Yes
	1368	16.8	27	180	Yes
Violation for Yellow ASTM Type III is less than or equal to a retroreflectivity of 55.					

a) Observation #1362

b) Observation #1368

c) Observation #1344 has been replaced as of 04/20/2002

Figure B-2: Pictures of Low Retroreflectivity Yellow ASTM Type III Signs

Table B-7: Low Retroreflectivity for Unwiped Yellow ASTM Type III Background Color

Observation #	Age	Reading			Range
		1	2	3	
1344	16.8	71	65	24	48
1358	16.8	66	73	40	34
1362	16.8	39	23	7	32
1368	16.8	38	29	14	24

Table B-8: Low Retroreflectivity for Wiped Yellow ASTM Type III Background Color

Observation #	Age	Reading			Range
		1	2	3	
1344	16.8	70	62	25	45
1358	16.8	67	74	43	31
1362	16.8	39	20	8	31
1368	16.8	39	31	15	25

Table B-9: Signs with A Red/White ASTM Type III Ratio > 20

Observation Number	Age in Years	Ratio	Red Retroreflectivity	White Retroreflectivity	From Crawfordsville Bonepile	Sign Flagged
24	10.5	38.4	7	254	Yes	No
35	11.5	21.2	8	179	Yes	No
72	13.5	117.8	2	267	Yes	No
342	11.5	20.7	4	83	Yes	No
351	11.5	110.0	1	132	Yes	No
352	11.5	132.1	1	79	Yes	No
360	11.5	25.6	9	238	Yes	No
654	10.5	34.0	5	179	No	Yes
695	11.5	31.9	7	229	No	Replaced
759	8.6	20.8	11	226	No	Yes
910	10.6	21.9	9	191	No	Yes
1753	9.9	96.8	3	255	No	Yes
1939	10.1	70.3	4	255	No	Yes

Table B-10: Signs Observed to be Below the Proposed 4:1 Red/White ASTM Type III Ratio Requirement

Observation Number	Age in Years	Ratio	Red Retroreflectivity	White Retroreflectivity	From Crawfordsville Bonepile	Sign Flagged
10	12.5	3.1	17	51	Yes	No
30	10.5	2.9	30	84	Yes	No
66	13.5	3.7	65	244	Yes	No
73	9.5	3.2	34	106	Yes	No
96	9.5	4.0	21	83	Yes	No
106	11.5	3.9	23	89	Yes	No
118	11.7	3.4	39	133	Yes	No
119	13.5	3.9	50	194	Yes	No
328	10.5	3.7	17	65	Yes	No
329	8.5	4.0	49	194	Yes	No
357	13.5	3.6	26	93	Yes	No
377	14.1	2.8	75	209	Yes	No
577	0.6	3.6	62	223	No	Yes
624	0.7	3.5	60	210	No	Yes
625	1.8	3.8	56	211	No	Yes
633	0.3	3.8	59	225	No	Yes
648	1.8	3.7	54	203	No	Yes
858	8.6	3.9	59	223	No	Removed
1192	0.2	3.6	67	244	No	Yes
1643	10.3	3.9	59	223	No	Yes
1886	5.8	3.7	34	129	No	Yes
1957	2.5	3.8	60	228	No	Yes

a) Observation #654

b) Observation #695 has been replaced as of 04/20/2002

c) Observation #759

d) Observation #910

e) Observation #1753

f) Observation #1939

Figure B-3: Pictures of Signs Observed to have A Red/White Ratio > 20

a) Observation #577

b) Observation #624

c) Observation #625

d) Observation #633

e) Observation #648

f) Observation #858 has been removed as of 05/14/02

Figure B-4: Pictures of Signs Observed to be Below the Proposed 4:1 Red/White Ratio Requirement

a) Observation #1192

b) Observation #1643

c) Observation #1886

d) Observation #1957

Figure B-5: Pictures of Signs Observed to be Below the Proposed 4:1 Red/White Ratio Requirement Continued

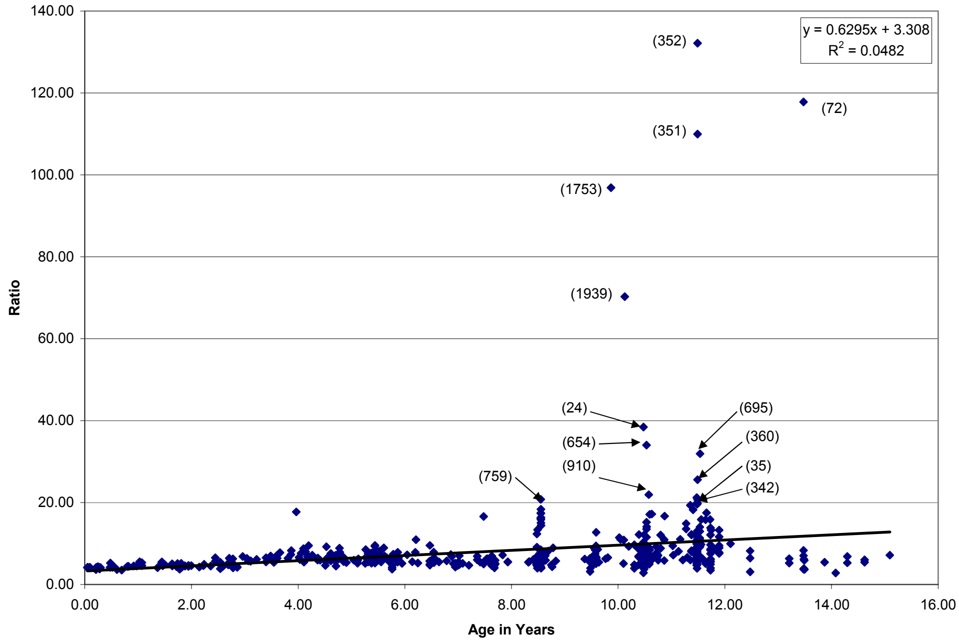


Figure B-6: Red/White ASTM Type III Ratio versus Age for Unwiped Signs Including the Crawfordsville Bonepile (non-cropped) (n = 578)

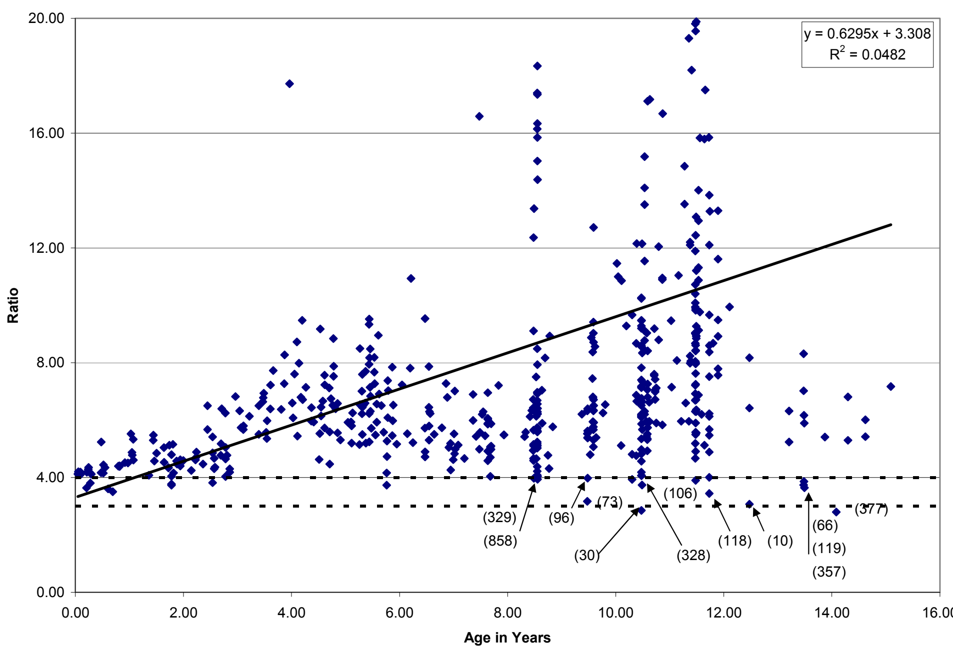


Figure B-7: Red/White ASTM Type III Ratio versus Age for Unwiped Signs Including the Crawfordsville Bonepile (cropped) (n = 578)

Table B-11: Range of Unwiped Retroreflectivity Values for Red ASTM Type III Background Color Excluding the Crawfordsville Bonepile

Observation #	Age	Reading			Range
		1	2	3	
934	0.5	26	11	47	36
1400	10.4	31	17	48	31
696	1.4	54	56	28	28
615	11.5	6	30	30	24
1582	5.3	33	36	17	19
1167	1.5	64	61	46	18
614	2.8	56	55	38	18
652	1.4	61	62	47	15
649	2.8	59	45	47	14
643	2.7	41	53	40	14
1910	9.4	36	31	45	14
802	0.8	51	37	49	13
1726	8.8	30	22	34	12
1078	10.6	29	29	17	12
718	6.5	30	39	42	12
2039	7.1	39	44	33	12
627	1.0	44	43	33	11
811	1.0	45	36	47	11
636	5.1	31	38	42	11
1969	2.5	46	36	35	11
2081	4.1	35	25	36	11
1658	9.8	27	25	35	10
1628	14.6	36	37	46	10
2115	6.0	38	28	37	10
1636	10.3	17	27	27	10
1702	3.6	31	39	40	9
765	8.5	33	39	42	9
1565	11.9	28	24	19	9
1284	10.6	41	32	40	9
1016	9.6	41	44	36	8
1933	11.4	11	19	13	8
2047	5.4	36	36	28	8
1495	1.8	45	40	48	8
1643	10.3	63	60	55	8
632	4.4	37	29	30	8
2089	3.5	49	57	55	8
786	8.5	38	38	31	8
700	13.9	40	33	36	8
1706	4.8	23	23	30	7

Table B-12: Range of Wiped Retroreflectivity Values for Red ASTM Type III Background Color Excluding the Crawfordsville Bonepile

Observation #	Age	Reading			Range
		1	2	3	
1400	10.4	32	18	49	31
934	0.5	29	18	40	23
1167	1.5	63	62	40	23
615	11.5	9	31	31	22
652	1.4	63	62	45	18
696	1.4	55	56	40	16
643	2.7	38	53	41	16
1582	5.3	29	29	14	16
614	2.8	57	56	43	14
649	2.8	58	46	44	14
627	1.0	44	43	31	13
1078	10.6	24	11	11	13
765	8.5	30	40	43	13
1910	9.4	36	33	45	13
1726	8.8	30	22	33	12
2115	6.0	36	27	38	11
636	5.1	31	40	42	11
1421	1.9	50	46	39	11
1679	10.0	21	11	22	11
2081	4.1	32	25	36	11
1565	11.9	28	25	18	10
1702	3.6	31	38	41	10
1693	10.4	42	37	47	10
786	8.5	39	39	30	9
1641	9.8	45	44	35	9
1742	3.6	30	40	38	9
1628	14.6	48	50	57	9
1933	11.4	11	20	14	9
1969	2.5	45	41	37	8
1471	13.2	39	31	39	8
78	1.0	58	53	50	8
1462	5.9	41	37	33	8
1636	10.3	19	27	26	8
1952	14.3	37	36	29	8
1021	9.6	30	37	38	8
779	8.5	25	27	20	8
1714	7.4	37	29	36	8
806	8.5	38	44	37	8
1535	1.7	62	69	66	8

Table B-13: Range of Unwiped Retroreflectivity Values for White ASTM Type III Background Color Excluding the Crawfordsville Bonepile

Observation #	Age	Reading			Range
		1	2	3	
1530	13.1	305	307	83	224
1529	13.1	23	188	228	205
2083	4.5	119	260	262	143
1512	1.4	202	330	303	128
1820	3.0	280	180	271	100
2117	0.9	185	127	224	97
1919	10.0	257	248	171	86
1039	9.6	116	201	186	85
1430	12.4	230	277	200	77
774	3.5	264	261	190	74
1265	10.6	245	174	247	73
2101	13.1	267	195	222	72
1556	5.4	285	231	298	67
1958	2.5	178	236	219	58
1738	6.5	251	264	208	56
1962	2.5	163	204	216	53
1418	0.8	284	287	235	52
1548	13.1	204	256	251	52
1542	5.9	314	320	271	49
1260	0.6	227	276	236	49
1159	10.7	280	234	283	49
662	5.9	201	249	210	48
1807	3.8	200	200	246	46
1454	10.5	220	233	266	46
760	8.5	186	166	140	45
795	14.1	244	199	241	45
1407	7.5	295	297	252	45
1756	3.4	265	224	268	44
1465	2.2	246	286	290	44
1560	13.1	262	283	241	42
1994	1.8	139	180	161	42
1374	3.3	268	262	303	41
2070	1.8	262	223	264	41
889	11.6	225	242	201	41
1264	10.6	279	290	249	41
665	1.5	229	270	264	41
1352	8.4	260	301	286	41
1803	5.4	204	238	244	40
1171	10.7	284	244	278	40

Table B-14: Range of Wiped Retroreflectivity Values for White ASTM Type III Background Color Excluding the Crawfordsville Bonepile

Observation #	Age	Reading			Range
		1	2	3	
1529	13.1	23	183	219	196
1530	13.1	301	299	129	172
1264	10.6	271	282	194	88
1039	9.6	115	182	200	85
1919	10.0	263	258	178	85
1430	12.4	228	282	201	81
1946	1.8	176	256	244	81
1265	10.6	207	163	243	80
754	9.5	209	163	242	79
1820	3.0	290	215	283	75
1548	13.1	209	281	281	72
1418	0.8	298	300	232	68
581	10.5	227	173	239	67
1733	6.5	248	247	184	64
1556	5.4	292	242	298	56
1958	2.5	188	242	230	54
1147	8.7	281	227	252	54
767	8.5	247	255	204	51
1847	2.5	222	231	272	50
2083	4.5	209	259	258	50
1030	9.6	217	226	177	49
1560	13.1	262	274	225	49
774	3.5	263	263	216	47
1486	5.6	242	208	195	47
760	8.5	183	182	137	46
864	9.6	217	261	263	46
1632	5.6	227	272	259	45
801	1.4	233	188	227	45
1385	12.9	283	286	242	44
752	9.5	249	251	207	44
1159	10.7	275	239	283	44
1542	5.9	298	314	272	42
1170	10.7	283	286	244	42
1454	10.5	227	252	269	42
662	5.9	213	252	255	42
1756	3.4	261	227	268	41
1171	10.7	288	247	278	41
1034	15.1	187	217	179	38
1404	4.0	259	221	244	38

Table B-15: Range of Unwiped Retroreflectivity Values for Yellow ASTM Type III Background Color Excluding the Crawfordsville Bonepile

Observation #	Age	Reading			Range
		1	2	3	
1906	6.0	182	112	107	75
1450	8.7	220	218	169	51
2021	3.7	211	209	162	49
1344	16.8	71	65	24	48
1141	16.5	157	164	117	46
1308	10.9	171	192	146	46
1099	16.5	140	94	119	45
1215	10.7	132	175	166	43
1449	16.8	167	125	168	43
685	11.5	93	134	118	40
1211	10.7	143	183	171	40
2119	13.1	170	132	154	38
1811	7.7	166	178	204	38
1087	10.6	138	167	174	37
1387	11.6	160	164	128	36
1573	11.9	191	160	195	35
1439	6.6	238	206	241	35
656	11.5	185	150	179	35
1382	3.2	207	240	241	34
1100	16.5	152	118	152	34
1358	16.8	66	73	40	34
1195	2.6	235	202	228	33
977	15.5	91	59	84	33
1362	16.8	39	23	7	32
1139	16.5	170	178	146	32
1188	2.7	228	230	198	32
1190	2.6	200	193	170	31
1131	3.7	152	162	182	30
564	5.5	149	179	169	30
1280	10.6	225	221	197	28
678	11.5	179	184	156	28
1278	10.6	233	206	229	27
1417	4.5	252	225	247	27
1145	16.5	172	178	151	27
1174	10.7	185	202	176	26
1597	7.3	153	177	152	25
1368	16.8	38	29	14	24
1189	2.7	233	233	209	24
2118	2.2	197	173	189	24

Table B-16: Range of Wiped Retroreflectivity Values for Yellow ASTM Type III Background Color Excluding the Crawfordsville Bonepile

Observation #	Age	Reading			Range
		1	2	3	
565	10.5	152	92	168	75
1439	6.6	243	195	245	50
656	11.5	193	144	186	49
2021	3.7	206	210	163	47
1188	2.7	224	226	180	46
1826	1.7	214	221	175	46
1344	16.8	70	62	25	45
685	11.5	94	136	121	41
1141	16.5	160	165	124	41
977	15.5	100	60	85	40
1449	16.8	170	130	168	40
1387	11.6	163	171	132	40
1896	5.7	194	173	155	39
1308	10.9	173	193	154	39
1278	10.6	233	195	225	38
1437	16.8	215	208	246	38
1195	2.6	238	200	224	38
1417	4.5	255	218	245	37
1099	16.5	140	103	122	37
2078	13.1	131	107	143	37
1087	10.6	141	167	176	36
1365	8.0	200	234	225	34
1227	10.8	143	175	160	32
1362	16.8	39	20	8	31
1358	16.8	67	74	43	31
1906	6.0	184	154	164	30
1100	16.5	154	126	148	28
1190	2.6	208	201	181	27
1211	10.7	158	185	168	27
932	15.1	124	109	136	27
564	5.5	158	185	177	27
1189	2.7	227	237	211	26
1163	10.7	204	204	179	25
1368	16.8	39	31	15	25
1145	16.5	173	176	152	24
1139	16.5	170	176	152	24
1210	10.7	179	202	191	23
1450	8.7	219	208	231	23
1593	4.8	221	244	234	23

Table B-17: Original Field Retroreflectivity Readings Done Using ART 920

		ART 920 in Field			
Sign #	**Color**	**1**	**2**	**3**	**Average**
Sample 1	Red	44	44	45	44
	White	280	275	272	276
Sample 2	Red	45	47	47	46
	White	273	278	283	278
577	Red	62	63	61	62
	White	224	219	226	223
624	Red	60	58	62	60
	White	214	199	217	210
625	Red	55	56	56	56
	White	173	231	228	211
633	Red	58	59	60	59
	White	221	224	224	223
648	Red	56	53	54	54
	White	173	214	222	203
654	Red	6	5	6	5
	White	107	212	218	179
759	Red	10	11	11	11
	White	224	226	229	226
910	Red	10	8	8	9
	White	265	264	262	264
1192	Red	65	69	69	67
	White	247	241	245	244
1362	Yellow	39	23	7	23
	Black	-	-	-	-
1368	Yellow	38	29	14	27
	Black	-	-	-	-
1643	Red	63	60	55	59
	White	228	234	237	233
1753	Red	2	3	3	3
	White	260	255	250	255
1939	Red	4	3	4	4
	White	253	261	252	255
1957	Red	60	59	60	60
	White	243	228	213	228

Table B-18: Retroreflectivity Readings Taken in Lab Using Loaner 820 from 3M

		820 in Lab 08/12/02			
Sign #	**Color**	**1**	**2**	**3**	**Average**
Sample 1	Red	48	49	49	48
	White	326	325	325	325
Sample 2	Red	47	45	51	48
	White	310	334	328	324
577	Red	78	81	80	80
	White	319	324	323	322
624	Red	69	64	69	67
	White	282	272	278	277
625	Red	68	67	67	67
	White	316	315	315	315
633	Red	68	68	70	69
	White	304	295	305	301
648	Red	68	67	67	67
	White	313	313	316	314
654	Red	6	5	5	6
	White	273	277	272	274
759	Red	9	9	9	9
	White	283	271	273	276
910	Red	10	10	10	10
	White	306	313	308	309
1192	Red	70	70	70	70
	White	296	289	291	292
1362	Yellow	66	35	7	36
	Black	-	-	-	-
1368	Yellow	62	70	16	49
	Black	-	-	-	-
1643	Red	56	59	55	57
	White	247	252	254	251
1753	Red	4	5	4	4
	White	303	302	307	304
1939	Red	5	5	6	5
	White	290	290	287	289
1957	Red	65	64	63	64
	White	306	299	302	302

Table B-19: Retroreflectivity Readings Taken in Lab Using ART 920

		ART 920 in Lab 08/22/02			
Sign #	**Color**	**1**	**2**	**3**	**Average**
Sample 1	Red	44	44	45	44
	White	271	273	283	276
Sample 2	Red	43	42	46	44
	White	254	276	284	271
577	Red	76	79	77	77
	White	279	286	281	282
624	Red	71	66	69	68
	White	258	249	253	253
625	Red	60	64	64	63
	White	272	271	271	271
633	Red	68	67	69	68
	White	269	263	269	267
648	Red	65	64	64	64
	White	270	269	270	270
654	Red	4	3	3	3
	White	238	241	236	238
759	Red	8	8	7	8
	White	250	249	241	247
910	Red	8	8	8	8
	White	264	271	268	268
1192	Red	70	67	67	68
	White	258	246	259	254
1362	Yellow	38	28	6	24
	Black	-	-	-	-
1368	Yellow	57	55	13	41
	Black	-	-	-	-
1643	Red	58	61	54	58
	White	219	227	225	224
1753	Red	2	3	2	2
	White	255	250	258	254
1939	Red	3	3	4	4
	White	246	239	247	244
1957	Red	60	60	60	60
	White	262	260	261	261