Designing an Efficient Nighttime Sign Inspection Procedure to Ensure Motorist Safety

by

Dr. William J. Rasdorf, Dr. Joseph E. Hummer, Elizabeth A. Harris,
Venkata Pavan K. Immaneni, Chunho Yeom

North Carolina State University
Department of Civil, Construction, and Environmental Engineering
Campus Box 7908
Raleigh, NC 27695

North Carolina Department of Transportation
Research and Development Group
Raleigh, NC 27699-1549

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16. Abstract

The major objective of this study, conducted for the North Carolina Department of Transportation (NCDOT), is to provide a road sign replacement simulation that NCDOT can use to optimize the management of signs. To create the simulation, the research team modeled the performance of NCDOT sign inspectors, determined sign retroreflectivity performance with age, and determined external factors that affect sign performance. Research assistants accompanied NCDOT sign crews during nighttime sign inspections. During these inspections, signs needing replacement were identified and noted by the research team. Replacement reasons included low retroreflectivity (either caused by natural decay or vandalism), knockdown, and damage. The following day, the research team measured the retroreflectivity and noted the age of the signs from the previous night's inspection.

Using the field data, the research team evaluated inspector performance and developed retroreflectivity deterioration rates over time, vandalism rates and sign damage rates over time. It was found that a linear curve typically best describes expected sign deterioration, however the R^2 values were usually less than 0.5 for the trend lines between age and retroreflectivity. The field study damage rate was found to be about 2.37% of inspected signs per year. A second investigation, based on cost data, enabled the study team to determine an overall annual sign replacement rate of 6.9%. Sign inspectors left very few signs in the field with a retroreflectivity value below 20. Across all five NCDOT Divisions visited as part of the study, 89% of signs were replaced with Type III sheeting, just over 10% short of the NCDOT goal of 100% Type III replacement.

The road sign replacement simulation used combinations of these rates generated from the field study to simulate several sign management scenarios. In the simulation, higher costs for sign management generally resulted in a lower number of signs below the standard. However, in the long run for four of the scenarios, increasing the sign management costs by only 10% resulted in a 50% decrease in the number of signs below the standard. Other Departments of Transportation and agencies can also use the simulation if the state or local sign retroreflectivity deterioration, inspection performance, and damage rates are available.

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EXECUTIVE SUMMARY

It is imperative that Departments of Transportation (DOTs) have effective sign testing and replacement programs to significantly reduce safety risks to motorists. One important aspect of sign performance for nighttime driving is retroreflectivity, measured by a coefficient of retroreflection. The coefficient of retroreflection (Ra) can be understood as the ratio of the light which the sign reflects to a driver (cd) to the light which illuminates the sign (lx) per unit area (m^2). In layman's terms it is a measure of how well the sign can be seen at night.

Proposed Federal Highway Administration (FHWA) minimum retroreflectivity standards will present several issues to agencies responsible for sign replacement and maintenance. In the case of North Carolina, the North Carolina DOT (NCDOT) owns and maintains approximately 78,000 miles of roadway. When the new standards are finally adopted, both compliance (for the safety and well being of the public) and proof of compliance (to protect against lawsuits) will be necessary.

The major objective of this study is to provide a road sign replacement simulation that NCDOT can use to judge compliance with the FHWA minimum retroreflectivity standards and optimize its sign management activities. To create the simulation, the research team modeled the performance of NCDOT sign inspectors, determined sign retroreflectivity performance with age, and determined external factors that affect sign performance.

Research assistants from North Carolina State University accompanied NCDOT sign crews during nighttime sign inspections. During these inspections, signs needing replacement were identified and noted by the research team. Replacement reasons included low retroreflectivity (either caused by natural decay or vandalism), knockdown, and damage. The following day the research team measured retroreflectivity using a RetroSign®4500 retroreflectometer and recorded the age and attributes of the signs evaluated during the previous night's inspection. The research team also conversed with NCDOT sign crews about their current sign management practices.

Using the field data, the research team evaluated inspector performance and developed retroreflectivity deterioration rates over time, vandalism rates, and sign damage rates over time. It was found that a linear curve typically best describes expected sign deterioration, however the R^2 values were usually less than 0.5 for the trend lines between age and retroreflectivity.

The field study damage rate was found to be about 2.37% of inspected signs per year. Of this total damage, 1.3% of signs are damaged irreparably by humans each year, 0.9% by natural causes each year, and about 0.17% of signs each year are damaged due to both natural and human causes. The most common types of damage were paint balls, gun, eggs, and tree sap. A second investigation, based on cost data, enabled the study team to determine an overall annual sign replacement rate of 6.9%. The researchers found that 4.7 percent of all signs are replaced due to damage each year and this percentage includes 2.4 percent of signs each year that are replaced outside the nighttime inspection process due to vandalism.

The field research data showed that NCDOT inspectors were generally responding to better retroreflectivity by rejecting fewer signs. Thus, they had a very low false negative rate (rejecting

good signs). However, the inspectors did not reject quite a few signs that had poor retroreflectivity. What this demonstrates is that they were using a different retroreflectivity standard than the FHWA proposed minimums. Still, rejection rates did increase as retroreflectivity decreased. In fact, there were very few signs left standing in the field with a retroreflectivity value below 20.

The study found that presently 54% of the Type I signs are below the proposed FHWA minimum standard. However, almost all of the Type III signs were well above the proposed minimum. The inspector accuracy (based on the proposed FHWA minimum for Type I signs) was 67% for white, 51% for yellow, 74% for red, and about 63% for green signs. The inspector accuracy for the different divisions varied from 54% to 83%.

Approximately 20% of the signs measured in 2005 had been replaced or removed by Division sign crews between the 2005 and a follow-up field study in 2006, with 2% of the signs removed and 18% replaced. Across the five inventoried Divisions, 89% of signs are replaced with Type III sheeting, just over 10% short of the NCDOT goal of 100% Type III replacement.

The road sign replacement simulation used combinations of these rates generated from the field study to simulate several sign management scenarios. As expected, more frequent inspection has higher costs but provides the best sign condition. When inspectors have adapted to the FHWA standard as their minimum retroreflectivity limit, the number of signs below the standard is expected to stabilize at around 10 percent, which is about half of the current rate. NCDOT will eventually have better sign performance and a smaller sign budget if the 100% conversion rate from Type I to Type III sheeting is continued. Sign management costs for total replacement by retroreflectivity loss and by warranty expiration are likely unacceptable to the NCDOT. According to the results, the sign management budget would have to increase by more than 10 times the current sign management budget in the early years to replace signs based on these criteria.

In the simulation, high costs for sign management generally result in a lower number of signs below the standard. However, in the long run for four of the scenarios, increasing the sign management costs by only 10% resulted in a 50% decrease in the number of signs below the standard. The NCDOT can use the simulation results to optimize its sign management program to maximize motorist safety, minimize costs, meet pending Federal requirements, and minimize the liability resulting from sign-related collisions. Other Departments of Transportation and agencies can also use the simulation if the state or local sign retroreflectivity deterioration, inspection performance, and damage rates are available.

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1.0 INTRODUCTION

The purpose of this project is to build a credible simulation of NCDOT sign management practices. The NCDOT needs such a simulation so that it can optimize its sign management program to maximize motorist safety, minimize costs, meet pending Federal requirements, and minimize the liability resulting from sign-related collisions.

Toward the end of a previous NCDOT project on sign management, some members of the NCSU research team built a sign inspection simulation program and have continued to refine the program since the original project ended [Vereen, et. al. 2002]. The current research team felt that validating a number of the key assumptions made when the simulation was built could further enhance the original program. The purpose of this project was, in part, to validate those key assumptions and allow NCDOT to use the simulation with confidence. The study incorporates the most accurate and well founded sign deterioration functions available into the simulation, adds the capability to analyze green and white signs in addition to yellow and red, and adds measured data specific to the performance of NCDOT sign inspectors.

1.1 Scope

The potential cost savings from using a simulation program to optimize the sign inspection program are tremendous. A credible simulation would allow the NCDOT to examine trade-offs and determine cost savings. Questions the NCDOT can address with the simulation program described herein include:

- Should we inspect signs every one, two, or three years?
- Should we inspect different types of signs or different types of roads more or less frequently?
- Should we train our sign inspectors to accept or reject signs more often?
- Should we use different grades of sheeting on different types of roads?

A credible simulation of the sign inspection program would also allow the NCDOT to respond to the proposed new Federal standard and reduce risk and liability. The FHWA has proposed a new standard for sign retroreflectivity that will present serious implementation challenges for large agencies like the NCDOT. When these new standards are finally adopted, both compliance (for the safety and well being of the public) and proof of compliance (to protect against lawsuits) will be necessary. Using a simulation would be an inexpensive and reliable way to insure compliance and provide proof.

1.2 Research Objectives

The major objectives of this study are to collect field data in several NCDOT divisions, establish inspector performance, determine sign deterioration rates using historical studies and measured data, and to determine sign replacement and damage rates. Once these objectives are accomplished, the research team can revise and expand the original sign inspection effectiveness simulation so that NCDOT can optimize its program. The main revisions necessary to allow NCDOT to use the simulation are to:

- Model the performance of NCDOT sign inspectors,
- Expand the simulation to include green and white signs in addition to yellow and red, and

- Utilize the best sign deterioration functions available.

The original version of the simulation utilized data from a State of Washington study that was based on 17 inspectors' ratings of engineer grade warning and stop signs in a laboratory setting, in a controlled highway setting, and in an uncontrolled highway setting [Lagergren 1987]. The purpose of the WA study was to compare "the individual observer rating of the signs with the rating of the signs calculated by using a retroreflectometer." Warning and stop signs were chosen because of their "high relative importance" and because they are commonly used on roads. The uncontrolled highway setting utilized two road courses, a rural highway containing 76 signs and an urban highway containing 54 signs.

The goal of our study was to expand the Washington study scope significantly to include green and white sign colors and Type III sign sheeting. Thus, the main data collection effort for this study was focused on recording the observations of actual NCDOT sign inspectors under field conditions on a pre-identified set of signs and then recording retroreflectometer readings for those same signs. The research team collected data from a number of sign inspectors across North Carolina to give the study results statistical stability and to ensure coverage of the varying conditions and terrain across the state.

The retroreflectivity readings provide a standard of comparison for the inspector observations. To maintain accuracy, retroreflectometers were calibrated before use. Some units are capable of data collection, storage, and download. The research team acquired a unit with these capabilities from NCDOT. It was used to acquire measurements for all signs in the study area and for comparison to the sign inspector observations.

The original version of the simulation contains a very simple function for approximating sign deterioration over time. The function assumes that engineer grade signs lose 1/7th of their effectiveness each year for the seven years of their useful lives. In reality of course, different types of signs deteriorate at various rates, in non-linear ways, over various lifespans, depending on a number of variables. In this study, the research team conducted an exhaustive literature search, contacted leading sign sheeting manufacturers, contacted other experts at FHWA and other agencies, and collected field data to identify more accurate sign deterioration functions to include in the simulation. The information from these sources were combined with sign age and retroreflectivity data from the research team's data collection effort.

2.0 BACKGROUND

Retroreflectivity is the process of light being placed on the surface of a retroreflective material and that light being sent back along a path at an angle, α, away from the path it came from as shown in Figure 2.1 [Vereen, et. al., 2002].

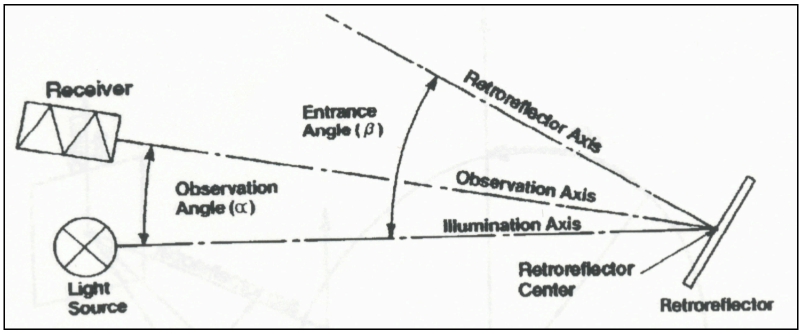


Figure 2.1. Basic Principles of Retroreflectivity

The light sources of interest here are the headlights of a vehicle. The light travels along the illumination axis, which is a half-line from the center of the source aperture to the center of the retroreflective device. It is then reflected back to a receiver, the human eye, along the observation axis, which is a half-line from the center of the retroreflector to the observation point or receiver. The observation angle, α, is the angle between the illumination axis and the observation axis. The entrance angle, β, is the angle between the illumination axis and the retroreflector axis. The retroreflector axis is a designated half-line from the retroreflector center [ASTM 1999].

At night, it is important that signs not illuminated by streetlights or their own lights maintain an adequate level of retroreflectivity. When light hits a sign at night, internal sign sheeting technologies cause the sign to appear as if it is glowing. Higher retroreflectivity means drivers are able to see signs from greater distances at night, thus improving their safety [Hatzi 2001]. "Retroreflective elements can serve to provide positive visual guidance that helps to keep cars in their lanes or on the road and … offers other information to drivers. Retroreflectivity is a critical ingredient in creating a much safer road environment." [Hasson 1999].

Retroreflectivity is a finite measure that assigns numerical values to roadway sign sheeting. These values can then be compared to the proposed minimum in-service retroreflectivity guidelines. The standard used to measure retroreflectivity of roadway signs is the coefficient of retroreflection, RA, which is also described as specific intensity per unit area, or SIA. The unit of measurement for RA is candelas per foot-candle per square foot (cd/fc/ft2) in English units or candelas per lux per meter squared (cd/lx/m2) in metric. A basic explanation of RA is "the amount of light (i.e. luminance measured as candelas per square foot or square meters) that comes out from the retroreflective material per amount of light coming in from the light source, i.e. the vehicle headlights (i.e., illuminance measured as foot-candels or lux)" [McGee, et. al. 1998a].

2.1 Proposed FHWA Standards

Since the early 1990's, the FHWA has sponsored several studies to develop recommendations for minimum retroreflectivity levels for traffic signs. These studies represent various attempts to define and refine the concept of minimum maintained sign retroreflectivity. Initial minimum retroreflectivity levels were developed through research in 1993 by Paniati [Paniati, et. al. 1993]. These levels were revised in 1998 in a report by McGee [McGee, et. al. 1998a]. Further Updated minimum levels were proposed in 2003 by Carlson [Carlson, et. al. 2003a] and are the ones that FHWA proposes for use. Carlson then wrote a paper that describes the evolution of the research to develop minimum levels of sign retroreflectivity [Carlson, et. al. 2003b].

The minimum levels of sign retroreflectivity [Carlson, et. al. 2003a] are generally similar in magnitude to levels published previously, but incorporate several refinements and updates. The following improvements were incorporated into the 2003 levels [Carlson, et. al. 2003a]:

- An improved computer model was used to develop the minimum levels.
- Additional sheeting types were incorporated into the minimum levels.
- Headlamp (headlight) performance was updated to represent the model year 2000 vehicle fleet.
- Vehicle size was increased to represent the greater prevalence of sport utility vehicles and pickup trucks.
- The luminance level needed for legibility was increased to better accommodate older drivers.
- Minimum retroreflectivity levels were consolidated across more sheeting types to reduce the number of minimum levels.

The updated minimum maintained retroreflectivity levels are shown in Table 2.1. The table shows the proposed minimum FHWA standard that must be met by a sign. The proposed minimums vary based on sign type and color. They represent the most current research recommendations, and are recommended by FHWA, but are limited to the current knowledge of nighttime luminance requirements of traffic signs.

Retroreflective sheeting is generally classified into one of eight categories defined by the American Society for Testing and Materials [ASTM Standards, 2000]. Table 2.2 shows the ASTM requirements for new sheeting for different sign colors and types. The difference between the two tables is that Table 2.1 shows the minimum proposed standards and the Table 2.2 shows the retroreflectivity requirements to be satisfied by a brand new sign.

Table 2.1. Preliminary Retroreflectivity Minimums [Carlson, 2003]

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

NOTE: Levels in cells represent legend retroreflectivity • •background retroreflectivity (for positive contrast signs). Units are cd/lx/m² measured at an observation angle of 0.2• •and an entrance angle of -4.0• •.
• •Minimum Contrast Ratio • •3:1 (white retroreflectivity ÷ red retroreflectivity).
• •For all bold symbol signs and text signs measuring 48 inches or more.
• •For all fine symbol signs 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

All symbol signs not listed in the bold category are considered fine symbol signs.

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, W4-4p – Cross Traffic Does Not Stop, or
- W13-2, -3, -1, -5 – Ramp & Curve Speed Advisory Plaques
- Use largest dimension

Table 2.2. ASTM Retroreflectivity Requirements for New Sheeting

ASTM D4956-01a	Color	Sheeting Type					
		I	II	III	VII	VIII	IX
	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/m²

A summary of the minimum performance requirements for Type I and Type III retroreflective sheeting is presented in Tables 2.3 and 2.4.

Table 2.3. Minimum Coefficient of Retroreflection (cd/lx/m^2) for Type I Sheeting

Observation Angle (Degrees)	Entrance Angle (Degrees)	White	Yellow	Orange	Green	Red	Blue	Brown
0.2	-4	70	50	25	9	14	4	1
0.2	30	30	22	7	3.5	6	1.7	0.3
0.5	-4	30	25	13	4.5	7.5	2	0.3
0.5	30	15	13	4	2.2	3	0.8	0.2

Table 2.4. Minimum Coefficient of Retroreflection (cd/lx/m^2) for Type III Sheeting

Observation Angle (Degrees)	Entrance Angle (Degrees)	White	Yellow	Orange	Green	Red	Blue	Brown
0.1	-4	300	200	120	54	54	24	14
0.1	30	180	120	72	32	32	14	10
0.2	-4	250	170	100	45	45	20	12
0.2	30	150	100	60	25	25	11	8.5
0.5	-4	95	62	30	15	15	7.5	5
0.5	30	65	45	25	10	10	5	3.5

The Tables 2.3 and 2.4 illustrate the minimum criteria for each sheeting color. The coefficients of retroreflection in these tables are given for several different entrance and observation angle values. These entrance and observation angles approximate the angles that exist in a highway environment under common driving conditions. It can be seen that the expected level of performance for lighter colored signs, like white and yellow, is higher than those of darker colored signs, like blue and brown. These values are consistent with the rates of light reflection and absorption for these colors.

The DOT specification values are based on the installation of new sheeting and indicate a minimum retroreflection measurement during a minimum of a seven year performance period for Type I sheeting and ten years for Type III sheeting. The performance periods are considerably shorter for orange signs (three years and five years respectively) because construction zones work area signs are subjected to more abuse and adverse environmental conditions. The DOT values differ slightly from the published ASTM and significantly from the end-of-service life criteria recommended by the Federal Highway Administration (FHWA). FHWA end-of-service life criteria are used to define the recommended service limits for retroreflective sheeting. For example, FHWA end-of-service minimum retroreflectivity values for Type III sheeting are between 30-70 cd/lx/m^2 for white and 30- 55 cd/lx/m^2 for yellow sheeting.

2.2 Retroreflective Sign Sheeting

Retroreflective sign sheeting is the material that returns light from vehicles headlights back to the driver. This makes roadway signs visible at night. Retroreflective sign sheeting has a thin continuous layer of small retroreflective elements on or very near its exposed surface as described by ASTM E808, Standard Practice for Describing Retroreflection [ASTM 1999].

There are two technologies that are currently used to create retroreflective sign sheeting. The first involves manufacturing very small glass spheres, or beads, into sheeting. Roundness and transparency are the properties that allow the glass beads to be retroreflective. The transparency allows light to pass through them and roundness causes the incident light beam to be refracted, sending the reflected light beam back at a slightly different angle than it entered the bead as shown in Figure 2.2.

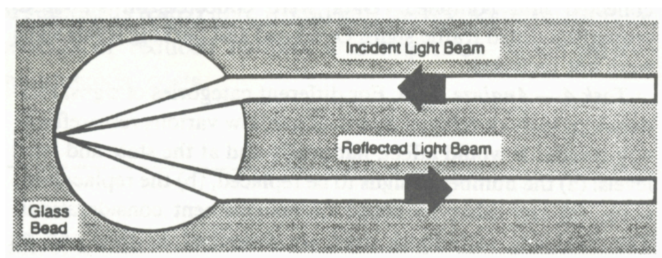


Figure 2.2. Glass Bead Retroreflection [Austin, et. al. 2001]

The second technology uses prismatic cube corner reflectors as shown in Figure 2.3. The incident light beam (a car's headlights) enters the reflector and bounces off the sides of the cube, sending the reflected light back to the driver.

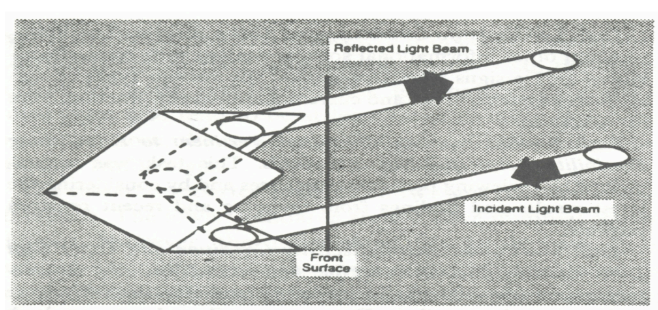


Figure 2.3. Prismatic Cube-corner Retroreflection [Austin, et. al. 2001]

Many of these tiny reflectors are embedded in sheets of retroreflective material.

<u>2.2.1 Types</u>

There are many types of reflective sheeting and different intensities and methods of reflection used for each one. The types vary among manufacturers; Avery Dennison, 3M Company, and Nikka Polymer Company are some commonly used brands. A state contract determines which manufacturer's product will be used by the Highway Divisions and the Department of Corrections. 3M holds the current state contract for sign sheeting Types I, III, VIII, and IX.

Table 2.5 lists the types of retroreflective sheeting, principles, and characteristics of each one. Sheeting types I – III increase in intensity and quality level; however, the remaining sheeting types do not necessarily increase in intensity or quality as their type number increases.

Table 2.5. Retroreflective Sheeting Types

TYPE	CHARACTERISITCS
I	Lowest type. Medium-intensity. Enclosed glass bead. Engineering Grade
IIIA III B	High Intensity/High Performance Grade. A – Encapsulated glass beads, B and C – Honeycomb type prismatic reflectors
VI	High Performance Vinyl Sheeting. Low durability, used on cones and temporary roll up signs.
VII	Stronger further away, strength diminishes as one approaches the sign. The 3M trade name for this sheeting is Long Distance Performance (LDP).
VIII	Equivalent to Type III. Prismatic technology used instead of honeycomb.
IX	Becomes much stronger the closer you get. Used on the new fluorescent yellow-green non-motorized warning signs. Its 3M trade name is Visual Impact Performance (VIP).

Source: ITE Traffic Sign Handbook, NCDOT Chief Signing Engineer

The physical composition and construction of each sheeting type varies. Enclosed lens sheeting, which is found in sheeting Types I and II, is illustrated in Figure 2.4. It consists of glass beads imbedded inside durable transparent plastic over a base of metallic reflector coating, a pre-coated adhesive, and a protective liner.

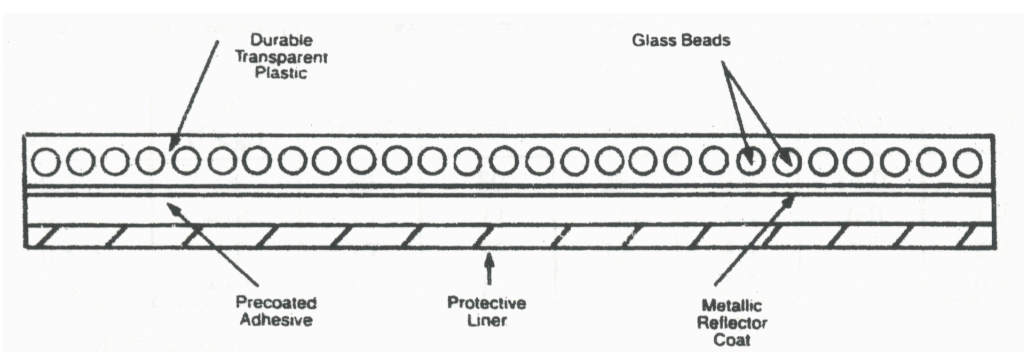


Figure 2.4. Enclosed Lens Sheeting [McGee, et. al. 1998a]

Figure 2.5 illustrates encapsulated lens sheeting, which is used in Type IIIA. It is similar to the enclosed; however, a transparent plastic film is placed over the top glass beads.

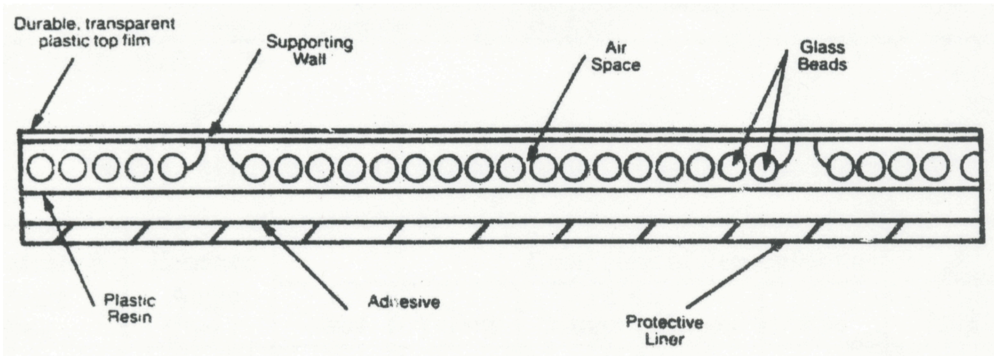


Figure 2.5. Encapsulated Lens Sheeting [Mc Gee, et. al. 1998a]

Figure 2.6 shows cube corner sheeting, also known as prismatic consists of many of the tiny cube corner reflectors.

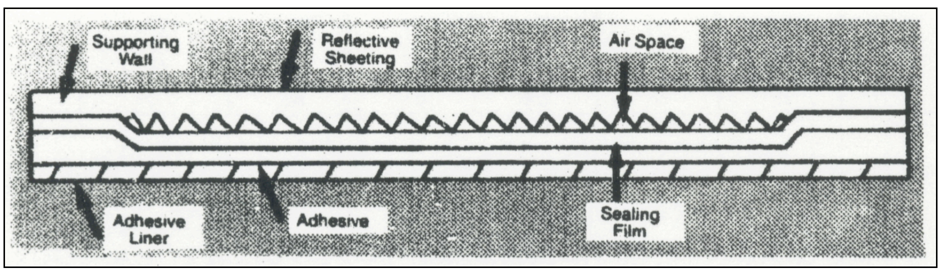


Figure 2.6. Prismatic Cube-Corner Sheeting [McGee, et. al. 1998a]

The main performance difference between the types of sheeting is captured in the R_A, or coefficient of reflection value [McGee, et. al. 1998a]. Table A compares the coefficient of retroreflection values between different sheeting types of the same color. The values in parenthesis are the proposed minimum in-service value for the same sheeting type and color expressed in cd/lux-m2. The value for the largest sign and highest speed value was chosen if more than one option was available for a color.

The intensity of light reflected back by each sheeting type varies greatly. A driver viewing light that enters and reflects back from signs that are the same color but different sheeting types, is likely seeing a wide range of intensities. At the same degradation rate, a higher quality sign sheeting should meet the proposed standard for a longer period of time, which leads to a lower replacement rate.

Table 2.6. Coefficient of Retroreflection of Various Sheeting Types and Colors

TYPE / COLOR	R_A Values (cd/lux-m2)*			
	TYPE I	TYPE II	TYPE III	TYPE IV and VII
RED	14 (8)	30 (8)	54 (8)	56 (8)
YELLOW	50 (20)	100 (25)	200 (30)	270 (40)
ORANGE	25 (20)	60 (25)	120 (30)	160 (40)
WHITE	70 (25)	140 (30)	300 (40)	400 (50)
GREEN	9 (7)	30 (7)	54 (7)	56 (7)

Source: McGee, et. al. 1998a

**Observation angle = 0.2 °, Entrance angle = -4°*

2.3 Literature Review and Related Studies

The literature review focused on two types of retroreflectivity studies; human vs. machine observation studies and sign sheeting degradation over time studies. The rest of this chapter discusses each relevant study in detail.

2.3.1 Human Vs Machine Observations

This section discusses the two studies that compared human retroreflectivity observations with machine observations. The Washingon (WA) State Study [Lagregren, et. al. 1987] and the Texas (TX) Study [Hawkins, et. al. 2001] are two studies that discuss the accuracy of human observers and the effectiveness of human observations compared to the retroreflectometer readings.

2.3.1.1 WA State Study

This study is an investigation of the methodology used to evaluate traffic sign retroreflectivity under actual highway conditions [Lagergren, et. al. 1987]. The study consisted of three parts: literature review, a questionnaire, and the training and analysis of human observers to rate traffic sign retroreflectivity.

2.3.1.1.1 Study Objectives

The research project had two primary objectives. The first objective was to review literature on maintaining retroreflective traffic signs and survey all state transportation agencies about the methodologies employed in making retroreflective judgments on highway signs. The second objective was to determine how accurately an observer can be trained to rate the retroreflectivity of traffic signs in a highway environment.

2.3.1.1.2 Literature Review

Mc Cormack of the WA State Transportation Center published a paper that summarized all the available research and information on the methods used to measure traffic sign retroreflectivity [Cormack 1986]. The paper describes three methods for examining the retroreflectivity of traffic signs:

- Human observers,

- Measuring instruments, and
- A combination of instruments and observers.

McCormack found that although the use of instruments to evaluate traffic sign retroreflectivity is fairly well documented and has been shown to be accurate, instruments are seldom used for field evaluation of sign retroreflectivity because of the amount time they require. On the other hand, the use of human observers for the field evaluation of traffic sign retroreflectivity is wide spread but is of unverified accuracy. He recommended that the accuracy of a human observer be further examined.

Another research report by Mace evaluated three methods of measuring sign performance, and two other methods were incidentally associated with the study:

- Comparison Standard method: Each sign was illuminated with a flashlight and then the closest match between the sign and patches of retroreflective sheeting attached to the sign was judged.
- Electroluminescent panel method: An electroluminescent (EL) panel was color matched to the federal specifications for yellow Type I sheeting and was adjustable for six levels of brightness. Subjects sat in the car and compared the panel to one of the six panel settings (six levels of brightness) from a distance of 300ft. Both sign mounted (similar to comparison standard method) and vehicle mounted procedures (panel mounted on the hood of a car) were tested.
- Legibility method: A passenger in a vehicle determined the legibility distance of the sign using a distance measuring instrument).
- Incidental methods: A Pritchard photometer (method 4) and a Retrotech retroreflectometer (method 5) were used to establish baseline and ground truth measures of luminance and retroreflectivity.

Of the methods that proved to be accurate and consistent, the time per measurement varied from two to ten minutes for the retroreflectometer; five to ten minutes for the comparison standard; ten to twenty minutes for the EL panel; and, ten to thirty minutes for the photometer. None of these methods could be economically used for large scale sign measurements. The study by Mace also showed that knowledgeable observers made replace/not replace decisions with some accuracy with no formal training.

The WA literature survey showed that instruments to evaluate traffic sign retroreflectivity are accurate but not used on a large scale because of the cost. They recommended that a computer based sign management system may prove to be satisfactory, provided that adequate weathering data and several other factors can be obtained.

2.3.1.1.3 Questionnaire

The WA study team mailed a questionnaire to each of 50 states. The purpose of the questionnaire was to obtain specific details of the policies and procedures used in maintaining retroreflective traffic signs. Eighty five percent (44 states) responded to the questionnaire and the results are summarized below.

Questionnaire Summary

- Six states had written, maintained performance standards for retroreflective sheeting material as follows:
    1. AZ - signs are replaced when not adequate as determined by night time visibility checks.
    2. CO - signs are replaced when major damage occurs, legibility is impaired by the fading of the letter message or symbol, or nighttime retroreflectivity is impaired.
    3. GA - policy is based on performance warranty.
    4. ID - policy is based on highway service levels and subjective retroreflectivity performance.
    5. VA - signs are considered for replacement when reflectivity falls below 50 percent of original brightness.
    6. WY - policy is based on manufacturer's data and their own experience.

- Most other states that had written or unwritten policies based their policies on how often signs should be reviewed.
- Thirty five states put either an installation date or fabrication date on their signs.
- Eight states used an installation date in their sign inventories as a priority to replace signs.
- Most states reviewed signs for replacement at least once a year.
- Sign inspectors were responsible maintenance and traffic personnel.
- Thirty five states used both day and night visual inspections; thirty five states used a combination of moving and stationary vehicles.
- Retrorefletometers or material patches were only used as a supplement to visual inspection; MS also used spot lights during day hours.
- A few states said they were able to make some general correlations between sign face characteristics and retroreflectometer readings; most states were not.
- Thirty one states did not and 13 states did have plans to modify their existing sign inspection procedures. Modifications and changes included hiring more personnel, improving record keeping, improving training, taking more retroreflectometer measurements, using material patches, decreasing or formalizing review frequencies, and formalizing inspection criteria and procedures.
- Only ten states claimed to be performing or planning research related to sign retroreflectivity in 1986. The most common research consisted of setting up and monitoring field weather decks for sign material evaluation. One state was working on the development of a retroreflectometer; one state was field evaluating various combinations of sign sheeting materials for legends and backgrounds; one state was working with accelerated weathering; and another state was developing a level of service document. One state also stated that present research was adequate.

2.3.1.1.4 Methodology

The primary objective of the research was to assess the accuracy of a human observer in determining levels of highway sign retroreflectivity in a highway environment. To accomplish this goal a series of experiments were conducted using impartial observers to rate the retroreflectivity of traffic signs. Seventeen observers were trained to rate warning and stop signs, first in a dark gymnasium and then from a stationary car on a straight level section of road. The observers rated a series of signs on a scale of 0 to 4 that were placed on a sign post from 100 to

300 feet away. After the training the observers were driven on two highway courses in which they rated 130 traffic signs. The results were then analyzed.

Two sign types were selected for the experiments because of their relative importance, the stop sign and the warning sign. Sign reflectivity experiments were performed under 3 conditions. The first set of experiments took place in Edmundson pavilion at the University of WA. The second set took place outdoors on the University of WA campus under controlled highway conditions. The third set took place in two parts on state highways under actual highway conditions. All experiments were performed in darkness.

2.3.1.1.4.1 Laboratory Experiment

The laboratory experiment was conducted to minimize variables by controlling ambient light, geometrics, and other environmental conditions. The experimental setup was as shown in Figure 2.7. Signs of known retroreflectivity were placed on a sign post with the bottom of the sign at seven feet. Observers marked their judgments on rating sheets using small flashlights to see. The experiment simulated a car parked on the shoulder with the driver observing the sign.

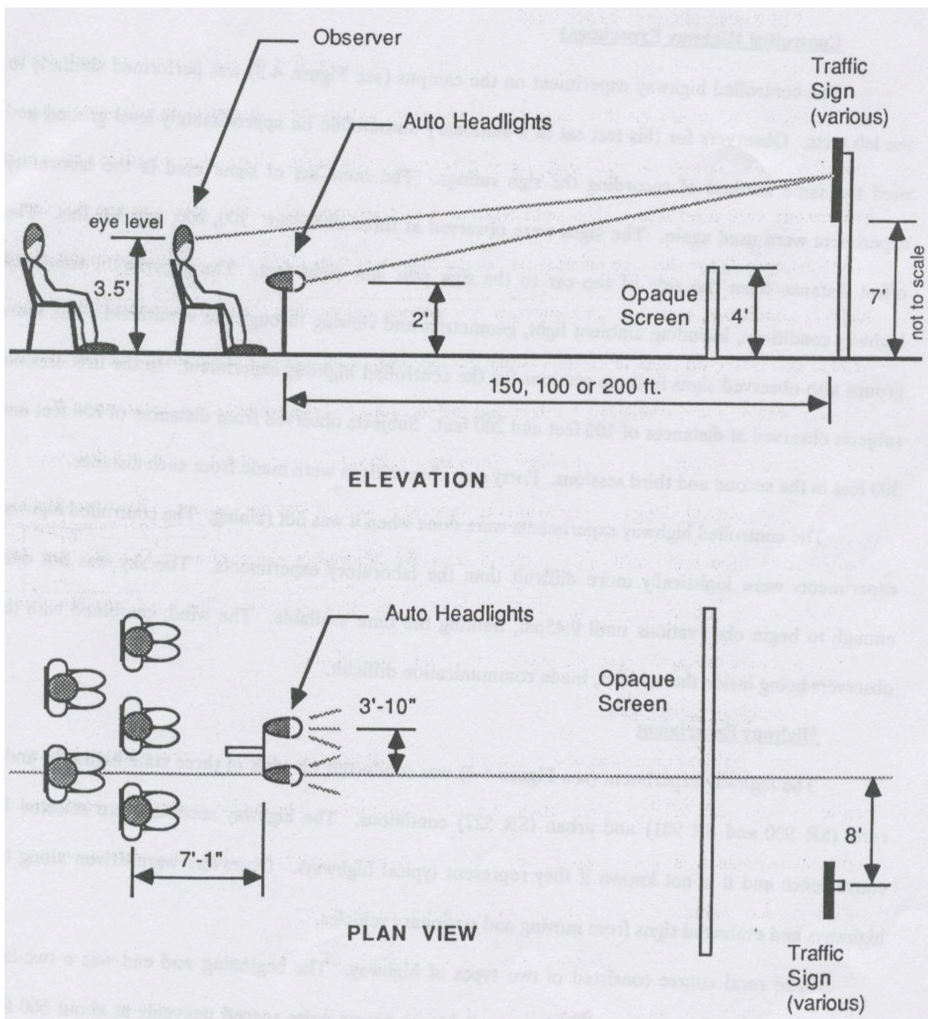


Figure 2.7. Laboratory Experimental Setup

2.3.1.1.4.2 Controlled Highway Experiment

The experiment was conducted using a stationary automobile on approximately level ground with the setup as shown in Figure 2.8. The experiment simulated highway conditions, including ambient light, geometrics and viewing through the windshield. The same group of observers who participated in laboratory experiment also participated in this experiment. The controlled highway experiments were logistically more difficult than the laboratory experiments. The wind, combined with the observers being inside the vehicle made communication difficult.

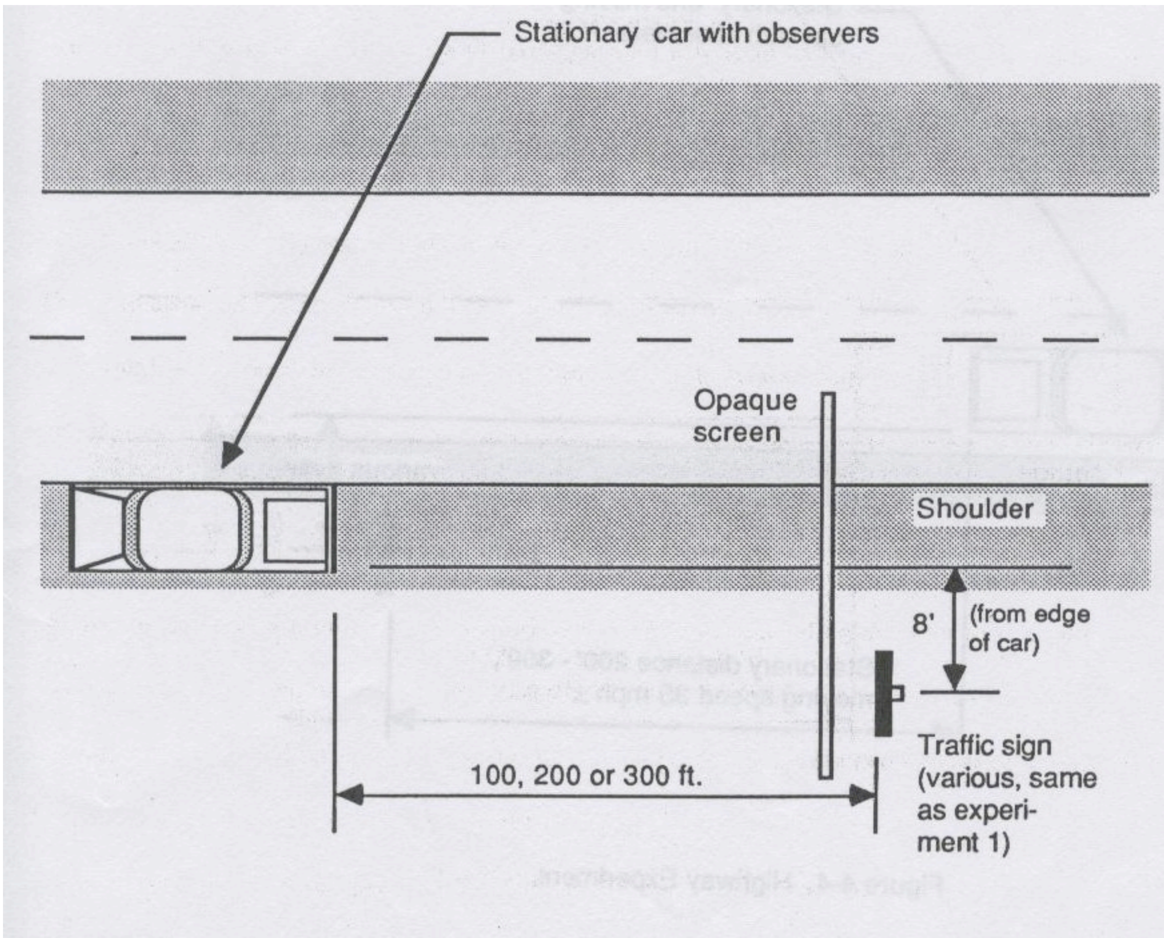


Figure 2.8. Controlled Highway Experiment

2.3.1.1.4.3 Highway Experiment

The highway experiment was conducted on parts of three state highways under rural and urban conditions. Observers were driven along highways and evaluated signs from moving and stationary vehicles. During the experiments, a driver and three observers rode in a car. Each observer had a clipboard with a rating sheet, a small flashlight and a writing instrument. In one direction, the driver stopped the vehicle approximately 200 to 300ft from the warning signs, trying to duplicate the controlled highway relationship between the car and sign. In the return direction the vehicles were driven past the warning signs at the speed limit or about 35 miles per hour, whichever speed was slower, as shown in Figure 2.9. The method of using the same observers on the same night to evaluate signs from a stationary and moving vehicle minimized the experimental variables, including ambient light condition, observer inconsistency from one day to the next, automobile headlight differences and any other factors. Both of the highway courses had numerous directional changes so that observations were in all directions for both the stationary and moving vehicle portions.

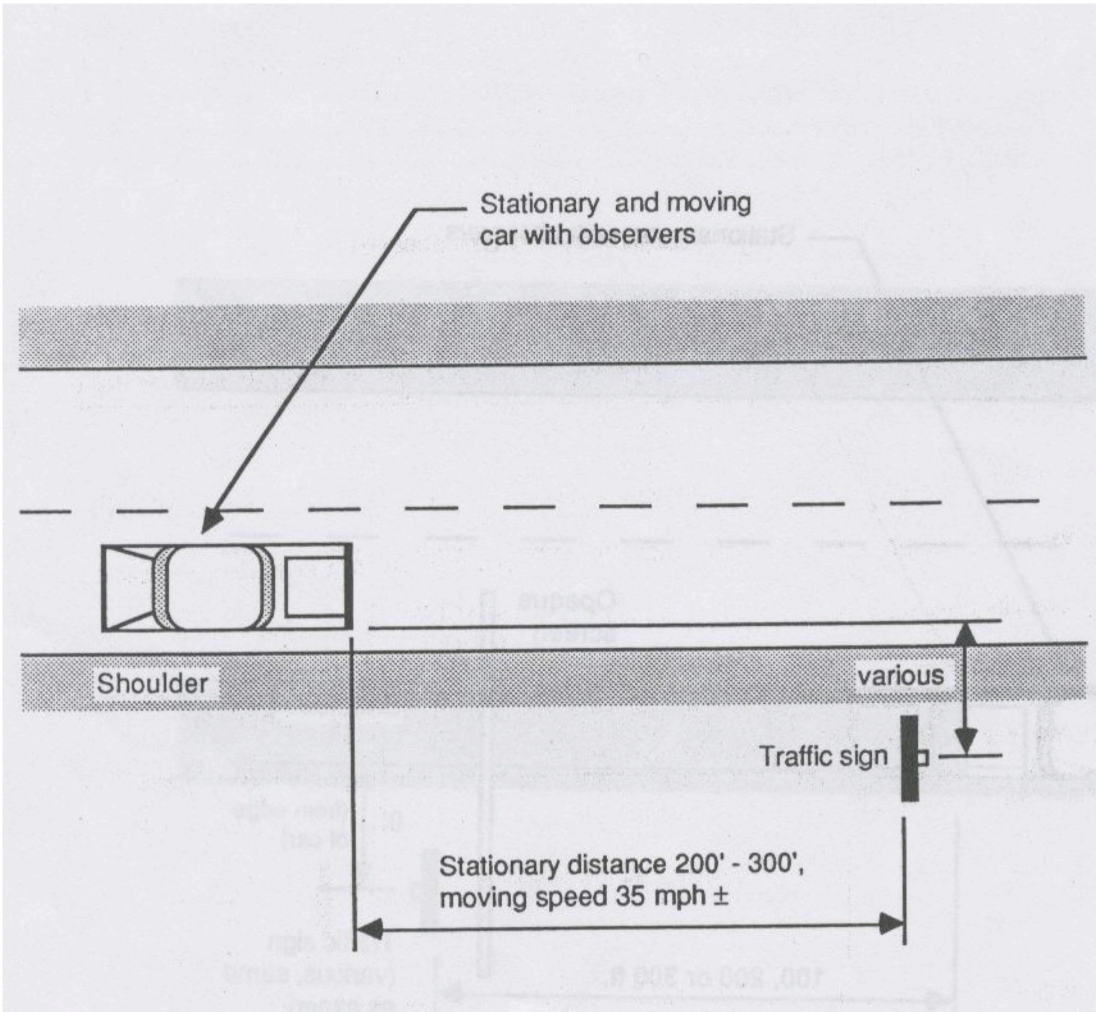


Figure 2.9. Highway Experiment

2.3.1.1.4.4 Sign Retroreflectivity Scale

The objective of the experiments was to determine if a human observer could be trained to accurately rate traffic sign retroreflectivity. During the training period a series of signs were shown to the observers and they rated them based on a retroreflective scale.

The literature included various studies in which observers rated background complexity, determined legibility distances, observation distances and other sign related observations. However all studies were from a drivers perspective of a sign. The WA State study was from a trained maintenance person's or traffic engineer's perspective, and for this reason a retroreflectivity scale for use in sign maintenance had to be developed.

The scale was described to the observers as 0 being the worst a sign could be and 4 being a brand new sign. Category 1 signs were described as having low retroreflectivity or some other defect that would make the sign ready for replacement. Category 2 signs were described as signs that had an adequate amount of retroreflectivity and looked ok. They might also have some defects but not defects detrimental to the function of the sign. A category 3 sign was described as a sign that had good retroreflectivity. The scale actually was three categories with the 0 and 4 classifications for the exceptionally bad or good signs, respectively.

2.3.1.1.4.5 Signs

To conduct the laboratory and controlled highway experiments, a collection of signs representing the range of retroreflectivity were needed. Some signs were obtained from a sign pile in WSDOT's office. These signs were primarily of low retroreflectivity. New signs with high retroreflectivity were obtained from a sign shop. Signs in the midrange were still in service along state highways.

The sign retroreflectivity measurement was done on the signs along the highway using a model 910F Retro Tech retroreflectometer. An extendable pole was used for high signs. Five measurements were taken for each sign and then averaged. First the warning and then the stop signs on a highway were measured. The retroreflectometer had to be recalibrated for each color. Ten signs per hour was the total measurement rate. Note also that only ground-mounted signs on the shoulder were measured.

The signs were presented to the observers in a random order. During the first two sessions in the laboratory, the warning and stop signs were presented separately. During the remaining sessions the signs were mixed.

2.3.1.1.4.6 Observers

Nineteen observers were hired for the traffic sign retroreflectivity experiments. Observers were contacted with a classified advertisement in the University of WA Daily, notice posted at the WA DOT and word of mouth. All were licensed drivers with a high school education and residents of the Seattle area. Observers had corrected acuity with no color deficiencies. The observers were not a statistical sample and do not represent the entire population.

Observers received instruction on how to rate signs in several ways. Two sizes of color chips were used; signs with different ratings were shown together for comparison; observers were shown signs and told their ratings after they had rated the signs; and, observers were shown signs and told what the signs rating were without rating the signs. Observers were also shown graphs of the results of their previous sessions, which showed them their mean for each category of warning and stop signs.

In the first session, observers were given a brief description of the reason for the experiment and how they would be rating signs. Next they were shown two types of signs they would be rating (the warning and stop signs) and a series of color chips that had been cut from both types of signs in each category. The rating scale was described to the observers.

Until now the observers had been shown signs and chips under lighted conditions. Next they were seated in chairs behind the headlights about 150 ft from the sign post, the laboratory lights were turned off, and observations in the dark began. Signs with different ratings, as well as a series of color chips, were held up for comparison to calibrate by the observers. Observers were shown graphs of how well they had done in previous sessions, reminded of the rating scale and what the rating meant, shown the large color chips in the dark condition and shown signs for calibration.

2.3.1.1.4.7 Test Vehicles

Vehicles used were four door sedans. All the vehicles were equipped with two square halogen headlamps that were used on low beam.

2.3.1.1.5 Data Analysis

The objective of the experiment was to determine how well an observer can be trained to evaluate the retroreflectivity of traffic signs. Before each session the observers were shown graphs of how well their mean evaluation for each category of signs compared to the actual value.

A rating value based on the mean squared difference between the actual sign rating and the observers rating was used to rank the observers. This value was in observer rating units (ORU) and was calculated for each category by squaring the difference between the observer rating and the actual sign rating, summing these values for all the observations in each category, dividing by the number of sign observations in that category and then taking the square root. The values for each category were summed and then divided by the number of categories to obtain an average value or unit value per category.

The ORU for all the observers at every session was calculated and plotted on a graph. Figure 2.10 shows a dot for each observer's ORU, along with the mean and standard deviation of the ORU's for each session. The observation distance as well as whether the car was moving or stationary for rating the warning signs in the highway experiment is also shown.

The improvement of the observers can be seen from left to right, starting with the laboratory experiment, then the controlled highway experiment, and finally the uncontrolled highway experiment. As the Figure shows, the observers did not dramatically improve throughout the experiments. The mean and standard deviation of the ORU's exhibited a general downward trend for the laboratory and controlled highway experiments. This trend indicated an increase in accuracy and consistency for the observers. However some of the signs had recognizable defects and some improvements could be attributed to the observer's familiarization with the signs. Some observer boredom was also evident towards the end of controlled highway experiment, which could also have affected the results.

The final analysis of the observers also shows that the ORU mean and standard deviation did not change much between the controlled highway and the highway experiments considering and of the 200 to 300 foot distances or the stationary or moving observations. The standard deviation was high for one road session but the mean was the lowest. Observers in this session seemed to be separated into two groups. One group was average with respect to the other sessions while the other group was much better than average.

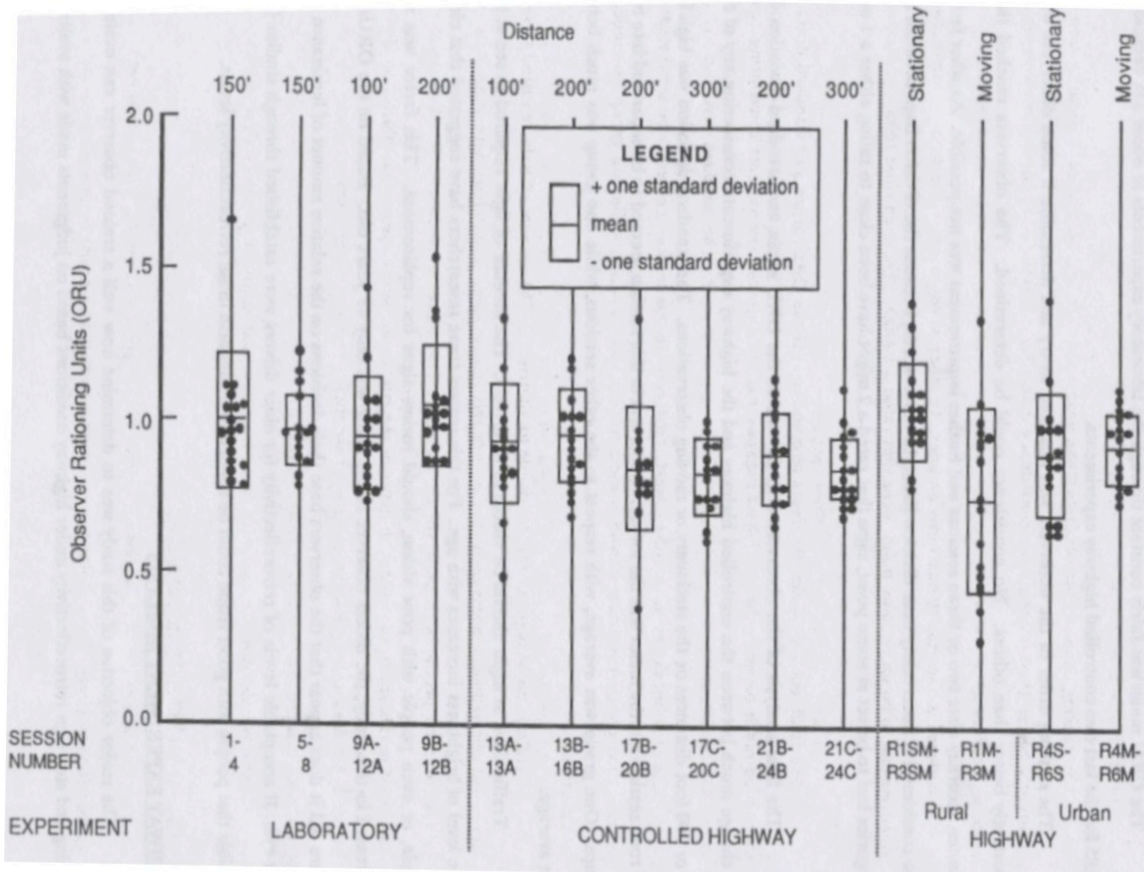


Figure 2.10. Observer Accuracy

2.3.1.1.5.1 Highway Experiment Analysis

The primary results of the highway experiments were the comparisons of the observers rating of the signs and the rating of the signs calculated by using the retroreflectometer. The replacement retroreflectivity level for both types of signs was based on visual complexity for each sign location. Signs would be replaced if a sign on rural road with dark conditions rated 1 and if a sign in an area illuminated by streetlights and/or commercial lights rated 2. A sign with a rating of 3 would remain in place under all conditions. The use of these criteria essentially reduced the scale from one of five categories to only three. The 0 and 4 became special cases of 1 and 3 ratings, respectively.

The observer's median rating combined with the replacement criteria discussed earlier in the Sign Retroreflectivity Scale Section resulted in one of four possible decisions. The decision to replace or not to replace a sign either agreed or disagreed with the decision model to replace or not replace the sign based on the true retroreflectometer rating of the sign. Two of the four decisions would have been correct - the observers could have replaced the sign in agreement with the decision model or they could have let the sign remain in place in agreement with the decision model. The two incorrect decisions by the observer would have had differing consequences. A decision by the observers not to replace a sign that was scheduled for replacement by the decision model would have created an unsafe condition for the driver and increased liability for the agency. The decision to replace a sign unnecessarily would have created an additional expense for the highway agency.

Table 2.7. Highway Experiment Results

Observers Decision	Replace		Do Not Replace	
Decision Model	Replace	Do Not Replace	Replace	Do Not Replace
Warning Signs				
Rural				
Number of Signs	15	0	0	41
Median	13	9	2	32
Individual	13	10	2	31
Urban				
Number of Signs	11	0	0	19
Median	9	6	2	13
Individual	8	7	3	12
Total Number of Signs	26	0	0	60
Median	22	15	4	45
Individual	21	17	5	43
Stop Signs				
Rural				
Number of Signs	9	0	0	11
Median	7	2	2	9
Individual	6	2	3	9
Urban				
Number of Signs	18	0	0	6
Median	14	0	4	6
Individual	13	1	5	5
Total Number of Signs	27	0	0	17
Median	21	2	6	15
Individual	19	3	8	14
Combined				
Total Number of Signs	53	0	0	77
Median	43	17	10	60
Individual	40	20	13	57

Table 2.7 summarizes the decisions of the observers and the decision model for the highway experiments. The Table is partitioned by warning and stop signs as well as by rural and urban

experiments. The Table shows that of the 130 signs in the highway experiment, the observer's median rating and the decision model were in agreement on 103 signs or 79 percent of the total. Seventeen signs were replaced that should have remained in place. Ten signs were not replaced that should have been replaced. The Table also lists the average sign replacement decisions for the seventeen observers in each of the four rating decision categories.

Figures 2.11, 2.12, and 2.13 were constructed to determine at what levels of retroreflectivity signs were replaced in the highway experiments. In Figure 2.11 the range of retroreflectivity for the warning signs is partitioned into sub-categories within the limits of each rating category. The Figure is also separated into two graphs for the two different replacement levels. The number of signs in each sub-category is shown as well as the number of signs in each category that were replaced. The graphs show that of the 17 warning signs in the 0 and 1 category, at the two replacement levels, 16 signs were replaced. The observers were very accurate in replacing warning signs at this level. Thirteen of the seventeen signs scheduled for replacement in the 2nd category were replaced. The graph also shows unnecessary replacements. At replacement level 1, six unnecessary sign replacements are scattered throughout the remainder of the scale. At replacement level 2, nine unnecessary sign replacement are distributed throughout the three and four range. This means that when a sign is to be replaced at level 2, more signs will be replaced unnecessarily.

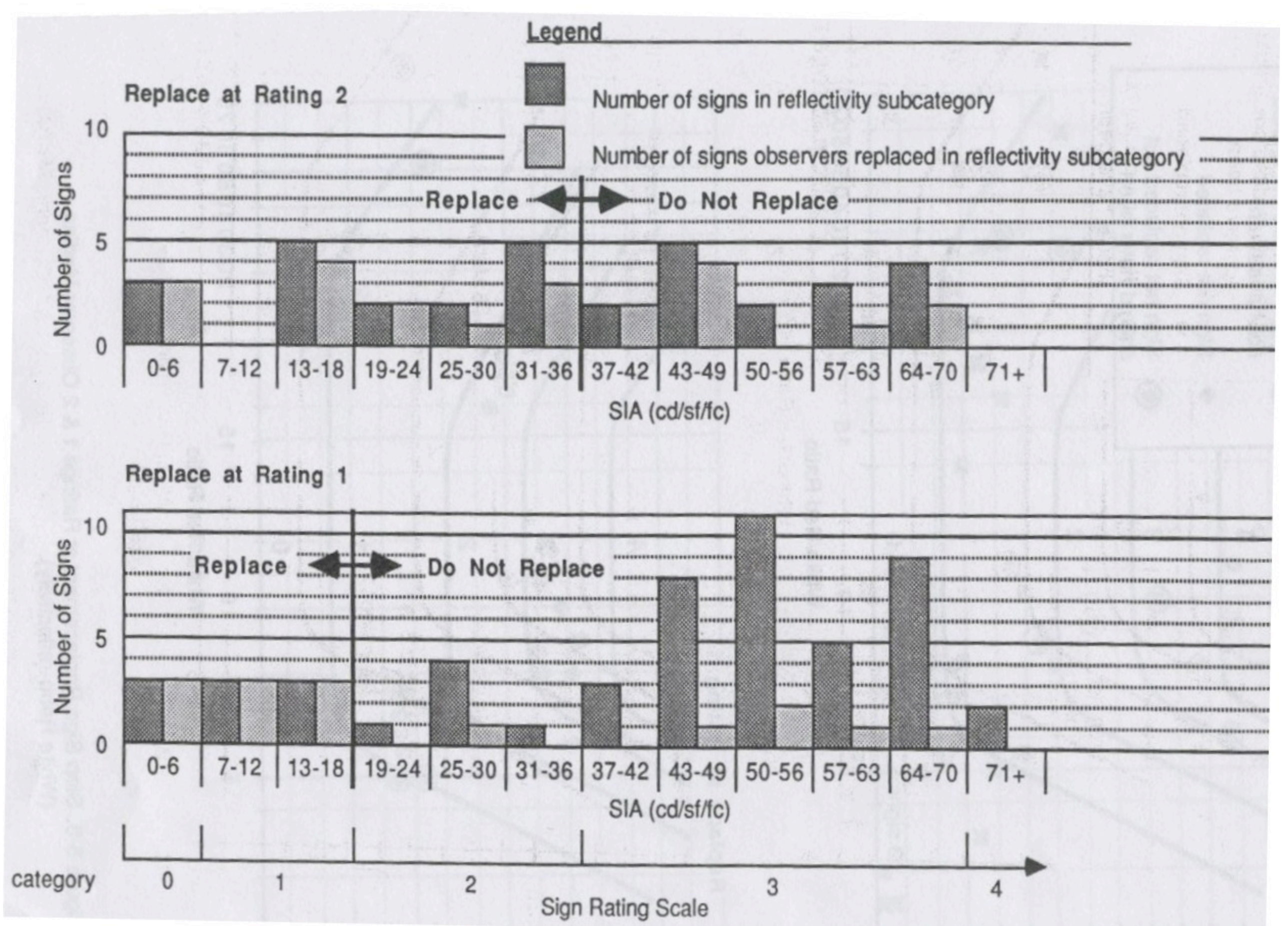


Figure 2.11. Warning Sign Replacement at Ratings 1 & 2 Observer Median

Figures 2.12 and 2.13 represent the observer's decisions about the stop signs in the highway experiments. The Figures are separated into two graphs for the two replacement levels and show the same results in different ways. Figure 2.12 is a plot of the observer's decisions using the same scales as the rating graphs, the SIA of the white on the vertical axis, and the white/red ratios on the horizontal axis. Figure 2.13 is a plot of the observer's decisions with the overall SIA of the sign on the vertical axis and the white/red ratios on the horizontal axis.

Figure 2.12 and 2.13 at replacement level 1 show that signs with an SIA of the white over 80 and an overall SIA over 30 remained in place. The Figures at replacement level 2 show that observers generally replaced all stop signs below a white SIA of 100 or an overall SIA of 40.

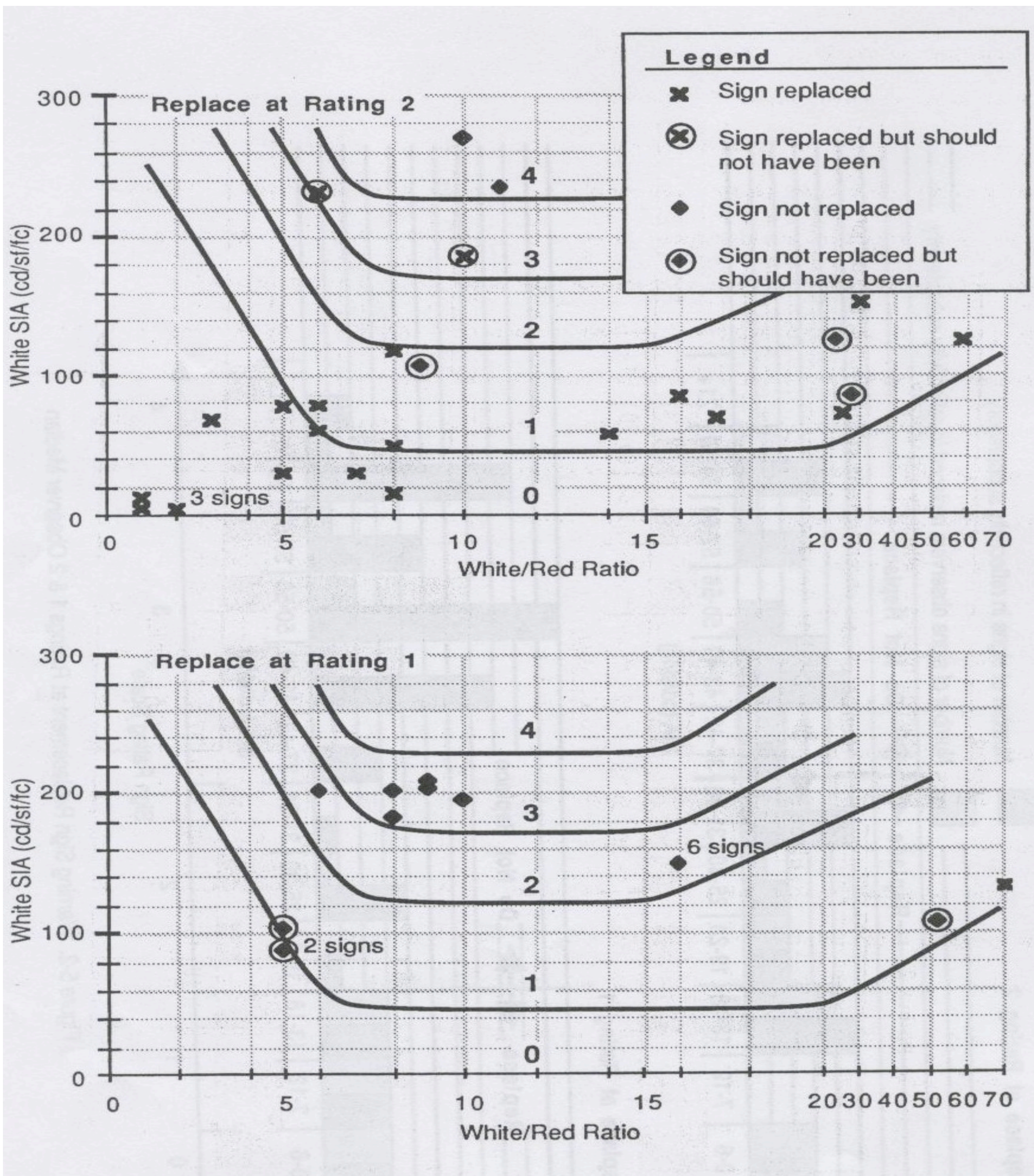


Figure 2.12. Observer's Decision for Stop Signs

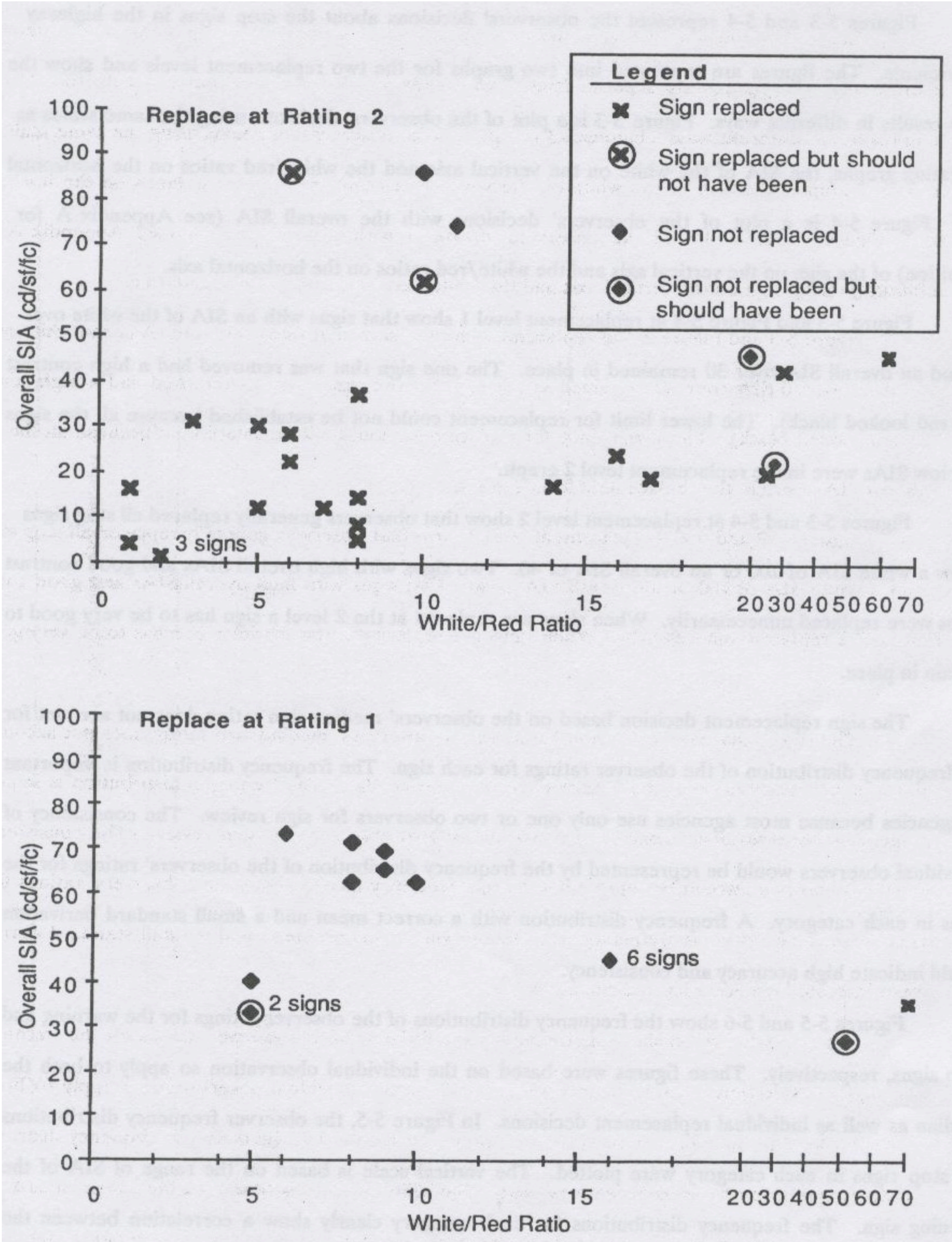


Figure 2.13. Observer's Decision for Stop Signs

Figures 2.14 and 2.15 show the frequency distributions of the observer ratings for the warning and stop signs, respectively. These Figures were based on the individual observation so apply to both the median as well as individual replacement decisions. In Figure 2.14, the observer frequency distributions for stop signs in each category were plotted. The vertical scale is based on the range of SIA of the warning sign. The frequency distributions for each category clearly show a correlation between the observer's ratings and the sign ratings calculated based on retroreflectometer readings. The observers were very accurate rating signs in the 0 and 1 categories. The frequency distribution of the observer's ratings for signs in the 2 category shows about 50 percent of the ratings at the 2 level with about 22 percent of the ratings either one rating category higher or lower. The frequency distribution for the 3 categories shows the mean observation to be about 2.4 with a fairly wide spread. Eighty percent of the ratings of the signs in category 4 were about equally split between ratings 3 and 4 with a small percentage of signs being rated 0, 1, or 2.

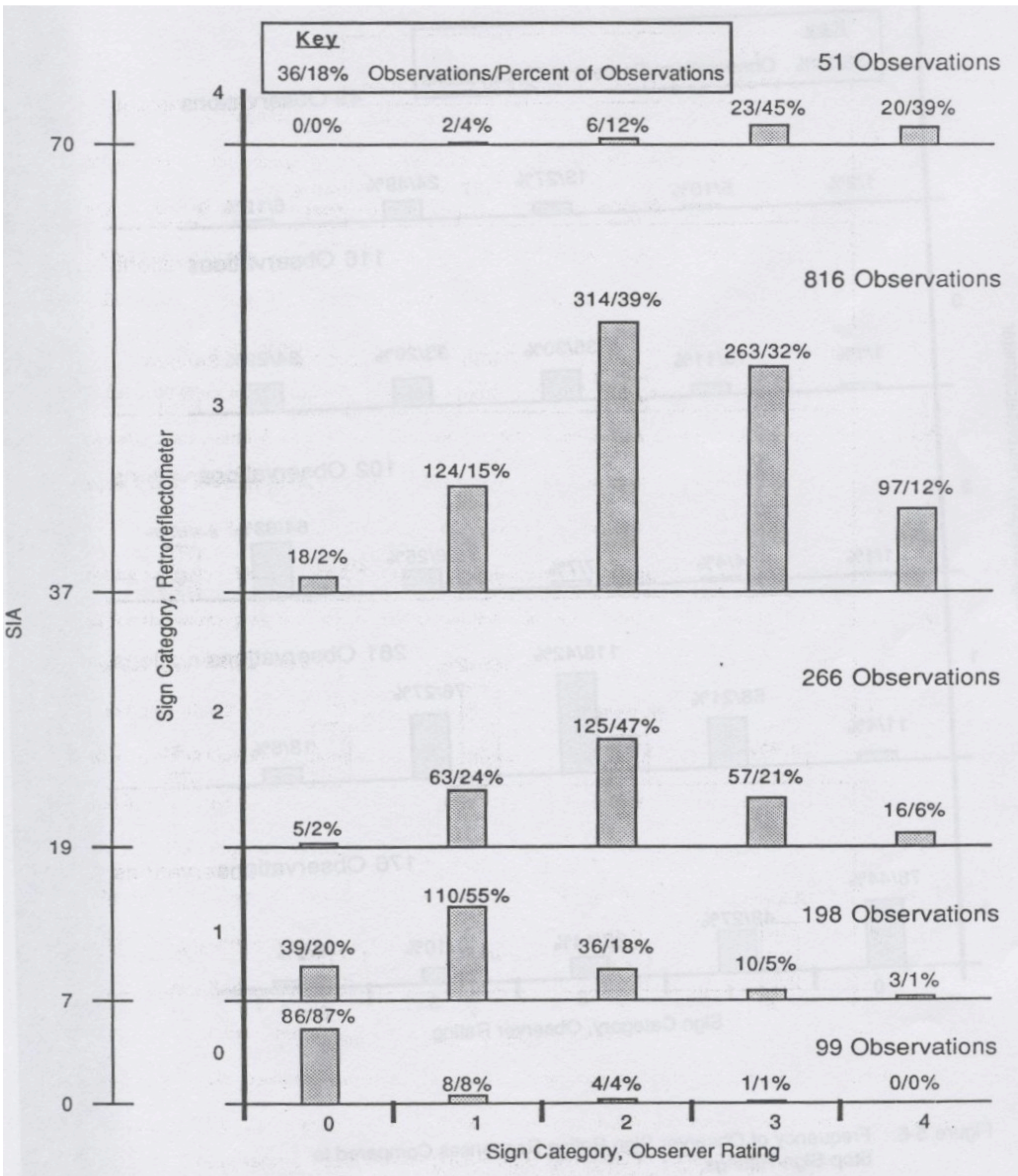


Figure 2.14. Frequency Distribution based on Sign Retroreflectivity

The Figure generally shows that observers have a high accuracy and consistency for signs rating 0 or 1, that the frequency distribution for signs in category 2 is fairly wide, and that the frequency distributions for signs in category 3 and 4 tend to be a little on the low or conservative side. Observers generally rate good signs a little lower than they should, probably due to poor geometries or other factors.

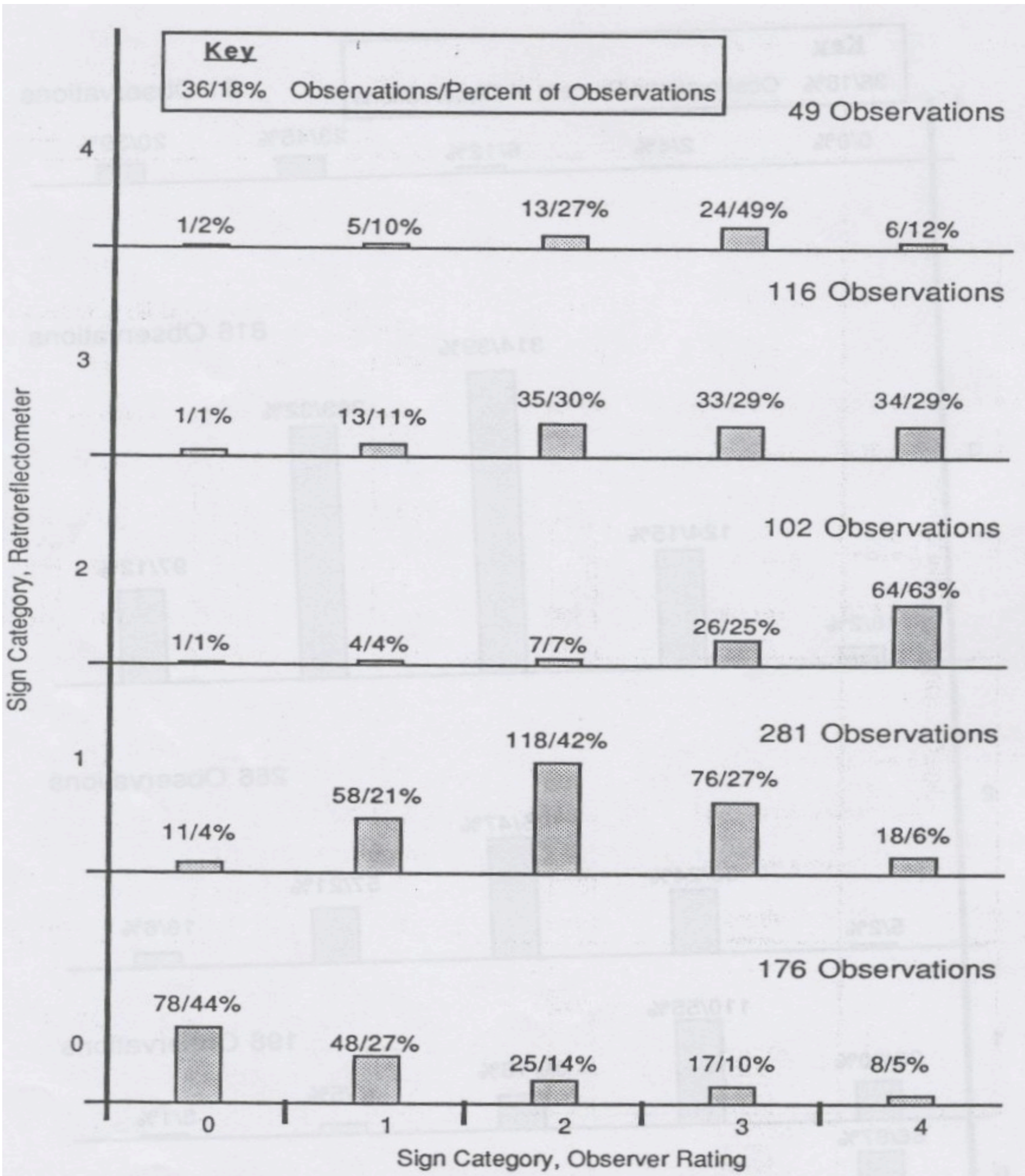


Figure 2.15. Frequency Distribution Based on Sign Category

Figure 2.15 shows the frequency distributions of the observer's ratings for the stop sign in each rating category. The correlation between the observer's ratings and the calculated ratings is not as strong as for the warning signs. Observers were able to rate stop signs in the 0 category with some consistency but did tend to rate somewhat high. Signs in category 1 for retroreflectometer readings were rated in all observer rating sign categories with 42 percent rated into the 2 observer rating category; about 25 percent rated into each of observer rating categories 1 and 3; and, the remaining 10 percent of the observations evenly split into observer rating categories 0 and 4. The majority of the signs in categories 2, 3, and 4 were rated about evenly into categories 2, 3 and 4 with a small percent at either 0 or 1.

2.3.1.1.5.2 Retroreflectometer Versus Human Eye

A Retrotech 910F retroreflectometer was used to measure the retroreflectivity of the signs used in the experiments. While the Retrotech 910F was easy to use and reliable, certain discrepancies between how a retroreflectometer sees a sign and how a human sees a sign became evident.

The retroreflectometer can measure only 0.4 percent of the sign area. Vandalism, dents and damages are not seen by the retroreflectometer while an observer sees the luminance of the entire sign and this is sometimes quite different. According to the author, a thin uniform layer of dirt on a sign does not have as much of an effect on the retroreflectometer reading as one would think. Dirt tends to be the heaviest at the bottom of the sign. Any substance thrown at the sign tends to stick in blotches and is often not measured. If a sign is cleaned it must be cleaned entirely to avoid it look blotchy.

2.3.1.1.5.3 Sign Rating Scales

The warning sign rating scale was satisfactory. While the signs seemed to degrade gradually from one category to another, at the point where the SIA reached about 18, the sign would degrade rapidly. This was the point where all signs were replaced in the study.

Figure 2.16 shows the stop sign rating scale for all sheeting materials. The Figure shows the final stop sign rating lines for all the sheeting materials. Upon completion of the experiments a closer examination of the stop sign rating system was performed. The objective of the examination was to evaluate exactly how the observers were rating the signs. First the average rating for each sign was calculated. These values were then placed on two separate graphs. The first graph was similar to the original scale with the SIA of the white and the white/red ratio. The second graph had the overall SIA of the sign on the vertical axis and the white/red ratio on the horizontal axis. The study team believed that contour lines of equal rating could be drawn and would indicate more closely how observers were rating the signs. Definite contour lines could not be drawn on the graphs, but several conclusions could be drawn from the graphs. On both graphs a 0-1 contour line could be drawn with same confidence. Other contour lines on both graphs were inconclusive.

2.3.1.1.6 Summary

The literature survey and the questionnaire sent to the 50 state agencies showed that instruments to evaluate traffic sign retroreflectivity are accurate but not used on a large scale because of the cost required to use them. At present the human observer is almost exclusively used to evaluate sign retroreflectivity, but had been of unverified accuracy.

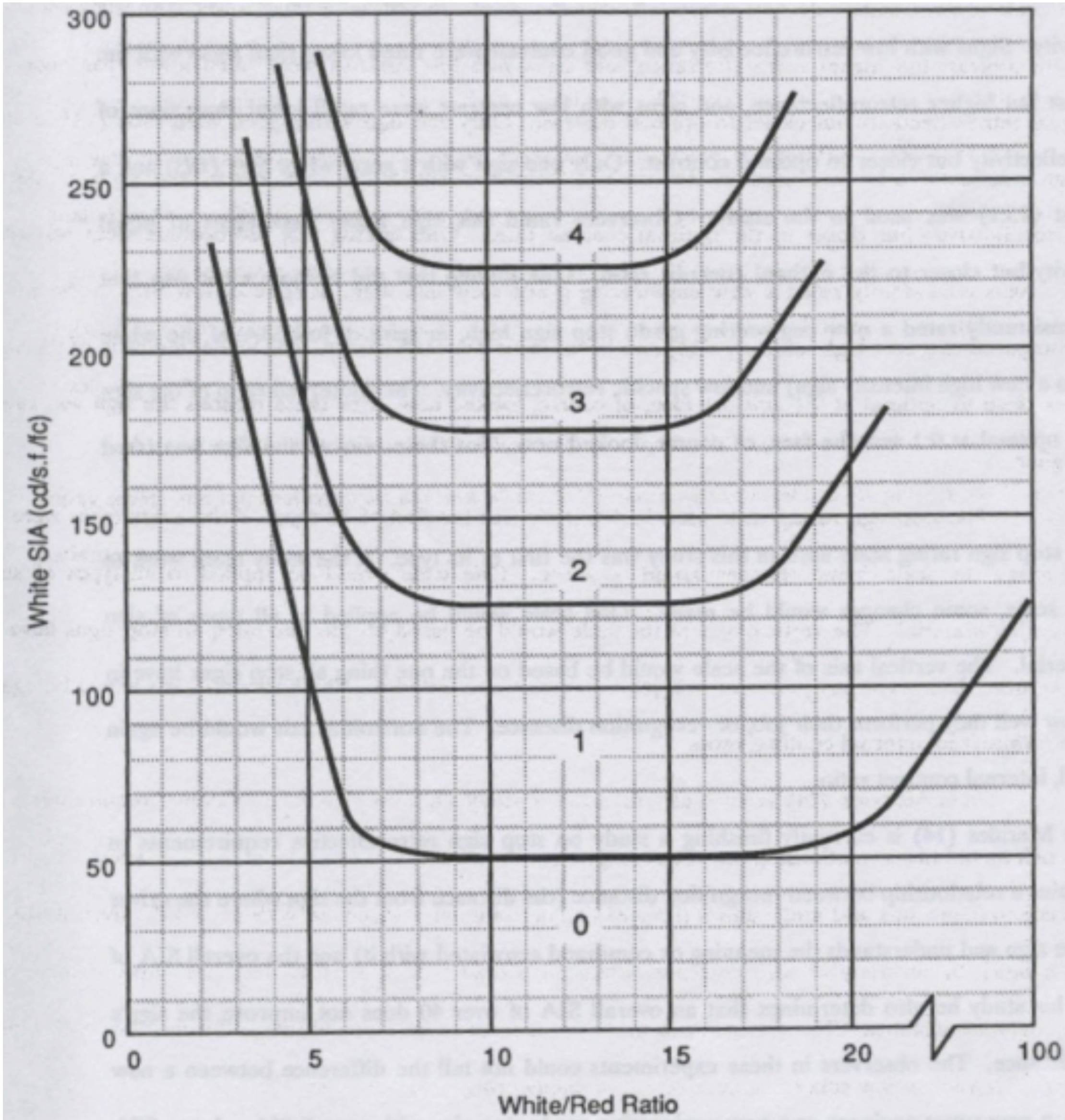


Figure 2.16. Stop Sign Rating Scale - All Sheeting Materials

Major findings of the survey questionnaire were as follows

- Few states (15) have any policy for sign replacement;
- 23 states supplement visual inspection, most using retroreflectometers;
- Most states (31) do not have any plans to modify their inspection procedures, indicating that current procedures are adequate; and
- Only nine states are planning or performing research related to sign retroreflectivity.

The main objective of the report, to assess the accuracy of the trained observer in evaluating traffic sign retroreflectivity, was accomplished through a series of experiments.

The primary results of the highway experiments are the comparisons of the individual observer rating of the signs and the rating of the signs calculated by using the retroreflectometer. The individual observer rating was incorporated into a decision model to replace or not to replace the sign the sign based on the retroreflectivity of the sign and visual complexity of the sign environment. Figure 2.17 shows the highway experiment results by sign type. A and D are the correct decision to replace and to not replace a sign, respectively. B is the incorrect observer decision to permit a sign to remain in place when it should have been replaced. C is an incorrect observer decision to replace a sign when it should have remained in the field. The observers were correct on 74 percent of the warning signs and on 75 percent of the stop signs. The observer correctly rated a high percentage of signs. The experiments have shown that a trained observer is a valuable part of the sign maintenance program. The trained observer sees a sign in the same way that a driver sees a sign. The retroreflectometer, while extremely accurate and consistent, overlooks many factors important to the driver.

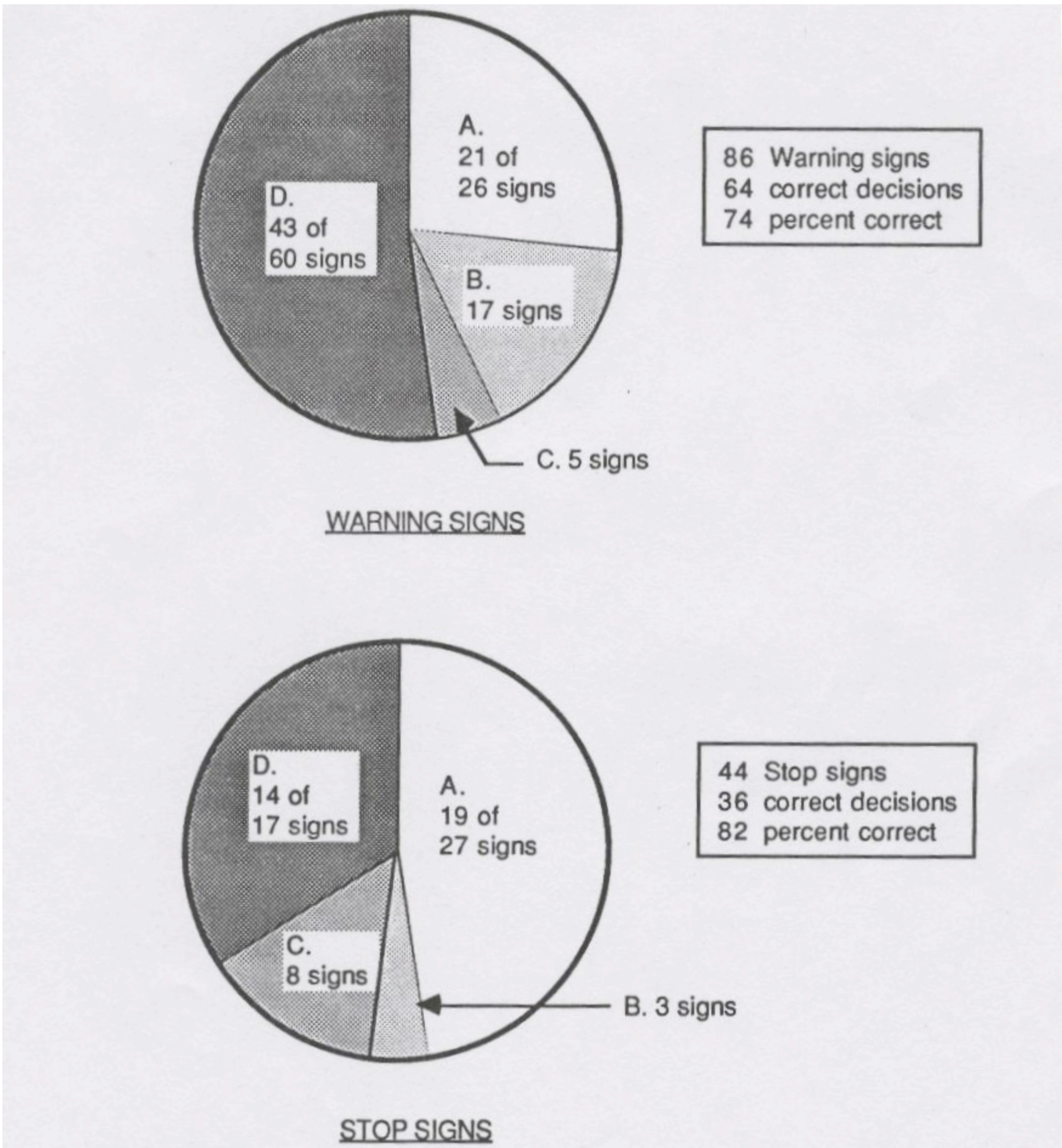
2.3.1.1.7 Conclusions

Figure 2.18 shows observer accuracy and demonstrates that the observers used in the study performed equally as well. The Figure shows how different observers rated a given sign. Most of the observers rated signs similarly thus demonstrating that all observers rated signs equally well. Observers were able to easily tell a good sign from a bad sign, but because of the category division lines and other variables (including the sensitivity of the eye) the observer cannot be totally accurate. The observers used in the study all had good vision.

It was determined that trained observers can make accurate and reliable decisions to replace signs. Several factors encountered in the study would improve their accuracy:

- Observers should be used in pairs-one to drive the vehicle and one to keep records;
- The approach to a sign should be clear of obstructions;
- Nighttime observations should be made under favorable weather conditions.
- Straight, level approach geometries.
- The sign should be plumb and approximately 90 degrees to the observer;
- Dirty signs should be cleaned;
- The observer should be used in conjunction with a sign management system which includes the installation date and the life expectancy of the sign;
- A comprehensive daylight review should be performed prior to the nighttime review;
- The trained observer should be used as the final check after the obvious corrections to the signs on a highway have been made;
- The trained observer should be familiar with sign criticality; and
- Signs rating 2 should also be checked with a retroreflectometer for final replacement decision.

Sign maintenance will cost agencies money but it is necessary to decrease nighttime accidents and agency liability. The WA study team observed many stop signs in all states of serviceability. An incidental conclusion was that the thickness of the transparent red ink on a new stop sign makes a considerable difference in the appearance of the sign at night. The light reflected through the red ink must travel through the ink twice. If the ink is too thick, even the red on a brand new sign will look black at night.



LEGEND

Individual Observer	Replaced		Not Replaced	
Decision Model	Replace	Do Not Replace	Replace	Do Not Replace
	A (correct)	B (incorrect)	C (incorrect)	D (correct)

Figure 2.17. Warning and Stop Sign Replacement, Individual Observer

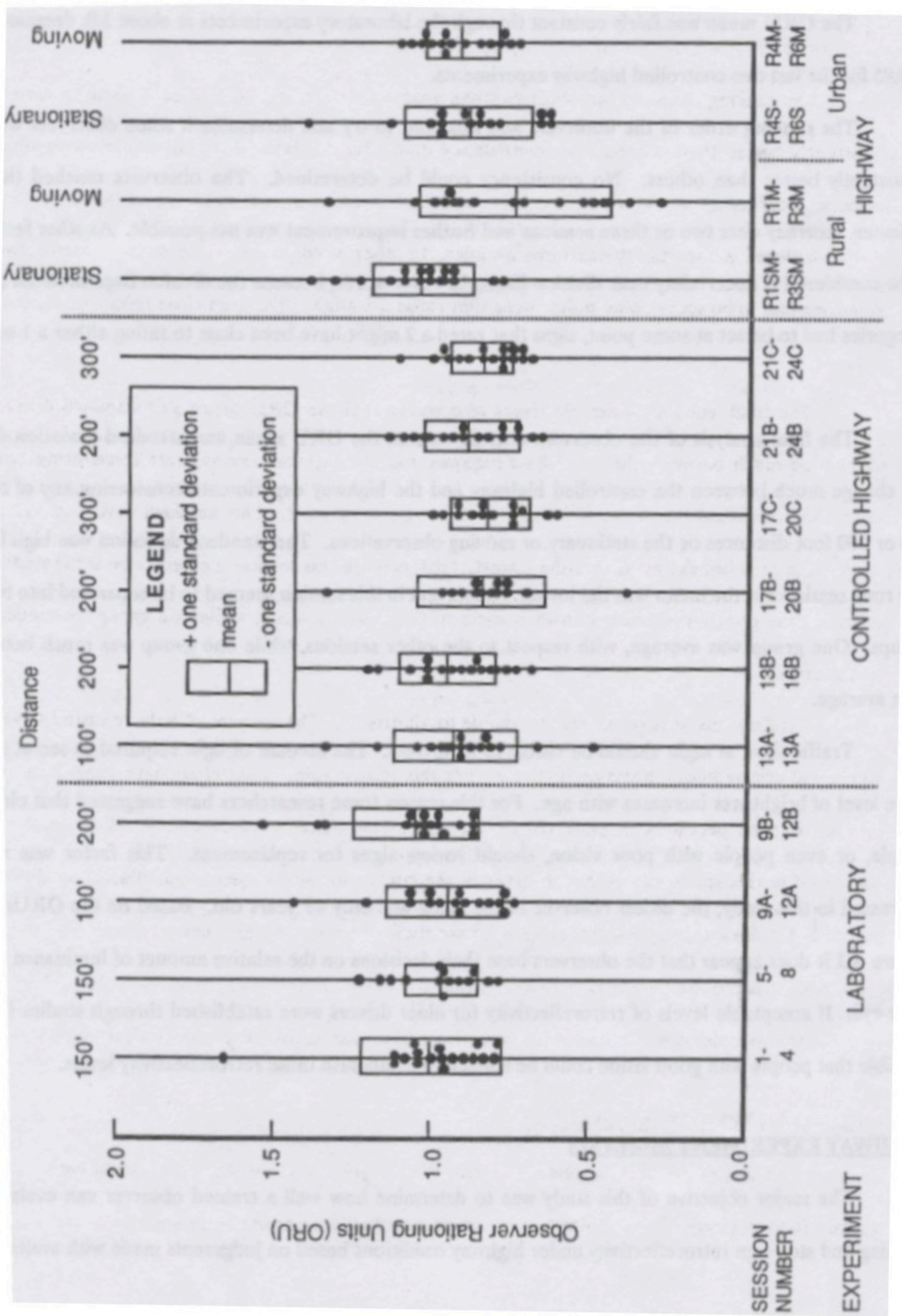


Figure 2.18. Observer Accuracy

2.3.1.1.8 Recommendations

1. Trained observers should be seriously considered before undertaking research to develop an expensive retroreflectometer to evaluate traffic sign retroreflectivity.
2. Agencies should design a training program to instruct personnel who are currently making sign replacement decisions. Training would make sign replacement more uniform throughout a jurisdiction and create safer highways for the motorist. Instruction of observers would demonstrate that agencies are actively training personnel to inspect signs. Observer training, in combination with regular day and night inspection, substantiated with record keeping indicating that effective remedial action is taken in a timely manner, would be the key elements in a tort action.
3. Several states maintain their signs at different levels of retroreflectivity for different classifications (speeds) of highways. Sign criticality could also be considered in sign replacement. These policies may be good ways to stretch limited funds.
4. The last recommendation is incidentally to the study. The transparent red ink used on stop signs should have a specified thickness. At the present time the only requirement for the application of the ink is that it is put on uniformly and that borders are clear and sharp. With this specification agencies will be able to control the internal contrast ratio of the sign.

Table 2.8. WA Study Summary

Objective	To determine the accuracy of trained observers in rating the retroreflectivity of traffic signs.
Important Parameters	• Study was completed in the year 1987. • Both indoor and outdoor observation of signs. • 910F RetroTech retroreflectometer used. • Stop and Warning signs studied. • Type I sheeting studied. • Observers trained before observation of signs. • Signs were not cleaned before taking data. • Sample size of 130 signs. • No deterioration factors considered.
Key Findings	Observers correctly rated 75% of warning signs and 82% of stop signs based on visual observation.

2.3.1.2 TX Study

In 1993, the FHWA published research recommendations for minimum levels of retroreflectivity [Paniati, et. al. 1993]. The values were later revised in a 1998 FHWA report [Gee, et. al. 1998]. The minimum values were developed as part of a process to add end-of-service life retroreflectivity values to the MUTCD. At that time there had been little or no comparison of using the minimum values to define end of service life versus the results of typical nighttime visual inspections.

In an effort to gain a better understanding of the relationship between the FHWA research recommendations for minimum retroreflectivity and nighttime visual inspections of sign retroreflectivity, researchers at the TX Transportation Institute compared the results of visual sign evaluations to the minimum retroreflectivity values. The evaluation was conducted as a part of a TX Department of Transportation (TxDOT) Sign Crew Workshop. Over 50 TxDOT sign personnel from the field attended the workshop. In the workshop, participants were asked to evaluate the nighttime appearance of signs in the same manner as they would while conducting their annual nighttime sign inspection. Although TxDOT requires an annual nighttime inspection of all signs, there are no specific criteria for conducting the evaluation. This study gives the results of the nighttime sign inspections and compares the results to the minimum retroreflectivity guidelines.

2.3.1.2.1 Experimental Method

The Nighttime retroreflectivity inspection was conducted by having the participants drive a closed course, during which they observed numerous sign installations. As participants approached a sign installation, they rated the sign or signs on the post as “acceptable,” “marginal,” or “unacceptable.” The results of the visual evaluation were then compared to the measured retroreflectivity of the sign. The retroreflectivity of all these signs was measured using a Delta Retrosign 4500.

2.3.1.2.1.1 Evaluation Course

A five mile course at a former Air Force base with inactive runways was used as the evaluation course. There were a total of 49 signs on this course. The sign installations were approximately 500 ft apart. And there were several distinct road sections so that no more than 8 sign installations were in the field of view at any one time. The bottom of the lowest sign at each installation was set at seven feet in height and the sign left edges were offset 12 feet from the right edge of the lane. There was very little ambient lighting on the course.

2.3.1.2.1.2 Sign Selection and Retroreflectivity Measurements

In preparing for the Sign Crew Workshop, the researchers collected approximately 200 signs from scrap yards of various divisions for potential inclusion in the evaluation. The use of scrap signs was the only practical means of presenting signs that had retroreflectivity values at or near minimum standards.

The researchers selected signs for the evaluation that represented a range of sign colors, legends, and retroreflectivity values. Retroreflectivity values were selected to represent a range of retroreflectivity levels at or above the FHWA research recommendations. Initially the many signs at or below the FHWA minimum levels of retroreflectivity but when these signs were observed with pilot evaluations with TxDOT staff, it was determined that the signs were obviously unacceptable. Thus, were therefore eliminated from the evaluation and replaced with signs having higher retroreflectivity values. The researchers and TxDOT staff coordinating the sign crew workshop determined that this was appropriate, as the signs selected for the evaluation represented an appropriate mix of clearly acceptable, questionable, and clearly unacceptable signs similar to those found on TX highways.

2.3.1.2.1.3 Evaluation Procedure

A total of 30 vehicles participated in the evaluation. There were typically two people in each vehicle, one driving and the other filling out an evaluation form. A small number of vehicles had three people. Participants drove the couse at a speed between 30 to 40 mph and filled out an evaluation form as they traveled through the course. The evaluation form consisted of a graphic of each sign assembly and the rating scale for each sign assembly. The participants were instructed to evaluate the sign retroreflectivity in the same manner that they would do their normal TxDOT sign inspection.

2.3.1.2.1.4 Experimental Control

TxDOT has no specific departmental guidelines on how to conduct nighttime sign inspections beyond a guideline that inspections be conducted annually. Therefore, the researchers did not attempt to control for any sign evaluation factors such as the visual acuity of the evaluators, the distance or speed at which the signs were evaluated, or the illuminance of the vehicle headlights.

2.3.1.2.2 Findings

Several analyses were conducted using the evaluation results and headlamp data. In one evaluation, the results were tabulated for each sign and compared to the result of applying the minimum retroreflectivity values to the signs. Another evaluation attempted to identify potential impacts of the headlight illuminance on the evaluation results.

2.3.1.2.2.1 Visual Evaluation Results

The evaluation results for each sign were tabulated by assigning a value of +1 for each acceptable rating, a value of 0 for each marginal rating, and a value of -1 for each unacceptable rating. The total score was then divided by the number of ratings to get an average rating for each sign. For analysis purpose the researchers established that an average rating of zero or less defined unacceptable sign.

As a result of the screening process used in the pilot evaluation, there was only one stop sign that did not meet the low speed FHWA minimums (4:1 contrast ratio). The low speed retroreflectivity values were used because the evaluations were conducted at speeds between 30 and 40 mph. The researchers also identified the signs in the evaluation that did not meet the FHWA high speed research recommendations. There were only three of these signs and all were white signs.

Since all signs were acquired from various scrap piles, they did not have a consistent level of uniformity across the face. Therefore, the researchers also developed a sign face uniformity rating (A, B, or C) to assess the uniformity of the sign retroreflectivity, as described below:

- A-Even, consistent appearances across the sign face.
- B-Some visible inconsistencies across the sign face, but inconsistencies do not interfere with the sign legibility.
- C-Significant inconsistencies across the sign face or inconsistencies impair sign legibility.

When the effect of sign sheeting was included the following became apparent:

- There were four signs with no sign face inconsistencies (A rating) that had an average rating less than zero.

- The signs with minor inconsistencies (B rating) were approximately evenly split between acceptable and unacceptable evaluation. Among the unacceptable ratings four had low retroreflectivity values (less than 50).
- None of the signs with significant sign face inconsistencies (C rating) had an average rating higher than 0.03.

When the evaluation results were considered with respect to the sign material the following findings were identified:

- White engineering grade signs were rated acceptable if the retroreflectivity value was over 50 and the sign was displayed alone on a sign post.
- White engineering signs with retroreflectivity values below 50 or that were displayed in combination with another sign were rated as unacceptable.
- None of the yellow engineering grade signs were rated as acceptable. All of these signs had uniformity ratings of B or C.
- Positive contrast engineering grade signs had to be new or nearly new to be evaluated as acceptable.
- All of the high intensity signs with a uniformity rating of A or B were evaluated as acceptable, with one exception.

One of the interesting findings of the evaluation occurred when there were multiple signs on a single post. Seven of the 41 installations had multiple signs. In two cases, different materials were combined on the same post. One example of the complexity of material variation was that a cardinal direction marker with new super engineering grade sheeting (Ra=165), the route marker was old high intensity sheeting (Ra=253), and the arrow marker was nearly new engineering grade sheeting (Ra=97). However, even though the two markers were new, their retroreflectivity was lower than the route markers and they were evaluated as unacceptable.

2.3.1.2.2.2 Relationship Between Evaluation Results and Headlight Illuminance

Retroreflectivity of a sign material is only one factor in determining the overall luminance of a sign at night. A retroreflective material can only return a portion of light that is directed at the sign. A sign with high retroreflectivity can have low luminance if only a small amount of light falls upon the sign. Conversely, a sign with low retroreflectivity can appear bright if the illuminance is high. The luminance is defined as the amount of light reflected by sign while illuminance is the amount of light incident on sign.

There was significant variability in the illuminance of the vehicles taking part in the evaluation. In an attempt to relate visual evaluations to headlight performance, the researchers calculated an average rating for each vehicle for all of the signs in the evaluation. The average rating per vehicle was then plotted as a function of the illuminance at 250 ft and 500 ft. A regression analysis was done for the plot of illuminance versus average rating/vehicle. For both distances, the linear regression line has a positive slope, indicating that the average rating per vehicle increased as the headlight illuminance increased.

2.3.1.2.2.3 Other Findings

In the process of conducting the evaluations, the researchers identified several other findings that could have an impact on nighttime inspections:

1. Several problems were encountered in determining the appropriate retroreflectivity minimum to assign to various signs in the evaluation. These problems included the following:
    a. Three of the minimum retroreflectivity tables use sign size as a criteria. However, there is no guidance on how the sign size should be measured. For the evaluations, the researchers assumed that the sign size represented the horizontal dimension of rectangular sign and the diagonal dimension of diamond signs. For a sign such as the speed limit sign this is a critical issue. The 24 inch width establishes one minimum value, but the 30 inch height establishes a lower minimum.
    b. There were several signs that were considered for inclusion in the evaluation, but they were not included because no minimum values have been proposed.
    c. There are no guidelines for the retroreflective legend that is a part of signs with a white, yellow, or orange background.

2. The FHWA's current minimum retroreflectivity values represent recommendations that have been developed from the FHWA research program. The FHWA has not formally recommended minimum retroreflectivity values in the Federal Register proposed rule. Before minimum retroreflectivity values can be added to the MUTCD, the FHWA must publish a proposed rule, receive public comment on the proposed rule, and issue a final rule.

2.3.1.2.3 Conclusions and Recommendations

In this research the results of a comparison of two methods of evaluating the nighttime performance of traffic signs - a nighttime visual inspection and the application of FHWA research recommendations for minimum levels of sign retroreflectivity were described. Based on the activities and findings associated with the evaluation results, the researchers offer the following conclusions and recommendations:

- The evaluation described in this paper was intended to assess the sign inspection procedure in actual use by a TxDOT sign crew, and not as a scientifically controlled evaluation. As such, there were no controls for the visual acuity of the evaluators, the distance at which signs were evaluated, or the illuminance from the evaluation vehicles.
- Retroreflectivity is only one factor in considering the nighttime effectiveness of a sign. The overall appearance and uniformity of the retroreflectivity is as important as the retroreflectivity level. The visual evaluation identified numerous signs that were unacceptable because of inconsistencies or damage in the visual appearance of the sign, but these inconsistencies were not identified through the measure of the sign's retroreflectivity. Visual nighttime inspections should be conducted to identify sign inconsistencies or damage.
- The evaluation results indicate that a visual nighttime inspection resulted in greater numbers of unacceptable signs than the pure application of FHWA research

recommendations for minimum retroreflectivity levels. Visual nighttime sign inspections should be a critical component of any process that evaluates the nighttime visibility of traffic signs.

- Placing signs of significantly different retroreflectivity, or signs of different sheeting materials, on the same post limits the effectiveness of the visual inspection procedure. When replacing a sign, all signs in a single installation should be replaced at the same time and the same sheeting material should be used throughout the sign installation.
- The stop sign in the evaluation that had the contrast ratio of less than 4:1 was rated as acceptable, although the sign would fail the FHWA minimum contrast ratio value. It may be that the contrast ratio threshold is too high, but the sample size was not adequate to address this issue.
- The evaluation described in the research represented a dark rural environment. Higher minimum levels of retroreflectivity may be needed in a complex urban environment, but this was not evaluated as a part of the research.
- The researchers could not establish a strong correlation between headlight performance and the visual evaluation results. While headlight illuminance had a direct relationship to the sign luminance, participants with poor headlights simply may not have evaluated the signs until they were closer.

Table 2.9. TX Study Summary

Objective	To compare nighttime visual inspection with a sign's measured retroreflectivity values.
Important Parameters	• Study was completed in the year 2001. • Only outdoor observation of signs. • Retrosign 4500 retroreflectometer used. • White, Yellow, Red, and Green color signs studied. • Type I and III sheeting studied. • Observers were TxDOT sign inspectors. • Signs were not cleaned before taking data. • Sample size of 49 signs. • No deterioration factors considered.
Key Findings	Factors other than retroreflectivity influence the effectiveness of signs at night such as uniformity of the sign face, damage, and type of sheeting material.

2.3.2 Sign Sheeting Degradation Rates

This section includes literature that discusses the data collection effort from literature and the analysis of this data leading to sign sheeting degradation due to age, orientation, distance from road edge, and other environmental factors. The section also discusses the effect of cleaning on sign retroreflectivity.

2.3.2.1 Purdue University Study

The study was conducted at Purdue University under the guidance of Professor Darcy Bullock [Bischoff, et. al. 2002]. The purpose of this study was to determine whether or not the majority of signs currently used by INDOT meet the new minimum requirements proposed by the FHWA. Also, the study investigated the current sign replacement program used by the IN Department of

Transportation (INDOT) to 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 majority of the data collection took place in central and northwestern IN from July of 2001 until May of 2002. Data collection was performed on typical days with no rain, snow, or extreme temperatures. Overall, 2200 samples of signs (about 500 of which were decommissioned signs from Crawfordsville) were collected.

2.3.2.1.1 Data Collection

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. Once the sign was determined to be satisfactory for sampling, several measurements and observations were taken of and around the sign.

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. While taking this measurement the tape measure was held as level and tight as possible so that it was reading was perpendicular to the sign post and so there was no excess slack which would affect the measurement. Next, the distance from the level of the roadway to the bottom of the sign was measured to the nearest inch. 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 taken on the bottom edge of the sign and for triangular signs the distance was measured along the diagonal bottom edge of the sign.

Next, a handheld global positioning satellite (GPS) receiver 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 on the roadway, and any visible damage to or deterioration of the sign was recorded.

The next series of measurements was taken on the sign itself using a portable retroreflectometer. The retroreflectometer model used in the study was the Advanced Retro Technologies Sign Master 920 SEL model (ART 920 SEL). For each sign three readings were taken on each sheeting color, the sign was wiped with a dry mop sponge, and then three more readings were taken in the same places as before. A stop sign required 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 that allowed the retroreflectivity readings to be taken on these signs.

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 for cleaning because it was easier and faster to use a dry mop than to use a wet mop. It was also 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 from 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. Once the data was entered into the database, the analyses of the collected data could be performed and the number of samples taken overall (as well as in which districts) could be determined. 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.

2.3.2.1.2 Analysis

The focus of the analysis was to determine if the retroreflectivity of sheeting can be predicted using age, whether or not a wiped sign has a significantly higher retroreflectivity than an unwiped sign, whether 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 one type of retroreflectometer to another type of retroreflectometer.

Only data collected from the in-service signs with ASTM Type III sheeting were used in the data analyses. A total of 1341 samples (out of 2200) were used in the analyses. For the analyses the retroreflectivity readings taken from the different colors were averaged together to get one retroreflectivity value for each color on the sign.

2.3.2.1.2.1 Red Sheeting Age Analysis

The Purdue researchers performed an age sheeting analysis on 3 different colors (red, yellow, and white). This was necessary to determine if age is a factor in affecting sign deterioration rates. The Purdue literature study did not provide an answer to this question.

The Purdue researchers thought that red is 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 loses its color. Figures 2.19, 2.20, and 2.21 show the graph of retroreflectivity versus age for red color signs where the retroreflectivity is the average, minimum unwiped, and minimum wiped retroreflectivity, respectively.

In Figure 2.19, there is a very distinct downward trend. However, there is no real predictability of a sign's average retroreflectivity as shown by the R^2 value which shows that there is about a 32 percent correlation between the age and the average retroreflectivity. The reason this correlation is so low according to the Purdue researchers is because of the variability of the readings as the sheeting gets older. From the graph in Figure 2.19 it is clear that the range of average retroreflectivity values as the sheeting ages does increase. The dotted lines in the Figure are the different minimum retroreflectivity standards proposed by different sources.

There are only 4 data points that fall below the two dotted lines. These 4 signs represent 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 retroreflectivity 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 retroreflectivity these graphs use the minimum of the 3 readings taken for both the unwiped and wiped readings. The graph of the minimum unwiped retroreflectivity readings versus the age is located in Figure 2.20. The graph of the minimum wiped retroreflectivity readings versus the age is located in Figure 2.21.

Figure 2.20 shows a similar downward trend compared to the trend shown in Figure 2.19. One of the 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. A lower R^2 value 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.

Another difference between the average retroreflectivity and the minimum unwiped retroreflectivity is the number of signs that violate the proposed retroreflectivity minimums. As can be seen in Figure 2.20 there are 6 signs that violate the proposed retroreflectivity minimums as compared to just 4 in Figure 2.19. This difference is largely due to the effect that averaging has on a set of readings.

Averaging the retroreflectivity readings taken from the sign masks the variability found on that sign. This is illustrated by an example by the Purdue Researchers. 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 the one bad reading taken. This is the reason that there are 2 more signs that do not meet the proposed retroreflectivity minimums.

The last analysis done for the red sheeting age analysis is a graph of the minimum wiped retroreflectivity readings versus age. This graph illustrates the minimum of the wiped readings instead of the average of the wiped readings. These results show 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 retroreflectivity (Figure 2.20). 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 that also show that there is really no difference between the wiped and unwiped readings.

The graph in Figure 2.21 shows 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 retroreflectivity.

2.3.2.1.2.2 White Sheeting Age Analysis

According to the Purdue Researchers 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 and these represent the majority of signs used. Because of this the number of data points collected by the Purdue Researchers for white background signs is 683 which is 30 percent more than the red samples and almost 3 times more than the yellow samples. The graph in Figure 2.22 shows that the majority of samples collected fall between 0 and 10 years of age with many samples older than 10 years as compared to the number of red samples. Also 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 value and the age. This suggests that the white sheeting is not affected by the elements and will last well beyond the 10 year warranty offered by the vendor. The dotted lines in the Figure are the different minimum retroreflectivity standards proposed by different sources.

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 retroreflectivity over 150. Given this performance seen in the field the Purdue Researchers say that 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 currently performed by INDOT. The same set of analyses was performed on the white samples as was performed on the red samples.

The graph in Figure 2.23 shows the minimum unwiped retroreflectivity reading versus the age for signs with a white background. There is more of a downward trend than there was in for the average. 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 that are caused by "dead" spots.

Also from the graph in Figure 2.23 there is a sign that is now below the proposed minimums. There was a dead spot on the sign which caused the sign to fall below the proposed minimums. Also a vast majority of the signs sampled were 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. This means that there is essentially no link between the age of the sheeting and the retroreflectivity. This suggests that signs with 3M ASTM Type III sheeting could be left out in the field longer than most DOT's currently allow, thus affording some fiscal savings in the form of sheeting cost and labor for fabrication and installation of signs.

The final analysis performed on signs with white backgrounds was a plot of the minimum wiped retroreflectivity versus the age. This graph is shown in Figure 2.24. This correlation is only about 3.6 percent. Again, 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.

2.3.2.1.2.3 Yellow Sheeting Age Analysis

Age analysis was also performed by the Purdue Researchers on signs with yellow backgrounds. Figure 2.25 shows the average unwiped retroreflectivity versus the age of the sign. The trend line on the graph shows an apparent downward trend as the age of the sheeting increases. This downward trend is not as much as in the case of signs with red backgrounds but is more so than 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 dotted lines in the Figure are the different minimum retroreflectivity standards proposed by different sources.

Figure 2.25 shows 5 points which violate the minimum. This is about 2.1 percent of the entire yellow sample. Given the age of these signs it appears that their sheeting 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 seem to indicate that it is acceptable to allow signs made with 3M ASTM Type III yellow sheeting to remain in the field longer than the current 10 year cycle used by INDOT.

The next analysis performed on the yellow background data is the minimum unwiped retroreflectivity versus age. The plot of the minimum unwiped retroreflectivity is shown in Figure 2.26. This graph shows that there is still a downward trend in the data points, but it is actually slightly less than in Figure 2.25. 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. Given that the number of violators remained the same, the trend really did not change that much. Because 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.

The last analysis done on the yellow background sign sample is the minimum wiped retroreflectivity versus the age. The graph for this sample, shown in Figure 2.27, indicates the 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.

From the analysis of the age of the signs the Purdue researchers have concluded the following things. 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 one 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. This means that these graphs are basically the same. Finally, given the trends of the red samples taken, signs with red sheeting 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.

2.3.2.1.2.4 Unwiped Versus Wiped Analysis

The unwiped versus wiped retroreflectivity analysis was performed 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 compared the unwiped and wiped average retroreflectivity readings in the Crawfordsville and Greenfield Districts. The second analysis was performed on the Laporte district. The t-test tables are presented in 3 sections (by color) and in each section by age group.

The analysis results are shown in Table 2.10. They indicate 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. Thus, there is no significant improvement of the retroreflectivities due to wiping of the sign.

The analysis done on the Laporte District of IN (an area with significant industrial activity and low air quality), located in Table 2.11, 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 retroreflectivity after a white 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 statistically different. Because these two age categories account for most of the sample, once they are combined it causes the difference to be significant. However, this does raise the question of 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 do 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. In other words, the authors say that the values of both wiped and unwiped signs are so high above the minimum standards and the difference between them is so small compared to retroreflectivity, so it need not be further considered.

2.3.2.1.2.5 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.

It is theorized that sun exposure has a significant impact on 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 performed on different sign facing directions to determine if there was a statistical difference between signs facing in different directions.

The graphs showed no clear trend for signs around the 180 degree marker (south facing signs) having lower retroreflectivities than the others. From the graphs it is not possible to determine that any one direction fades significantly more quickly than another.

The other set of analyses performed on signs with red backgrounds was a t-test on each of the average retroreflectivity values in the cardinal directions. To do so 90 degree bins were made which included 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. None of the directions came out significantly different from the south facing signs. Thus, there was no statistically significant difference in average retroreflectivities between each of the directions. This means that for this sample there was no significant statistical evidence to suggest that red signs facing south fade faster than red signs facing any other direction.

For regulatory signs with a white background the orientation of the sign face did not appear to affect its average retroreflectivity. There were no samples which fell below the proposed minimums.

For yellow sheeting the graphs showed no obvious effect of the sign orientation on the average retroreflectivity. The data was relatively evenly distributed over the entire graph in each case except for the 15 and older graph. In the graph with 15+ years old signs there were 3 violators and all had developed dead spots on the sign at various points.

In all cases the orientation of the sign face did not significantly affect the average retroreflectivity of a sign. In all cases no signs violated the proposed minimums for signs in the range 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. For white signs, no sign violated the proposed minimums. Given these results the researchers found it 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.

2.3.2.1.2.6 Four to One White to Red Ratio Analysis

The 4 to 1 ratio for red and white signs was included in the 2001 proposed minimums. This ratio was established to make sure that red and white signs had enough internal contrast so they could be seen at night. Over time the red overlay used on white signs fades and eventually starts to reflect more light than it is supposed to. This ratio was added so that this effect could be quantified. 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 wanted to make sure that signs did not reach this point so they added the 4 to 1 ratio.

The Purdue researchers actually observed an increasing trend in the white to red ratios. The reason for this trend was that as the red ink fades over time the white sheeting was not fading, thus causing the ratio of white divided by red to increase as the sign ages. The few ratio violators were between 0 and 3 years of age. The reason for this was thought to be that the red ink was overlaid too thickly thus causing the red retroreflectivity readings to be very low. In all the cases of signs failing the proposed 4 to 1 ratio the retroreflectivity readings of the red and white colors were above the proposed minimums, but the red retroreflectivity was too high and the white retroreflectivity was not high enough.

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. These accounted for about 2.4 percent of the entire sample. Because this amount was 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.

2.3.2.1.2.7 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 normally within 5 to 10 percent of each other. However signs can loose beads from the sheeting. This causes dead spots in the sign, which in turn cause the uniformity of the sign face to decrease and result in visibility problems. In order to see this, the analysis was performed on each of the main colors (red, white, and yellow).

The red color sign sheeting showed a concentrated section of ranges which were below 10. There were only a few signs with high ranges. This means that the uniformity of the sign face is, for the most part, staying the same as the sign ages. This 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 observation for red color sheeting is that there was really no significant difference between the wiped and unwiped points. If there had been a significant difference between the wiped and unwiped ranges then the wiped ranges should have been lower then the unwiped, but this was not the case. This suggests that there was no apparent benefit from wiping the sign faces because the uniformity of the sign face has not changed enough to have a major impact on the range of the retroreflectivity readings from the same sign.

The white color sign sheeting showed that that the white ranges were quite a bit larger but the majority of them are below 50. There were only a few of the signs that had wiped and unwiped retroreflectivity ranges above 50. As in the previous case, 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 did not change very much as whole. However for some of the signs that have high ranges, that range is reduced when they are wiped. This could mean that in the case of white signs wiping could increase the consistency of a small percentage of signs.

The last set of data analyzed for range were those with a yellow background color. Their range of retroreflectivity readings was similar to white signs. Only a few of the signs had ranges less than 50 and the majority had retroreflectivity ranges less than 30. There was 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 had high retroreflectivity ranges. This was probably due to sheeting deterioration. As in the previous two graphs there was really not much of a difference between the wiped and unwiped ranges. This also suggested that there was really no benefit from wiping the yellow signs because there was no major improvement in the retroreflectivity ranges.

2.3.2.1.2.8 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 problems 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 loaner was assumed to be calibrated and it was assumed that it 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 the Purdue research team contacted 3M for sample sheeting to test the retroreflectometer used in the field on new sheeting. 3M sent them 2 sample stop signs made of ASTM Type III sheeting also known as high intensity sheeting. Before 3M sent the sheeting it was tested 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 provided the 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. Using the ART 920 the Purdue research team measured 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 was that the different machines are calibrated using different methods. However, the authors mentioned that for the samples taken, the ART 920 was consistently reading lower than the 3M retroreflectometer.

Because it was found that the retroreflectometer that was used to take 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 were removed from service and brought in for testing.

The research team found that majority of the signs tested using the ART 920 had lower retroreflectivities for the white and about the same measurements for the red. This indicated that the ART 920 consistently read lower for the white readings than the machine borrowed from 3M. Another interesting point about these tables was that the ratios for the signs taken using the 3M machine did not violate the 4 to 1 ratio. 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 were some differences between the 920 retroreflectometer and the older machine as used by 3M. However there was no major difference between the readings taken by the different ART 920 retroreflectometers. In most cases the ART 920 was reading around the same readings as the older retroreflectometer or below. Because the ART 920 was reading lower than what the sheeting actually was the research team got more conservative retroreflectivity values than the older retroreflectometers. The Purdue research team believed that these discrepancies did not have an adverse impact because the readings were within 10 percent of the other 920 readings and were lower than the readings given by the 820 retroreflectometer.

2.3.2.1.3 Conclusion

Based on the analysis the Purdue research team came up with certain crucial conclusions. Their conclusions were as follows.

- There was no real link between age and retroreflectivity readings of white and yellow signs.
- There was a much more apparent downward trend in the retroreflectivity of red signs as the signs age. This trend was not considered very strong as there was only a 33 percent correlation between age and average retroreflectivity of the sign.
- Orientation did not play a major role in sign deterioration.
- The majority of signs that had white and yellow backgrounds kept retroreflectivity levels above the proposed minimums out past 15 years of age.
- Due to the long lasting nature of signs it is possible that the white and yellow type III signs could be left out in the field longer than they currently are and could save INDOT money in life cycle costs.
- 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.

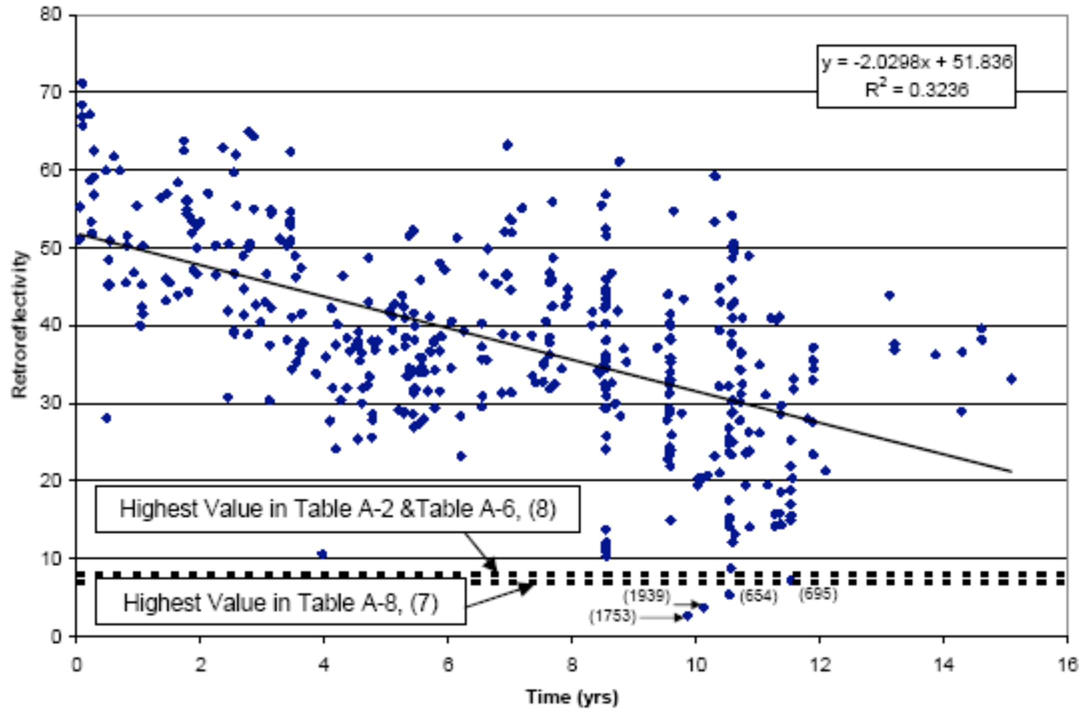


Figure 2.19. Red ASTM Type III Average Unwiped Background Retroreflectivity Versus Time

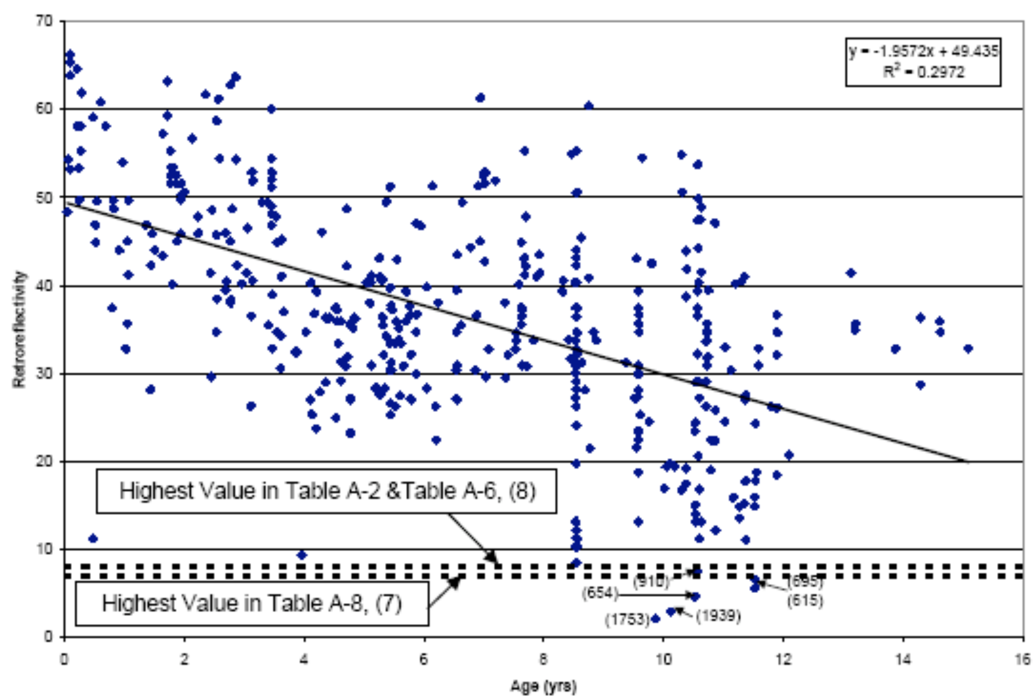


Figure 2.20. Red ASTM Type III Minimum Unwiped Background Color Retroreflectivity Versus Time

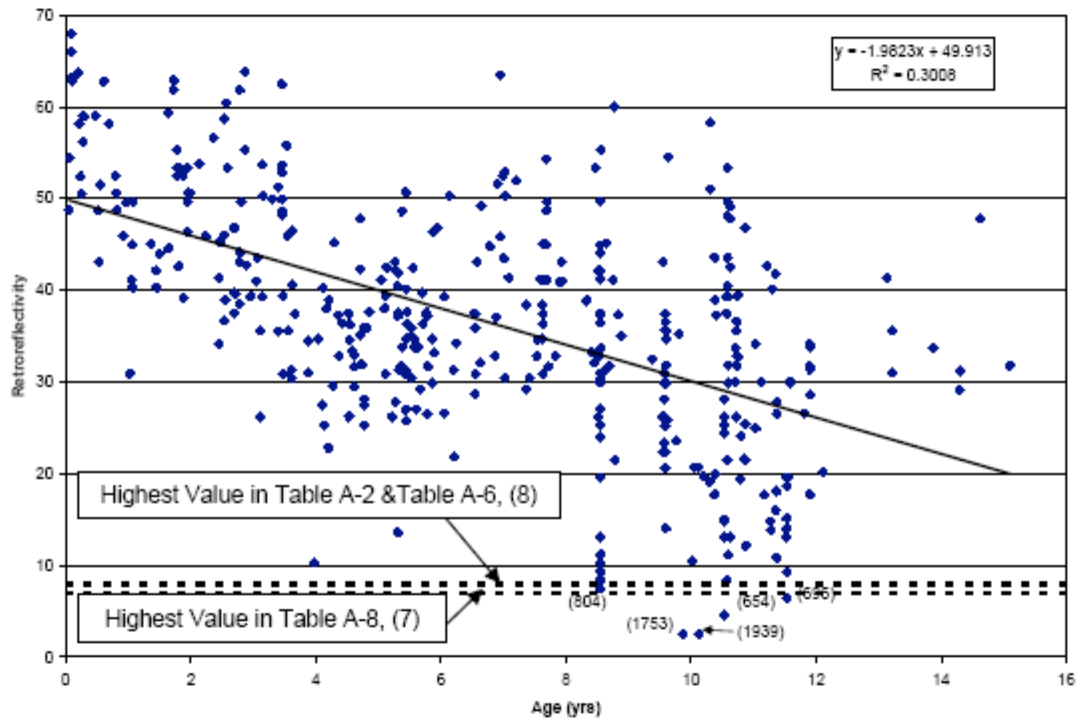


Figure 2.21. Red ASTM Type III Minimum Wiped Background Color Retroreflectivity Versus Time

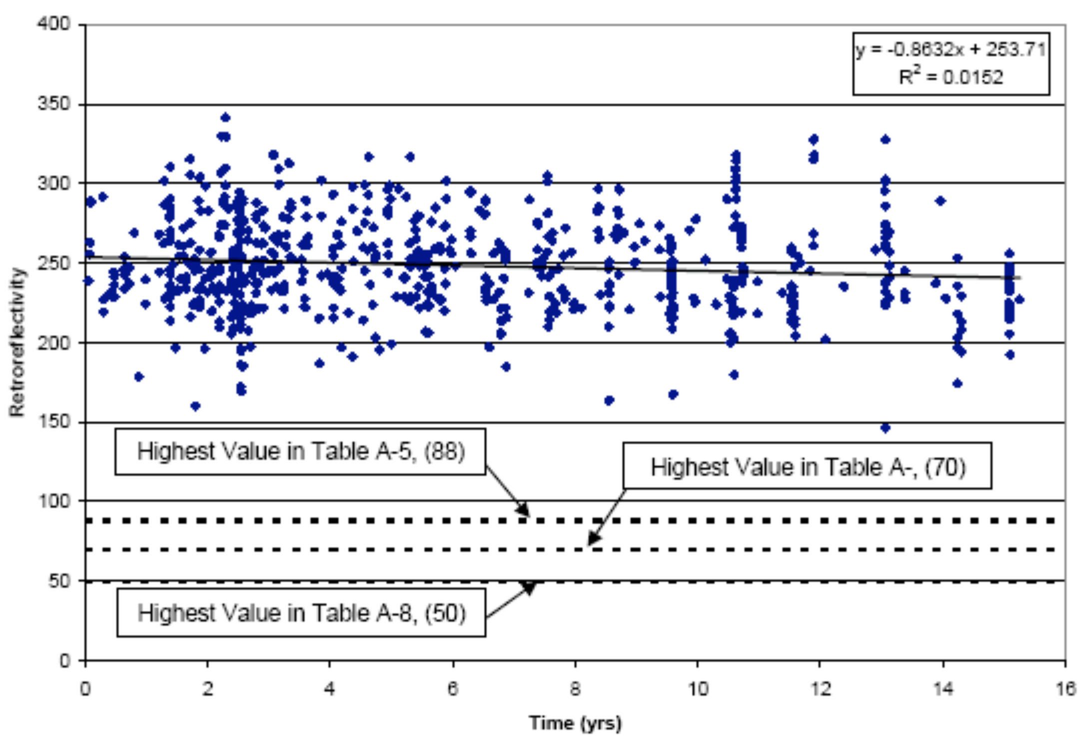


Figure 2.22. White ASTM Type III Average Unwiped Background Retroreflectivity Versus Time

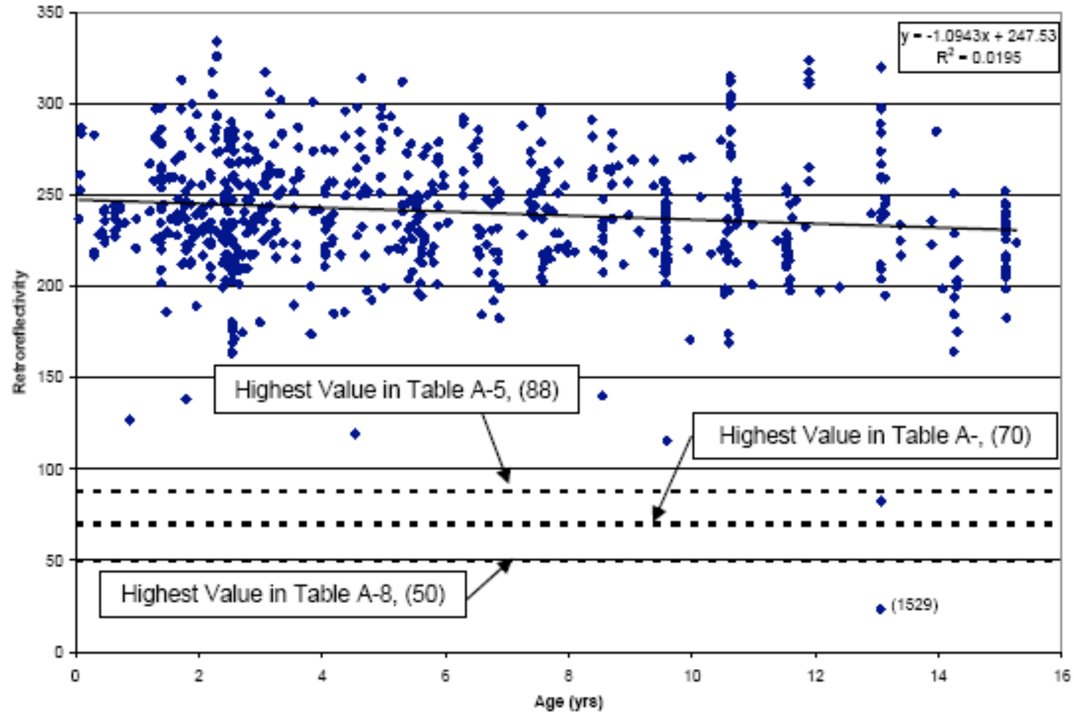


Figure 2.23. White ASTM Type III Minimum Unwiped Background Retroreflectivity Versus Time

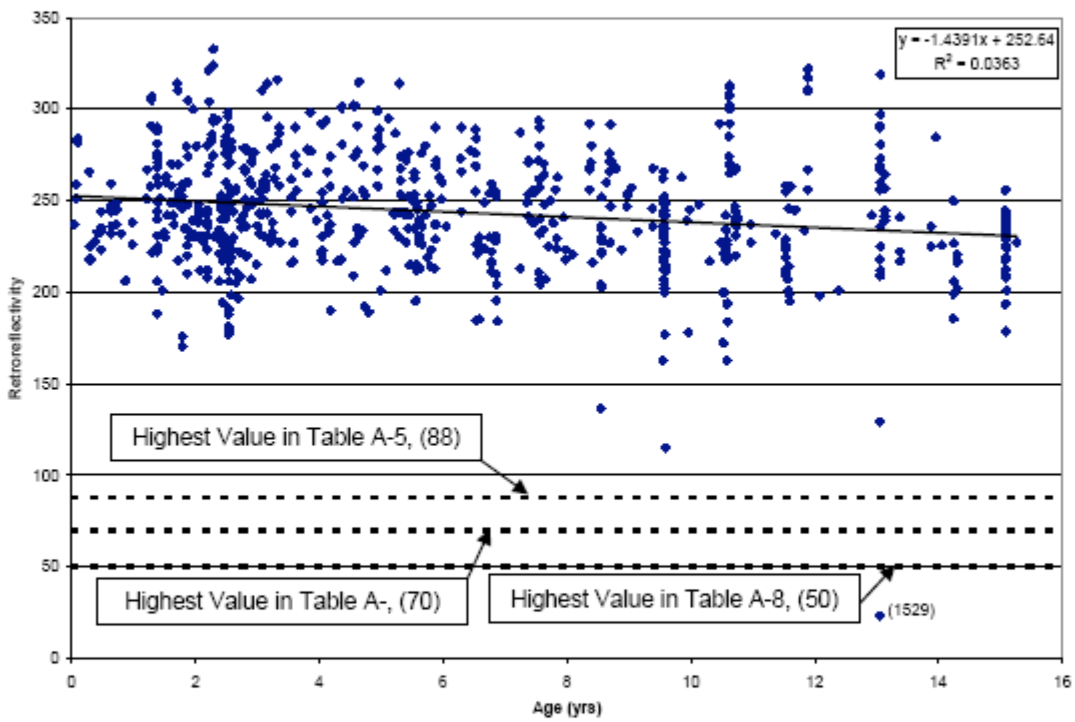


Figure 2.24. White ASTM Type III Minimum Wiped Background Retroreflectivity Versus Time

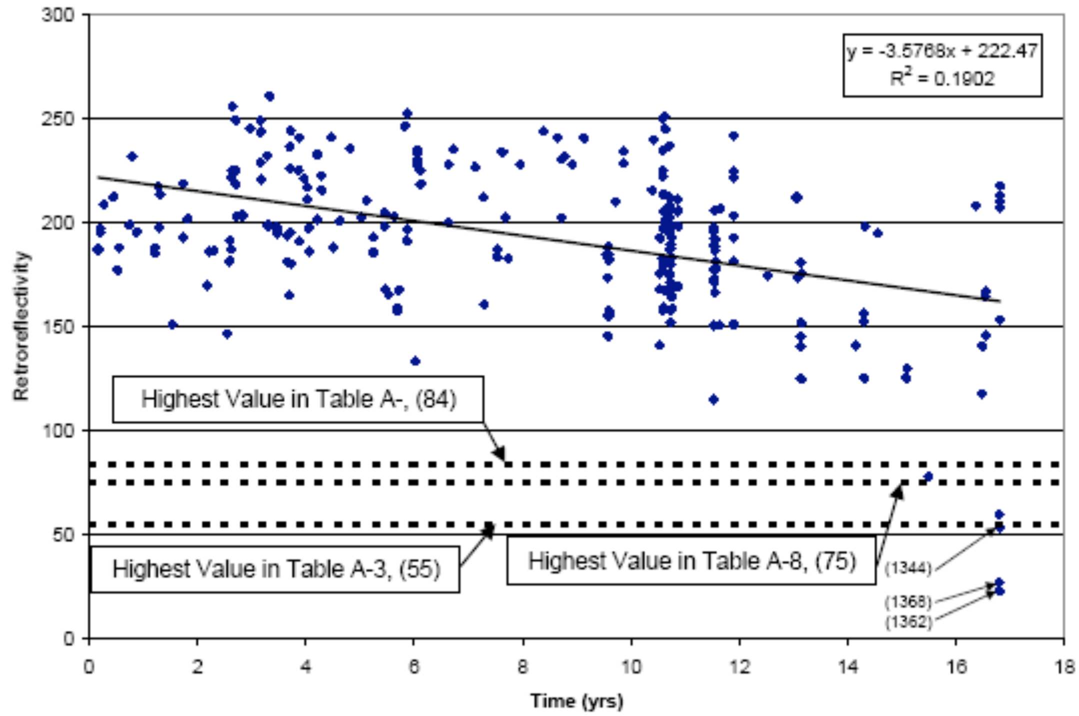


Figure 2.25. Yellow ASTM Type III Average Unwiped Background Retroreflectivity Versus Time

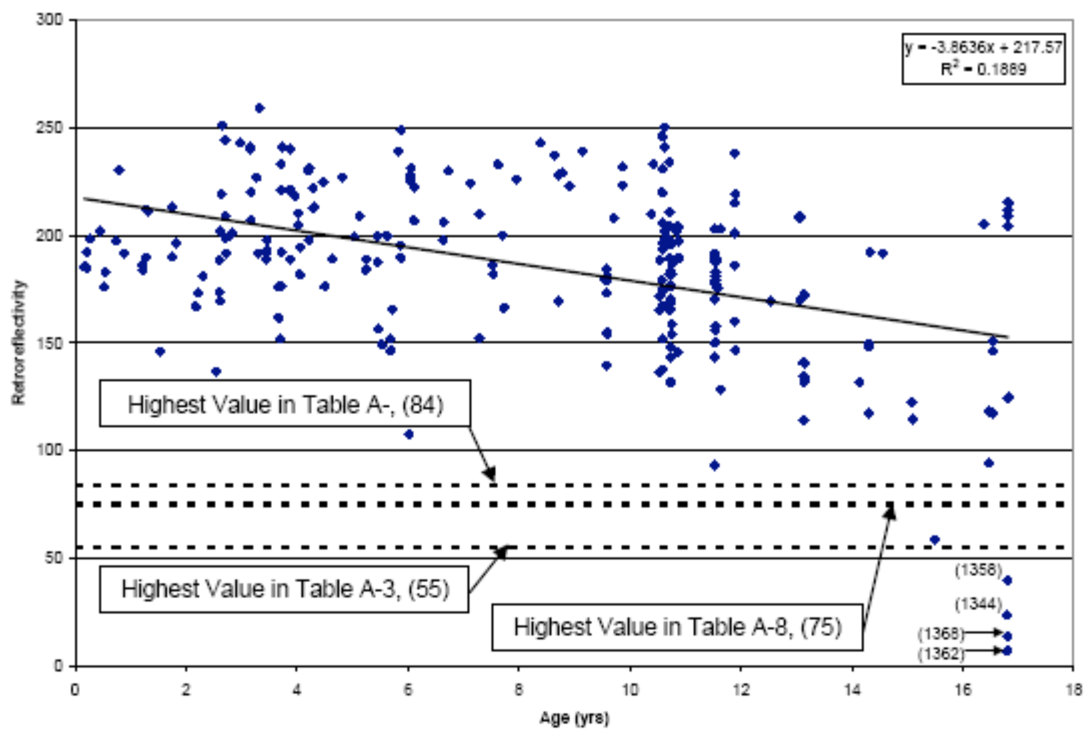


Figure 2.26. Yellow ASTM Type III Minimum Unwiped Background Retroreflectivity Versus Time

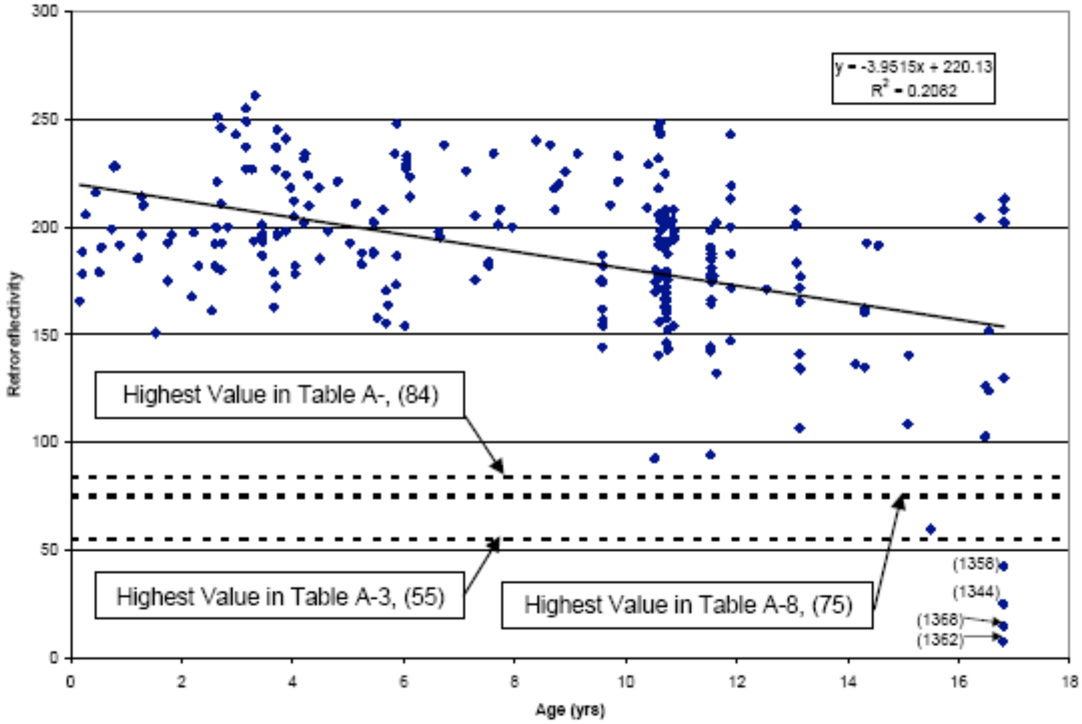


Figure 2.27. Yellow ASTM Type III Minimum Wiped Background Retroreflectivity Versus Time

Table 2.10. T - Test Table of Wiped Versus Unwiped for Background and Legend 1 Colors for the Crawfordsville and Greenfield Districts

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 2.11. 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

Table 2.12. Purdue Study Summary

Objective	To check if the 10 year replacement cycle is adequate and to find the effects of age, cleaning, and orientation on sign deterioration.
Important Parameters	• Study was completed in the year 2002. • Only Outdoor observation of signs. • 920 SEL retroreflectometer used. • White, Yellow, and Red color signs studied. • Type III sheeting studied. • Observers were researchers. • Data for uncleaned and cleaned signs taken. • Sample size of 49 signs. • Deterioration factors considered were age, orientation, environmental factors, and offset distance to road. • G.P.S coordinates of all signs were measured.
Key Findings	Replacement cycle could be extended to 12 years. Orientation did not effect deterioration. Cleaning did not have an effect on the retroreflectivity values.

2.3.2.2 OR Study

This study was undertaken to better understand the factors that may affect road sign retroreflectivity with respect to age and physical orientation [Kirk, et. al. 2001]. A better understanding of these factors could provide guidance to ODOT in managing its inventory of road signs. The findings showed that over a twelve-year age span most sign retroreflectivity readings were above the minimum ODOT standard. Retroreflectivity did not vary predictably with age. There was some evidence that retroreflectivity may be affected by sign orientation (direction facing) due to the weathering effects of windblown dust and precipitation. Additional data collection in more severe climates of OR might provide more evidence to support this finding. The report includes recommendations for further study and for record keeping in the ODOT sign maintenance program to provide a larger body of data.

2.3.2.2.1 Research Objectives

The objectives of this study were as follows:

1. To determine a baseline for sign retroreflectivity over time, i.e. to establish the relationship between sign age and retroreflectivity and
2. To examine the relationship between the physical orientation of signs and retroreflectivity. As the orientation of signs varies, so does the amount of exposure to solar radiation and windblown dust and precipitation.

2.3.2.2.2 Research Methods

To collect data on sign retroreflectivity, the OR research team used a hand-held retroreflectometer – a RetroSign, Model 4500. To accomplish the research objectives, the following tasks were performed:

- Retroreflectivity readings were collected on 80 high intensity (Type III) signs – 20 each of red, yellow, green and white – located in the mid-Willamette Valley of OR. Ten readings per sign were recorded. The retroreflectometer was calibrated before the readings were taken on each sign.
- The sign was washed and dried prior to any readings being taken, to detect the optimum retroreflectivity of the sign. Measurements were taken on the sign background only, not on the legend. The physical condition of signs ranged from poor to excellent.
- Information was recorded on the age and predominant physical orientation of each sign (north, south, east or west).

These were factors considered to have a possible effect on sign retroreflectivity. Following the initial data collection the research team found that insufficient sign data had been collected from each color at every physical orientation. Thus data for an additional 57 signs were collected to provide a more complete data set. The same methods used in the first round of data collection were followed in the second.

2.3.2.2.3 Results

The second round of data collection produced readings markedly higher than those taken in the first round. The average increase in SIA values from the first to the second round ranged from 71% for red signs to 107% for yellow signs. The research team thought the probable reason for this difference was that the instrument had been returned to the factory for servicing between the two data collection rounds, and adjustments to the instrument resulted in much higher readings in the second round. Test measurements of standard Type III sheeting material and repeat field measurements on a sub-sample of signs led researchers to conclude that the readings recorded in the first round were very likely to have been inaccurate. In order to be able to use the readings from the first data collection round, a weighting factor was applied to the first round data. The weighting factor for each color of sign was derived from the average percentage difference of the second round readings compared to the first.

2.3.2.2.3.1 Measurement Variability

On any given sign the retroreflectivity measurements varied among the ten readings recorded. This was due to the variability in the reflective surface. This expected variation was the reason for specifying ten readings per sign. The average of the ten readings was used to represent the overall sign retroreflectivity. The Coefficient of Variation (CV) is a measure of variability, which allows a comparison of variability among several data sets; it is the ratio of the standard deviation to the mean, expressed as a percent. Some signs were found to have much higher CVs than others. This variability could be considered an indicator of the uniformity of the sign retroreflectivity, hence an additional factor in gauging sign condition.

The differences in readings during the course of the study also prompted researchers to examine the instrument itself to determine if readings varied due to battery charge or some other aspect of operation. Over a test period of 55 days, readings were recorded from test sheeting material while monitoring the battery level of the instrument. In each test session a set of ten readings was collected without moving the instrument, and another set of ten readings was taken from various places on the sheeting material. Based on these tests, researchers made the following observations:

- The retroreflectivity readings were probably not affected by the battery charge,
- The variability of readings was not affected by the battery charge, and
- The variability of readings was negligible when they were taken from the same exact location on a given sign.

Thus the researchers came to a conclusion that the variability of readings observed in the field was likely due to actual variations in the reflective surface of the signs and not due to the operation of the instrument.

2.3.2.2.3.2 Retroreflectivity and Sign Color

Figure 2.28 shows the graph of average retroreflectivity versus age for Type III signs with colors white, yellow, red, and green. The retroreflectivity of Type III white signs was the highest, with average readings ranging from 189 to 305. The average readings for Type III yellow signs were somewhat lower, ranging from 129 to 248 (with an outlying data point at 5). The average readings for Type III green signs ranged from 34 to 80. The SIA values for Type III red signs ranged from 20 to 60.

For comparison purposes, the researchers used bars in Figure 2.28 to show the minimum retroreflectivity standards established for each sign color by OR Department of Transportation (ODOT) and the ASTM. The lower end of the range corresponds to the ODOT minimum standard at ten years of service. The upper end of the range corresponds to the ASTM standard. As Figure 2.28 shows, the overall levels of retroreflectivity measured for different sign colors were generally in the same order of magnitude as the ASTM standards. Virtually all of the readings were above the ODOT standard, and most were above the ASTM standard, with the exception of red signs.

2.3.2.2.3.3 Retroreflectivity and Sign Age

To determine the relationship between sign age and retroreflectivity, the average SIA value for each sign was plotted against the installation year. Figure 2.29 shows the results for each sign color. The trend lines showed little relationship, however, between the age of signs and their retroreflectivity values. The OR researchers used two factors to explain the apparent lack of relationship. First, the age range of the signs may not have been great enough to provide a complete picture of sign performance over time. Second, the installation year data may not have been entirely reliable. A more carefully controlled investigation covering a greater time span would be needed to further explore whether any relationship exists between sign retroreflectivity and sign age.

As a sign ages, it is possible that the variability of its retroreflectivity could increase, due to surface abrasion from wind-blown dust and precipitation. Figure 2.30 shows the relationship between sign age and the Coefficient of Variation for each sign color. The analysis shows, that there is no clear relationship between the variability of sign retroreflectivity readings and age.

2.3.2.2.3.4 Retroreflectivity and Sign Orientation

According to OR researchers signs with greater exposure to solar radiation or to windblown dust and precipitation might be expected to lose retroreflectivity sooner than more sheltered signs. Given the latitude of the area (approx. 45 degrees North) and the predominant weather patterns, west-facing and south-facing signs were expected to show lower levels of retroreflectivity. Although the plot showed was no strong trend, it appears that west-facing signs may tend to have slightly lower retroreflectivity than those facing other directions. Lower retroreflectivity for west-facing signs was recorded for three of the four sign colors – white, yellow and green. Among red signs, retroreflectivity values tended to be lowest among south-facing signs.

The retroreflectivity variability (Coefficient of Variation) was also examined for each sign orientation. Yellow and white signs facing west showed higher variability than those facing other directions; red and green signs facing south showed higher variability than those facing other directions. Using retroreflectivity variability as an indicator of sign condition, this finding suggested greater weathering effects among west-facing and south-facing signs, probably due to abrasion from windblown dust, dirt and precipitation. The magnitude of these effects, however, is not great enough to produce average retroreflectivity values below the ODOT minimum standards.

2.3.2.2.4 Conclusions

This study was undertaken to better understand the changes in road sign retroreflectivity over time, and to investigate factors that may affect sign retroreflectivity. A better understanding of these factors could provide guidance to ODOT in managing its road sign inventory.

The findings of the OR researchers were as follows:

- Virtually all of the signs in the sample exceeded the minimum ODOT retroreflectivity standards for an inservice period of ten years. The red signs yielded the lowest average value, exceeding the ODOT standard by only about 3%. The average values for signs of other colors exceeded the ODOT standard by 31% to 56%.

- High average retroreflectivity values (compared to the ODOT minimums), coupled with the lack of any apparent relationship between retroreflectivity and age over a twelve-year period, suggests that sign retroreflectivity may not change enough over time to warrant the use of age as a factor in planning for sign replacement.
- It seems likely that even if the level of retroreflectivity is not related to sign age, the variability might increase with age, as the clear plastic surface of a sign suffers the effects of abrasion from windblown dust, dirt and precipitation. The analysis of data in this study, however, shows no such relationship. It may be that more time is needed for the effects of sign weathering to have a measurable impact. The twelve-year sign age span may not have been long enough to detect weathering effects.
- In the analysis of the relationship between retroreflectivity and sign orientation, south-facing signs may have more retroreflectivity variability, although degradation in the average levels of retroreflectivity is not so evident. Thus weathering effects may indeed be a factor that at some point needs to be a sign maintenance program consideration.
- The accumulation of dust and dirt on a sign will decrease its retroreflectivity. The data collected in this study, however, is only from signs that had been washed beforehand. Thus the study cannot speak to the retroreflectivity of signs as they may appear to motorists.
- It is reasonable to conclude that the retroreflectivity of road signs oriented toward the prevailing weather patterns may be significantly affected by weathering over several years, depending on the severity of the environment.

In a relatively benign environment, however, the retroreflectivity can be expected to be above the ODOT minimum after a decade or more. Further research may help to reveal how great a role weathering plays in the more severe environments of OR. Consideration of other hazards, such as vandalism or other physical damage, may far outweigh the hazards of weathering in a sign maintenance and replacement program.

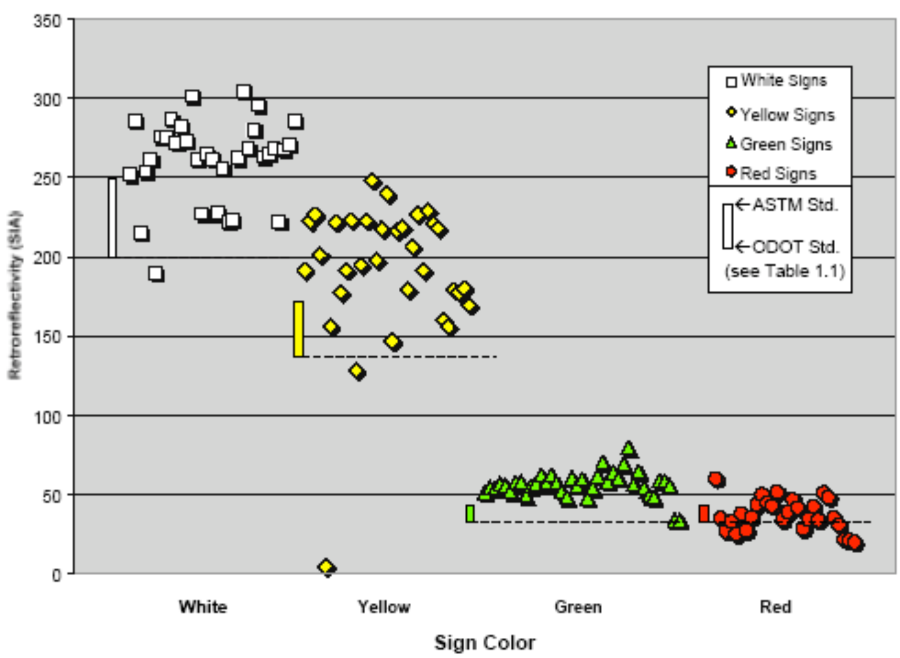


Figure 2.28. Retroreflectivity Values for Signs of Different Color

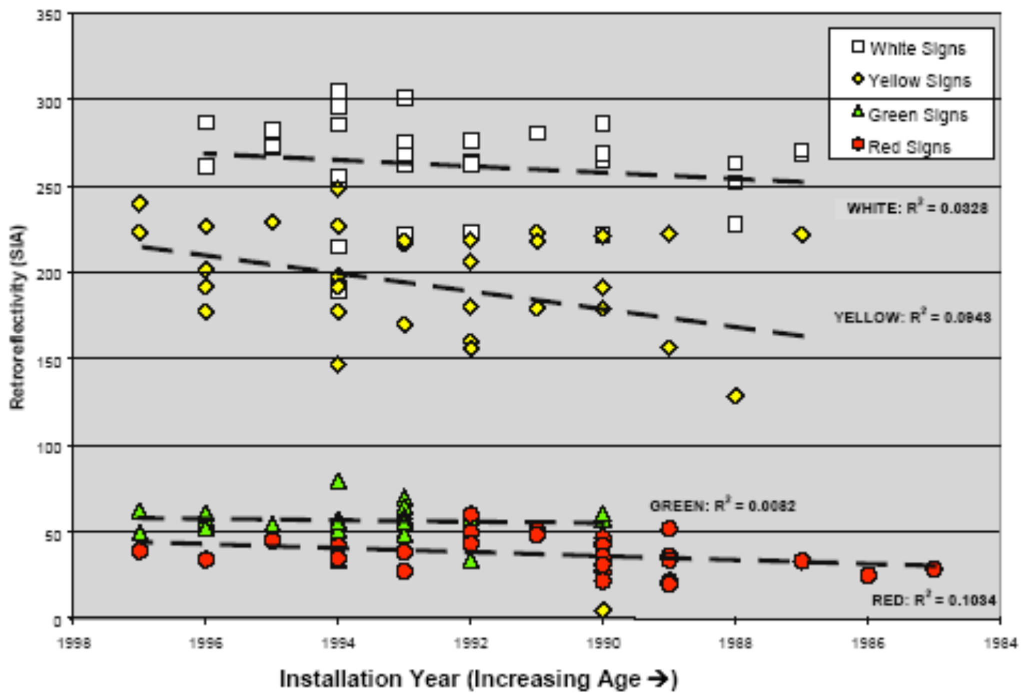


Figure 2.29. Retroreflectivity and Sign Age

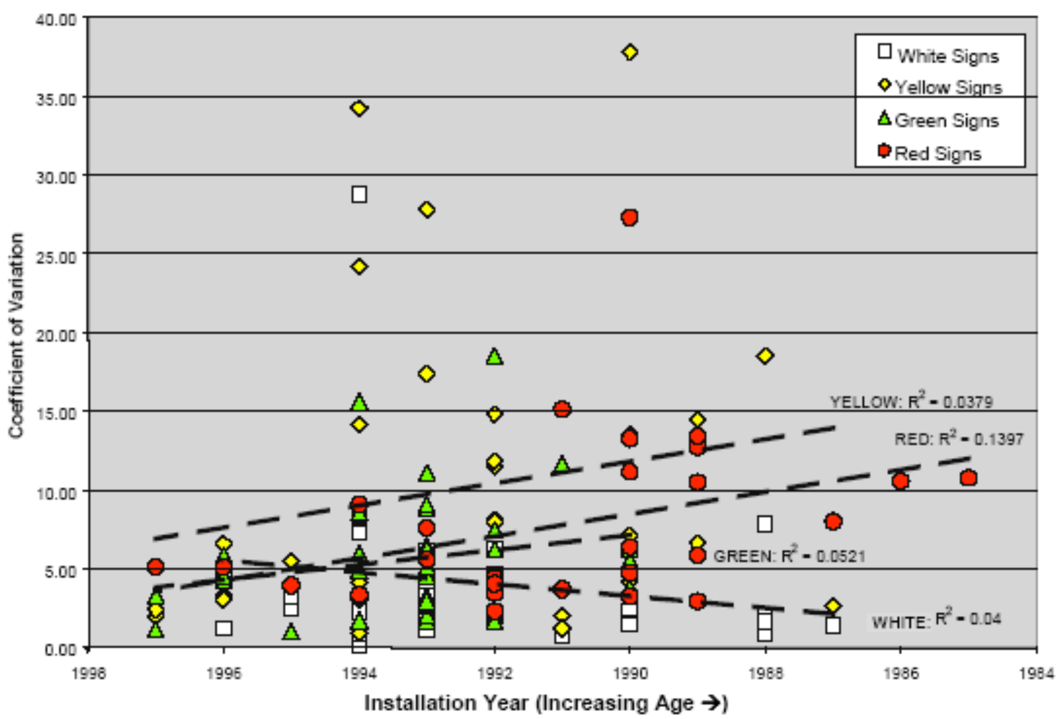


Figure 2.30. Coefficient of Variation and Sign Age

Table 2.13. OR Study Summary

Objective	To determine the effect of age and orientation on sign deterioration.
Important Parameters	• Study was completed in the year 2001. • Only Outdoor observation of signs. • Retrosign 4500 retroreflectometer used. • White, Yellow, Red, and Green color signs studied. • Type III sheeting studied. • Signs were cleaned before taking data. • Sample size of 137 signs. • Deterioration factors considered were age, orientation, and environmental factors.
Key Findings	Age cannot be considered as a factor for planning for sign replacement and there was not enough evidence to relate sign orientation to deterioration.

2.3.2.3 LA State University Study

The LA Department of Transportation and Development (DOTD) have over 400,000 traffic signs in its statewide inventory. In a typical year sign replacements number about 60,000. Some of the replacements occur as the result of collision damage. To assess the compliance of traffic signs to the performance requirements specified by the DOTD and to analyze the characteristics of traffic sign deterioration, a field study was undertaken to evaluate the performance of colored sign sheeting materials in the DOTD's field inventory [Wolshon, et. al. 2002].

The study incorporated a three-step approach including field data collection, data analysis, and predictive model formation. Data collection focused on factors thought to be critical to the performance of traffic signs. Various statistical analyses were used to identify and quantify the contribution of these key factors, both individually and in combination with others. Finally, mathematical models were developed to predict performance based on combinations of sign age, color, orientation, location, and type of sign sheeting material. Thus, the procedures and models presented in this investigation can be used to predict sign performance under a variety of field conditions to more effectively allocate sign maintenance resources.

2.3.2.3.1 Study Objectives

The overall goal of the study was to help maintenance personnel to develop sign testing, maintenance, and replacement schedules. To achieve this goal the following four objectives were set to quantify the rate of specification compliance and determine the characteristics of retroreflective sign sheeting deterioration:

1. Evaluate the compliance of traffic signs to the DOTD performance specifications,
2. Determine the effect of sign cleaning on the retroreflective properties of signs,
3. Analyze the interaction between various sign property and environmental factors to determine the factors that influence the rate of traffic sign deterioration, and
4. Develop mathematical models to predict future sign performance based on sign properties and field conditions.

2.3.2.3.2 Data Collection

Sign data were collected from traffic signs placed along Interstate and State Highway routes throughout LA. A Model 920 Field Retroreflectometer was used to make measurements of sign retroreflectivity. The Model 920 has fixed measurement geometry of a -4° entrance angle and a 0.2° observation angle. The DOTD specification uses eight colors of background sheeting (yellow, red, blue, green, brown, orange, black, and white) on its signs. In this study only white, green, and yellow signs were used in the analyses. All other colors were excluded for various reasons including manufacturing irregularities and a scarcity of signs. Orange signs were not used because they are erected primarily for temporary construction and are not consistently exposed to uniform field conditions. Black signs were not included because they are not retroreflective.

The sample of 237 signs was evenly distributed between the two sheeting grades and three colors. The ages of signs in the sample varied widely, from nearly new to over 20 years old. Sign orientation was recorded from azimuth angle measurements to determine the direction the sign was facing. Measurements of sign height (from the ground) and the lateral distance from the curb or travel lane were also taken. Retroreflectivity readings for each sign were recorded under existing (unwiped) and cleaned (wiped) conditions. The existing retroreflectivity measurement was taken as the sign was found in the field. The cleaned reading was taken after the test area was wiped free of dirt and grime with soap and water. The wiped reading was taken for comparative purposes, to determine the performance differences between clean and dirty signs. It was also used to record the true retroreflectivity, rather than one that was limited by dirt on the sign face.

2.3.2.3.3 Analysis

The research team studied how the signs were performing with respect to the specifications, both in terms of sheeting grade and color. The team mainly concentrated on the signs that were within the warrantee period and did not meet the minimum retroreflectivity standards. These signs could be replaced at no extra cost to the DOT. The team plotted sign retroreflectivity measurements as a function of sign age. Performance requirements for traffic sign sheeting in LA are specified in the LA DOTD's manual of specifications for the construction of roads and bridges. These specifications are based on ASTM criteria (discussed in section 2.1 of the report) and use age and coefficient of retroreflection to define the warrantee criteria.

As mentioned in section 2.1 of this report, performance requirements for traffic signs differ on the basis of sheeting type and sign color. To distinguish between the various grades and colors, the field data was categorized into six separate subsets based on combinations of color and grade. Figures 2.31 and 2.32 illustrate the distribution of the "wiped" Type I and Type III sign retroreflectivity measurements as a function of sign age, with respect to the performance specification criteria.

Figures 2.31 and 2.32 present the compliance data as four-quadrant maps. All data points in quadrant IV (the upper left) include the signs that were meeting the specification requirements and were within the warrantee period. Signs in quadrant II (the lower right) do not meet the performance specification requirements, but were also out of warrantee.

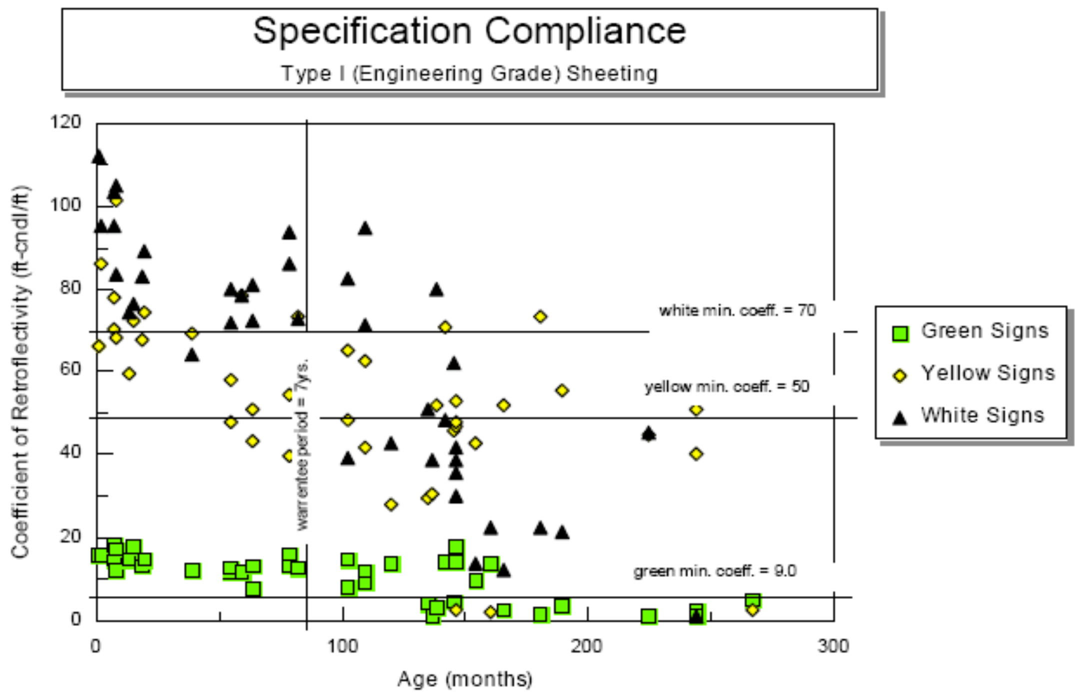


Figure 2.31. Sign Compliance Distribution - Type I Sheeting

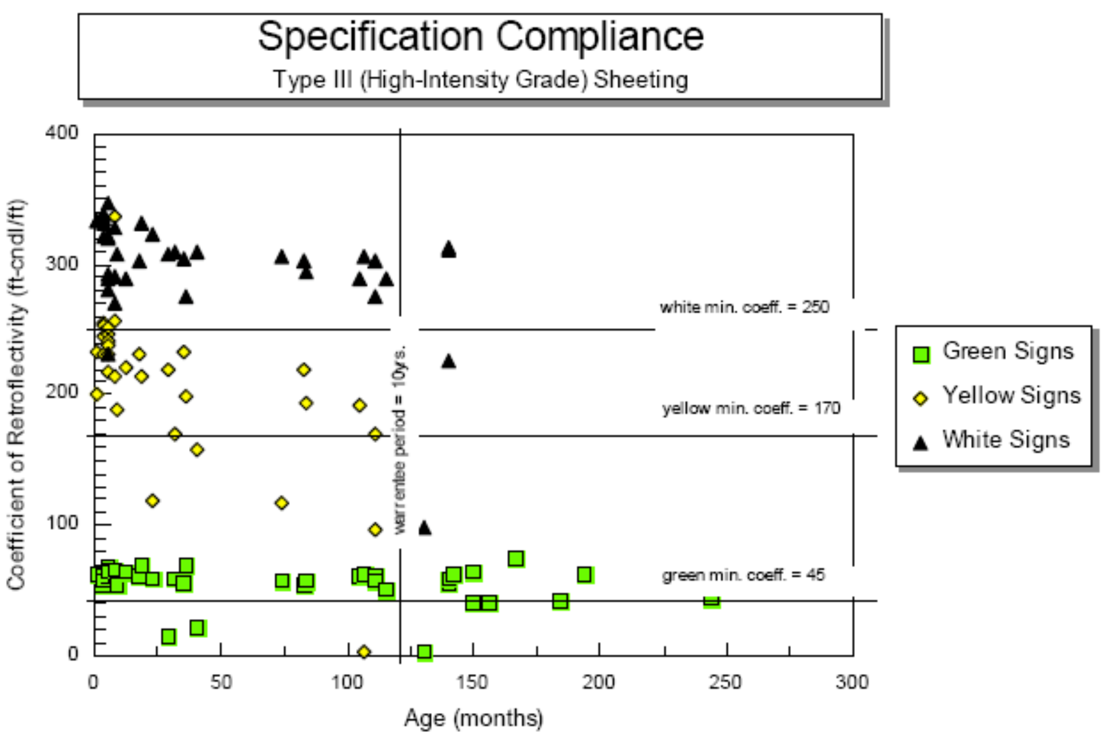


Figure 2.32. Sign Compliance Distribution - Type III Sheeting

The signs in quadrant I (upper right) were the best performers. These were signs that were out of warrantee but continued to meet the performance specification criteria. The area of greatest interest to the DOT was quadrant III (the lower left). Signs in this region were not meeting the performance specification while under warrantee. Thus, they could be replaced at no charge to the DOT.

The data presented in Figures 2.31 and 2.32 has been summarized in Tables 2.14, 2.15 and 2.16. Here the signs are categorized by color and sheeting type to show the number and percentage of signs in each group that were in compliance with the DOT specification criteria before and after the warrantee period. The table showed that both sheeting grades performed well during the warrantee period. Of the 149 signs under warrantee in the sample, only 12 (8.1 percent) failed to meet the performance specification.

Table 2.14. Sign Compliance Statistics for Type I Sheeting

Sign Color	Type 1 Sheeting					
	W/I Warrantee (Quadrant)			Post Warrantee (Quadrant)		
	Pass % (IV)	Fail % (III)	n	Pass % (I)	Fail % (II)	n
Green	94.7	5.3	19	56.6	43.5	23
Yellow	81.8	18.2	22	35	65	20
White	90.9	9.1	22	11.1	88.9	18
All Colors	88.9	11.1	63	36.1	63.9	61

Table 2.15. Sign Compliance Statistics for Type III Sheeting

Sign Color	Type III Sheeting					
	W/I Warrantee (Quadrant)			Post Warrantee (Quadrant)		
	Pass % (IV)	Fail % (III)	n	Pass % (I)	Fail % (II)	n
Green	94.1	5.9	34	58.3	41.7	12
Yellow	91.3	8.7	23	55.6	44.4	9
White	96.6	3.4	29	66.7	33.3	6
All Colors	94.2	5.8	86	59.3	40.7	27

Table 2.16. Sign Compliance Statistics for Both Type I and Type III Sheeting

Sign Color	Type I and III Sheeting Types					
	W/I Warrantee (Quadrant)			Post Warrantee (Quadrant)		
	Pass % (IV)	Fail % (III)	n	Pass % (I)	Fail % (II)	n
Green	94.3	5.7	53	57.1	42.9	35
Yellow	86.7	13.3	45	41.4	58.6	29
White	94.1	5.9	51	25	75	24
All Colors	91.9	8.1	149	43.2	56.8	88

In addition to rates of compliance among the various sign categories, the three tables also reveal several interesting relationships between certain grade and color groups. One of these relationships was the difference in performance between the Type I and Type III sheeting after the warrantee period. The table showed that nearly 60 percent of the Type III signs met the minimum performance requirements after the warrantee period. This was in contrast to 36 percent for the Type I signs.

Statistical tests were performed to see the difference between different sign groups. The results of the tests showed that Type III signs performed significantly better than signs in the Type I group after the warrantee period (at a 95 percent level of confidence).

2.3.2.3.4 Sign Cleaning

Sign retroreflectivity was measured in its original condition and again after the sign was cleaned with soap and water. These two readings were compared to determine the overall effect of sign cleaning with respect to the performance specifications and the effect within and across the various data categories.

On an aggregate basis signs showed that cleaning tended to benefit Type I (Engineering Grade) more than the Type III (High-Intensity Grade) signs. To test this difference these two sheeting groups were also statistically compared. T-testing showed the average improvement in Type I signs were significantly greater than the improvement of Type III signs after cleaning.

2.3.2.3.5 Sign Deterioration and Predictive Models

The information gained from the performance and sign cleaning evaluations indicated the existence of differences between several of the sheeting type and color categories. To further evaluate these results within the context of sign deterioration, additional analyses were conducted. The first of these was to determine which factors (if any) contributed to sign deterioration over time. This process was made somewhat more complicated by the potential for interaction between the various factors.

Using these relationships, a set of models to estimate sign performance based on specific properties and environmental characteristics was developed using linear modeling procedures. Each of the predictive model equations took the general form of:

$$\text{AdjRefx} = \text{Intercept} - (\text{Coeff1} \times \text{Age}) + (\text{Coeff2} \times \text{EOPD}) + \text{Korient}$$

where:

AdjRefx = Adjusted coefficient of retroreflectivity, the “x” subscript implies “u” for unwiped or “w” for wiped.
Intercept = Intercept for particular a color/sheeting type combination.
Coeff1 = Age coefficient for particular a color/sheeting type combination.
Coeff2 = EOPD coefficient for particular a color/sheeting type combination.
Korient = A constant to adjust for sign orientation. Specific Korient values were used for each sheeting type.

In this equation both the orientation and offset distance factors were included despite the finding that neither had a statistically significant effect on sign degradation over time. These two parameters were included because although they were not statistically linked, their effects were not shown to be non-existent.

Separate equations were developed for each color/sheeting type sign group, consistent with the specification criteria for each. Separate equations were also developed for the wiped and unwiped data sets. In the equations, the dependent variable AdjRef(u or w) gives an "adjusted" coefficient of retroreflectivity under a wiped or unwiped condition. Adjusted values of retroreflectivity were obtained by taking the field value for the coefficient of retroreflectivity and dividing it by the minimum performance specification value for that color/sheeting type. Thus, an adjusted coefficient of retroreflectivity value greater than 1.00 represented a sign performing above the minimum performance specification value and a value less than 1.00 represented a performance below the minimum acceptable value.

The deterioration equations developed in the study were all linear in nature. As a result, they did not account for all variation within the data distribution. They do, however, reveal many of the findings that were shown in the earlier tests. For example, the relatively "flat" resulting trend lines of the Type III signs are indicative of the superior performance, especially those in the green and white color categories. The deterioration equations are consistent with Tables 2.14, 2.15, and 2.16 where white colored Type I signs showed a higher percentage of specification failures, especially after the warrantee period for these models.

2.3.2.3.6 Conclusions

Based on their research the LSU research team developed the following conclusions:

1. Sign sheeting performed well both before and after the warrantee period.
2. No statistically significant links between key environmental factors such as proximity to the road or sign orientation contributed to premature deterioration.
3. On an average cleaning improves retroreflectivity by about 33% for both Type I and Type III signs.
4. Orientation and distance of sign from road has no effect on the deterioration.
5. Over 90 percent of the signs under warrantee in the sample were performing at or above the expected level.
6. Type III performed better than the Type I sheeting both during (94.2 to 88.9 percent) and after (59.3 to 36.1 percent) the warrantee period. This increased level of performance and durability is also reflected in the cost differences for the two types of sheeting. Type III sheeting typically costs more than three times as much as Type I ($2.34/square foot to $0.74/square foot).
7. The analyses to identify factors contributing to sign deterioration yielded some unexpected results. Of the three dependent variables (age, orientation, and the distance from the road), only age could be positively correlated to sign deterioration.
8. The models for Type I sheeting demonstrated fairly consistent rates of deterioration in the retroreflective sheeting properties over time. In the Type III sheeting category, the deterioration of yellow signs was shown to occur at a faster rate than those in the white and green categories. As a group, signs in the Type I sheeting group also showed a faster deterioration rate than the Type III group.

Table 2.17. LA Study Summary

Objective	To determine the factors affecting rate of sign deterioration and benefits of cleaning.
Important Parameters	• Study was completed in the year 2001. • Only Outdoor observation of signs. • 920 SEL retroreflectometer used. • White, Yellow, and Green color signs studied. • Type I and III sheeting studied. • Data for uncleaned and cleaned signs taken. • Sample size of 237 signs. • Deterioration factors considered were age, orientation, environmental factors, and offset distance to road.
Key Findings	Sign orientation and distance of sign from a road had no significant effect on sign deterioration. Cleaning improved the retroreflectivity of Type I and III sheeting on an average by 33%.

2.3.2.4 FHWA Report

This FHWA report titled Service Life of Retroreflective Traffic Signs evaluated the effects of climatological and geographical variables on sign sheeting deterioration [Black, et. al. 1991]. A national data collection effort was undertaken. Data samples from 6275 traffic signs were collected across the country. The data collected included sheeting retroreflectivity, ground elevation, orientation to the sun, date of installation, sheeting type, etc. Mathematical equations were developed using the key deterioration variables to predict in-service coefficient of retroreflectivity and legend to background contrast ratios. This study on deterioration rates was done in 1991 and is the oldest study on deterioration rates obtained be the NCSU research team.

This study focused on the two most commonly used sheetings at the time the study was conducted. They were Type II, engineering grade (EG) and Type III-A, high performance grade (HP). These are equivalent to the Type I and Type III signs used today, respectively. The general intent of the study was to isolate and monitor those factors which contribute to the deterioration of sign sheeting retroreflectivity. According to the authors, traffic signs are elements which are exposed to all of nature's and man induced weathering. The weathering of such polymeric organic materials was broken down into five main factors:

1. The effects of solar radiation
2. The speed of decomposition reaction with rising temperature, heat, water, and moisture effects of two kinds (soaking and drying out and chemical reaction of the polymeric organic material with water), and freeze and thaw cycles.
3. Oxygen contribution to photo-oxidative decomposition of the surface layer of the material in combination with the solar radiation.
4. Industrial pollution largely caused by atmospheric sulfuric dioxide in combination with water and the ultraviolet radiation of the sun (acid rain).
5. Wind erosion or abrasion in combination with sand, dirt, and salt particles.

According to the authors, not all of the above effects cause sign deterioration of the retroreflective properties.

2.3.2.4.1 Study Objectives

The ability to predict in-service retroreflectivity, and, with the establishment of minimum reflectance standards, specific traffic signs could be highlighted in a computer inventory for field inspection and replacement in a consistent, efficient, and cost effective manner.

To accomplish the stated goal several study objectives were established. The initial objective focused on the factors that cause sign sheeting deterioration and how these factors vary across the United States. To evaluate the deterioration factors, a national data collection effort was undertaken of in-service sign sheeting retroreflectivity. Based on the identification of deterioration factors and retroreflectivity measurements (i.e. in terms of SIA) mathematical equations were developed to predict in-service SIA based on the known deterioration variables. The research team evaluated legend to background retroreflectivity contrast ratio for standard red background signs. The mathematical equations to predict in-service retroreflectivity and/or contrast ratio of traffic signs are planned to be incorporated into FHWA's Sign Management System (SMS).

2.3.2.4.2 Data Collection

Data was collected for standard ground mounted regulatory, warning, and guide signs. Sheeting color of red, yellow, green, and white were included in the data collection effort. The sampling consisted of 2 most commonly used sheeting types, type II engineering grade (EG) and type III-A high performance grade (HP).

The sampling effort was developed considering six age categories at 2 years per category covering a sign age range of 0 to 12 years. Considering the 4 factors of sheeting color, 2 sheeting types, and 6 age categories, a total of 48 sampling units (2*4*6) were produced. Solar radiation and area climate were found to be key contributors to variations in sheeting deterioration in the research team's literature review. Hence a zone system with 8 zones was derived for the data collections. The assumption was that the sheeting deterioration conditions caused by solar radiation and climate would be similar within each of the eight zones. A general climate measure (heating degree days) was included in the zone system derivation. Heating degree days are the number of degrees the daily average temperature is below 65 degrees. This value is cumulated for every day of the year. There was a contractual requirement for data collection on approximately 6000 signs which is approximately 15 samples * 48 sampling units * 8 geographic zones.

The selection of the preferred agencies was completed considering the following criteria:

- Presence of updated computer inventory
- Sign type or sheeting color listed in the data base
- Date of installation listed in the data base
- Wide distribution of sign sheeting age
- Sheeting type
- Zone and geographic location

Six field technicians forming three teams were used to collect the retroreflectivity data. Each of the three teams were supplied with the following equipment:

- Dodge Caravan vehicle
- Model 920 retroreflectometer with extension pole and remote trigger
- Model 920 accessory (battery pack)
- Compass
- Altimeter
- Wash buckets, extension poles and washing apparatus

Severely deteriorated, cracked, or defaced areas on sign faces were avoided when taking retroreflectivity readings. Unusual sign conditions were noted in the comment section of the data collection form. The causes of these deterioration conditions were considered atypical and non geographic or climatological in nature and therefore, beyond the scope of the study. Also, extreme or site specific conditions such as those occurring in coastal or mountainous areas were avoided. Overhead signs were not included in the study because it was too difficult to measure these signs. Samples of green sheeting were obtained from ground mounted, roadside guide signs only.

Upon locating a particular sign on a roadway segment in the predetermined sequence, the ground elevation was determined using an altimeter and was recorded on the data collection form. Vans with sliding doors were acquired to facilitate the constant egress and ingress of the equipment. The driver carried the data collection forms and the passenger carried the retroreflectometer and washing equipment to the sign. The field technicians sponge washed the sign with a non-abrasive detergent from top to bottom and squeegee dried with a soft rubber surface to avoid abrading the sign surface. Retroreflectivity values were taken before and after sign washing on approximately 10 percent (600 signs) of the samples. Every 10^{th} sign sample was washed. Readings for washed signs were taken before and after washing while the readings for signs not washed was taken only before washing. The research team determined that four readings per sheeting color per sign were sufficient to accurately determine mean retroreflectivity.

2.3.2.4.3 Results from Data Collection Effort

Coefficient of retroreflectivity readings were taken on approximately 6275 traffic sign samples throughout the United States. Of the total data set 5722 sign samples were suitable for analysis. The remaining samples were found to erroneous or outlier. The original goal of the data collection was to obtain equal samples by sheeting color and type and age category. It became apparent early in the data collection effort that older high performance sheetings were difficult to find. Also, the use of green, high performance sheeting was not prevalent on ground mounted guide signs at any of the study locations.

2.3.2.4.3.1 Scatter Plots of Retroreflectivity versus Age

The data collected was plotted with retroreflectivity on the Y-axis and age on the X-axis for the different sign colors and sign types. The plot of red high performance sheeting showed pronounced effects of color fade. The standard practice for constructing red background traffic sign was to screen red paint over white sheeting. As the red paint wears away more of the white sheeting comes through resulting in higher retroreflectivity levels with lower contrast ratios. The plot of red high performance sheeting showed increasing retroreflectivity at older age categories. This occurrence was more pronounced in high performance signs as white, high performance sheeting typically has retroreflectivity values of over 300 SIA.

The researchers found a consistent SIA reduction as in-service signs with yellow sheeting aged. Numerous outliers existed but the major grouping of data supported a consistent downward trend.

As with the yellow sheeting, signs with white Type II sheeting displayed a consistent decrease in SIA with age. The downward trend of white high performance was less dramatic. The researchers found the white Type III-A sheeting signs to retain a higher level of retroreflectivity at older in-service ages.

The green type II sheeting signs showed little degradation in SIA until after 10 years of service. The researchers could not draw conclusions about the Type III-A signs as only a few samples over 8 years of service were found. However, green Type III-A seemed to retain much of its retroreflectivity for the samples found.

In general the researchers found the retroreflectivity levels of the signs sampled to be quite high with many older signs exceeding proposed minimum retroreflectivity levels. They found the scatter plots of SIA value and age category to have considerable variability in the data. While there was a reduction in SIA as the in-service age increased, the range (i.e. maximum to minimum values) of SIA values was similar across all age categories.

2.3.2.4.3.2 Orientation to the Sun

The field technicians recorded the bearing reading of orientation for each sign sample measured for retroreflectivity. Their preliminary analysis showed little difference in SIA values between east and west facing signs. To aid in the modeling effort, the sign samples with orientations greater than 180^0 from magnetic north were adjusted to conform to a 0^0 to 180^0 system. A sign facing at 270^0 was coded as facing 90^0 and 350^0 as 10^0, etc. The resulting orientation variable was one that had an assumed increasing effect on deterioration as the bearing from magnetic north increased up to 180^0. This adjustment was done to include the deterioration variable in the linear regression model.

Scatter plots of the adjusted orientation versus SIA for each sign sample by sheeting color and type revealed no distinct pattern of deterioration based on sign orientation. Scatter plots by sheeting color and type for each age category were also generated and reviewed for patterns of deterioration but they did not seem to provide a distinct deterioration pattern. The researchers found no consistent difference between north and south facing signs. The researchers suggested further controlled studies using test racks or selected sites while varying the orientation of the signs with same age.

2.3.2.4.3.3 Contrast Ratios

Red paint was screened over white sheeting in the manufacturing of STOP and YIELD signs. As the red paint wore off over time more of the white sheeting became visible. Therefore, the SIA level of the red background could actually increase over time. Contrast ratios of red background to white legend were calculated for approximately 1000 STOP and YIELD signs. The researchers found little variation in contrast ratios between the age categories for type II sheeting. This was consistent with the SIA plots for red and white engineering grade sheeting, which depicted a rather consistent SIA. Nearly all of the 1000 signs sampled for contrast had ratios greater than 5 to 1, which were cited as a minimum value in the literature review of the FHWA study researchers. However, minimum contrast ratios between 8 and 12 to 1 were also found in their literature search for red and white signs. Many of the signs sampled in this study failed to reach those higher minimum ratios for legend to background contrast.

2.3.2.4.3.4 Sign Washing Results

The primary objective of the study was to model the deterioration of sign retroreflectivity over time. Hence the research team decided to take readings on a sample (10 percent) of signs before and after sign washing. Every tenth sign was measured before and after washing. The research team found that type II sheeting benefited more from sign washing. The research team's explanation of the results were as follows:

- The population of engineering grade sheeting samples was older with a larger subjection to airborne pollutants.
- Numerous signing personnel have mentioned the slippery qualities of high performance sheeting which would seemingly benefit more from rainfall and natural cleaning.

2.3.2.4.4 Predictive Equations

This section presents the modeling effort undertaken by the researchers to develop mathematical equations by sign type and color to facilitate the prediction of in-service SIA values and contrast ratios. The equations were developed using regression analysis techniques to evaluate the significance of each independent variable presumed to effect sheeting deterioration rates. This analysis initially examined the correlation between the independent variables and the dependent variable based on the coefficient of multiple determination (R^2).

As mentioned before, an eight-region zone system was developed for the data collection effort. Mean SIA values by sheeting color/type and age category were compared using standard analysis of variance (ANOVA) methods. Due to the wide variation in the SIA values, no significant differences between geographic zones were found. Within each zone, little consistency between the sites in terms of mean SIA values was apparent. Therefore, for subsequent analysis the zone system collapsed. Also no significant differences between mean SIA from the effects of orientation to the sun were found.

The researchers considered the climatic variables heating degree days, precipitation, and solar radiation to be highly interrelated, hence careful testing for multicollinearity was conducted. The results of regression analysis showed that much of the collinearity between the climate variables was removed when certain insignificant variables (solar radiation and orientation) were eliminated.

Several climatic variables were added to the data set after the zone system was collapsed. Two of the variables (solar radiation levels and heating degree days) were originally used to derive the zone system; therefore, remnants of the zone system remained in the analysis. The third variable included was normal precipitation. The variable was included since it had the climatic importance of potentially less direct sunlight.

2.3.2.4.4.1 Independent Variable Screening

The basic relationships between the variables were first investigated using a correlation matrix. The correlation matrix was developed for each sheeting color and type. The initial review of the matrices by the researchers determined that climatological variables (i.e., solar radiation, heating degree days, precipitation, etc.) were highly correlated. Solar radiation was negatively correlated to heating degree days and precipitation for all the sheeting color and type combinations. The adjusted orientation to the sun variable was not strongly correlated to any of the other independent variables. This would initially indicate a good predictor variable. However, the adjusted orientation was also not correlated to the dependent variable.

The researchers found that precipitation, ground elevation, and heating degree days did show strong correlations. It was found that generally, precipitation and elevation had negative correlations, elevations and degree days had positive correlations, and precipitation and degree days had inconsistent correlations across the sheeting colors and types. Although this indicated the possible removal of one or more of the three variables, each of these variables did show a good correlation to the dependent variable for at least several of the sheeting combinations. As a result only solar radiation and orientation to the sun were removed from the preferred variable list.

2.3.2.4.4.2 Regression Equations

The regression equations were applicable only for predicting SIA of signs placed in service. The researchers had a few definitions and notes useful in reviewing the equations that were as follows:

- The equations were not applicable for sheeting age 0.
- SIAp=predicted coefficient of retroreflection (SIA) values of sheeting.
- AGE=age category of sign sheeting in years.
- PRECIP=annual precipitation in inches.
- DEG DAYS=annual heating degree days.
- ELEV=average ground elevation.
- Many effects of the climatological and geographic factors are already accounted for in the in-service age variability.
- No excessive multicollinearity between independent variables remained in the final equations.

Four independent variables were found to be significant for many of the nine regression equations developed for the eight sheeting color and type combinations by the researchers. As collaborated by the review of the correlation matrices, solar radiation and orientation to the sun were not significant in any of the equations. For some of the equations certain of the four selected variables were not significant at a 90 percent or 95 percent probability level. However, for consistency of the equation form each includes age (AGE), precipitation (PRECIP), heating degree days (DEG DAYS) and ground elevation (ELEV).

The nine equations had R^2 values ranging from 0.2 to 0.5. The AGE variable, which includes the impact of all deterioration factors, was the dominant predictor of in-service SIA. Of the six total independent variables tested only two (i.e., solar radiation and orientation to the sun) were removed from the equations. The regression equations according to the researchers were found to be significant but not accurate.

2.3.2.4.4.3 Contrast Ratio Evaluation

This section presents the evaluation and modeling of contrast ratios for red and white traffic signs. As age category was the dominant predictor of in-service SIA only this variable was deemed appropriate by the researchers for predicting in-service contrast ratios.

The general form of the equations included in-service contrast ratio (i.e., white legend divided by red background) as the dependent variable and age category as the independent predictor variable. Other variables (i.e., orientation to sun, elevation, etc) tested for the in-service SIA equations were evaluated here. These other variables were not found to be significant predictors of in-service contrast ratio. The researchers had a few definitions and notes useful in reviewing the equations that were as follows:

- CRp = predicted in-service contrast ratio of white legend to red background.
- AGE = age category of sign sheeting in years.
- The equations are not applicable for sheeting age = 0.

2.3.2.4.5 Validation

The results of validation of the ten significant regression equations by the researchers are presented here. Since the contrast ratio equations for engineering grade (type II) and high performance (type III-A) for AGE 1 and 3 sheeting were insignificant predictors, validation analysis was not appropriate. The purpose of the validation was to test the significance of the regression equations in predicting SIA for an independent data set. The validation was completed by computing predicted SIA values from the regression equations using the withheld data.

2.3.2.4.5.1 Validation Methodology

According to the researchers a review of literature and reports of similar statistical analysis failed to provide guidance on retention of data for validation. Sound judgment was exercised by the research team to select retention of 25 percent of the sample data for the validation analysis. The validation data was segregated from the population sample by random selection by sign color and type. Segregation by geometric zone was unnecessary as the zone system was collapsed when the solar radiation and climate variables were included in the regression testing.

The validation comparison consists of predicted in-service SIA or contrast ratio on the Y-axis and actual in-service SIA on the X-axis. The predicted values are the result of applying the independent variables (i.e., age, precipitation, degree days, and elevation) of the validation data set to the regression equations. The actual in-service SIA and contrast ratio values are simply from the measurements of retroreflection taken in the field.

2.3.2.4.5.2 Validation Results

The predicted versus actual SIA values were plotted for each sheeting color type with two plots for red, high performance sheeting. A similar plot of actual versus predicted ratios predicted for red and white type III-A for in-service ages of 5 to 12 years was also developed. Regression lines were calculated for each plot and compared to the 45^0 reference line. The reference line provides the perfect fit criteria where predicted equals actual.

According to the researchers, the validation results were poor as the regression equations had relatively low coefficients of determination (R^2). The validation results are summarized as follows:

- The validation plots for red type II, yellow type I and III, White type I and III, and Green type I and III overestimated SIA for the lower range and underestimated the higher values. In other words the regression line was above the reference line up to a certain SIA and below the reference line for the remaining portion of SIA.
- The validation plots for red type III-A for age categories 1 and 3, overestimated the actual SIA throughout the data set range and for age categories 5, 7, 9, and 11 the the regression line was negative showing an erroneous relationship between the actual and predicted SIA values.
- The validation plot for the contrast ratio equations for red and white, type III-A sheeting showed that underestimations of contrast ratio were made above 7 to 1. Within the range of 5 to 1 and 10 to 1 contrast ratio the regression line was reasonably accurate.

The validation analysis showed that the regression equations, except that for the red type III-A sheeting, provided significant predictions of actual in-service values. An investigation of the validation plots showed that within the range of SIA and contrast values for each sheeting color and type, the over/underestimation by the equations was not particularly severe.

2.3.2.4.5 Summary

The researchers summarized the following key findings from this study:

- Coefficient of retroreflection (R_A) values were extremely variable across all sheeting colors and types.
- Green sheeting was the least influenced by natural weathering.
- For even the oldest signs sampled (i.e., up to 12 years old) almost all mean SIA values exceeded the minimum retroreflective levels for new sheeting specified in FP-85.
- The nine regression equations used to predict in-service SIA values included sign age, precipitation levels, ground elevation, and heating degree days as independent variables.
- Each of the SIA regression equations was found to be significant but with rather low explained variance (i.e., R^2 values between 0.2 and 0.5).
- The AGE variable was the dominant predictor of in-service SIA. This variable quantifies the impacts of the other climate and geographic variables.
- The regression equations, excluding the ones for red high performance sheeting, were found to be reasonable predictors of actual SIA based on the validation analysis.
- The three regression equations used to predict in-service contrast ratio included sign age as the independent variable.

- Only the contrast ratio regression equation for high performance, red and white sheeting signs of in-service age greater than or equal to 5 years was found to be significant.
- Vandalism was found to be more prevalent in rural areas.

Table 2.18. FHWA Study Summary

Objective	To determine the factors affecting sign deterioration and to predict retroreflectivity of in-service signs.
Important Parameters	• Study was completed in the year 1991. • Only Outdoor observation of signs. • 920 SEL retroreflectometer used. • White, Yellow, Red, and Green color signs studied. • Type I and III sheeting studied. • Observers were trained prior to data collection. • Data for uncleaned and cleaned signs taken. • Sample size of 6000 signs. • Deterioration factors considered were age, orientation, solar radiation, degree days, precipitation, and elevation.
Key Findings	• Age was found to be significant variable in predicting the retroreflectivity of sign. • Degree days, precipitation, and elevation showed good correlation to retroreflectivity. • Orientation did not effect deterioration. • Cleaning affected type I signs more than type III.

2.3.2.5 AASHTO Report

The National Transportation Product Evaluation Program (NTPEP) is a program started to provide quality and responsive engineering for the testing and evaluation of products, materials, and devices that are commonly used by the AASHTO Member Departments of Transportation [NTPEP 2006].

Sign sheeting material evaluation has been managed through AASHTO's NTPEP since 1994. Prior to that time, the successful Regional Testing Facility operated by the SASHTO (southeastern states) administered the program. Under the umbrella of AASHTO, the program expanded from three test decks to six outdoor test decks, located nationwide. However, due to duplication of climatic conditions, the number of test decks has more recently been reduced from six to four, effective with the 2004 product submittals.

NTPEP evaluation of sign sheeting materials consists of three-year, outdoor exposure on fabricated test panels (specimens). Also, a series of laboratory tests are conducted on the sign sheeting material specimens. All testing is in accordance with the ASTM D 4956 specification. Lab and field testing is conducted by LA through a state DOT cooperative that includes the following states: VA, LA, MN, AZ, and MO. Industry participating in NTPEP evaluations includes all major manufacturers of sign sheeting materials. The key observation regarding the NTPEP program is that its duration is limited to 3 years.

2.3.2.5.1 Test Decks

NTPEP conducts ongoing field and lab testing of commercially available, retroreflective sign sheeting materials. Field test racks for outdoor exposure evaluation are located at six different sites nationally as follows:

- MN (cold, dry, altitude),
- VA (cold, semi-humid, altitude),
- NC (temperate, Atlantic coast),
- LA (hot, humid, gulf state),
- Phoenix, AZ (hot, dry, UV), and
- Flagstaff, AZ (hot, dry, UV, altitude).

Field evaluations in NC and Flagstaff, AZ were discontinued starting in 2003.

Each sign sheeting style submitted for NTPEP evaluation undergoes lab testing by LA DOTD Materials and Tests division. Outdoor exposure field-testing on NTPEP racks is presently conducted for 3 years, at four sites as previously noted. This outdoor exposure evaluation coincides with the latest ASTM D 4956 specification requirements for retroreflective sign sheeting.

2.3.2.5.2 Data Collection

Each test deck receives 3 panels for each sample submitted to the NTPEP for testing. Each panel received for testing is examined carefully and even the smallest flaw is recorded in a notebook. Each panel is examined at the top, middle, and bottom of the panel with a Retrosign 4500 retroreflectometer, positioned at a 0 degree rotation angle. The average of these readings is recorded in the report for each panel. The readings for the signs are also taken at a 90 degree rotation angle, that is, at 90 degrees to the original sign orientation readings.

2.3.2.5.3 NTPEP DataMine

NTPEP DataMine is a new service offered by AASHTO/NTPEP. DataMine is an online engineering tool for querying, analyzing and reporting on current and past NTPEP evaluations. The database allows dynamic queries of multiple products and specification overlays. DataMine includes features for graphical presentation of results. The application allows NTPEP Lead States to enter their evaluation collection data online; allows participating and NTPEP administration to review data collected online; and, ultimately it will allow real time reporting of data.

2.3.2.5.4 Assessment

As of now only 3 years of data is available through the NTPEP DataMine. Because of this, and because each year has only one sample of signs in each location for each color and type, there is no significant conclusion that can be made at this time about this data.

2.3.2.6 FL Study

This study was undertaken to gather information on sign retroreflectivity with the objective of quantifying the potential impact on Hillsborough County, FL, of meeting the new proposed

FHWA minimum standards [Rogoff et. al. 2005]. The FHWA minimum standards were discussed in the Section 2.1 of this report.

In the FL study data was collected on four signs. These were regulatory, school, stop, and warning signs. The sample size consisted of 1423 signs selected through random sampling. The GPS coordinates of each sign were measured during the survey.

The analysis of the data showed that the orientation of a sign did not play a significant role in its retroreflective deterioration. It was determined that 55% of the red signs, 40% of warning signs, 26% of regulatory signs, and 21% of school signs did not meet the proposed minimum standards.

In conclusion the study found that for replacing all the signs below the proposed minimums the county needed $1 million for the county itself to install all the signs and $2.1 million for the county to have a vendor supply the signs and perform the installation. The total number of signs needing replacement was projected to be 17,000. The costs were based on the current replacement costs for Hillsborough County being $60 per sign for private vendor fabrication and county installation and $125 per sign for private vendor fabrication and installation.

Table 2.19. FL Study Summary

Objective	To gather information on sign retroreflectivity with the objective of quantifying the potential impact on Hillsborough County, FL of meeting the new proposed FHWA minimum standards.
Important Parameters	• Study was completed in the year 2005. • Only outdoor observation of signs. • Red, warning, regulatory, and school signs studied. • Data for uncleaned signs taken. • Sample size of 1423 signs. • Current replacement costs for Hillsborough County is $60 per sign for private vendor fabrication and county installation and $125 per sign for private vendor fabrication and installation.
Key Findings	The study found that for replacing all the signs below the proposed minimums the county needed $1 million for county installation and $2.1 million for vendor installation

2.3.2.7 Other Deterioration Factors

Deterioration factors from other literature reviews have been compiled into the table shown below. These sources of literature were available from the FHWA study, which was discussed in Section 2.3.2.5 of this report. There were 2 main types of factors affecting sign deterioration. One type includes the factors relating to sign itself including the sign type, manufacturer, fabrication process, etc. The other factors are due to external variables affecting sign deterioration. These included dust, sunlight, pollution, etc.

Table 2.20. Factors Affecting Sign Deterioration

Source	Factors Affecting Sign Deterioration	
	Sign	External
Gennaoui, et. al. 1989		Time of day, moisture, area type, dirt accumulation
Mace, et. al. 1986	Sheeting type, manufacturer, color, adhesive type, fabrication and handling techniques	Damage, substrate, sunlight, orientation to sun, airborne abrasives, air pollution, proximity to road, climate, temperature, salt spray
Sator 1989		Solar radiation, moisture, temperature, pollution
The 3M Company 1988	Substrate type and coating, sheeting color, adhesives, fabrication process	Direction facing, ultraviolet light, angle of exposure, temperature ranges, humidity, frost, rain, snow, elevation, dew, salt spray, air pollution, post painting, weed control chemicals, sand/salt winter operations, snowplow debris impacts, road surface treatments
Awadallah 1987	Material type, manufacturer color	Orientation to sun, availability of shade, climatic conditions, in-service age, air pollution, salt spray
Nettleton 1984		Snow burials, extreme temperature change, ultraviolet rays

2.3.3 Summary

A series of summary tables is presented here so that the reader can visually see the relationship between all of the studies reviewed herein. Each table also enables the reader to compare those results.

Table 2.21 shows the name of all the studies discussed above, the organization that conducted the study, the purpose of the study and the year the report was published. Table 2.22 identifies the retroreflectometers used by each of the studies shown in Table 2.21 and also the sign color and sheeting type studied by them. Table 2.23 identifies which study teams cleaned the signs when taking measurements and specifies the sample size collected by each study. Table 2.24 shows the deterioration factors considered by different studies and also shows whether or not they collected G.P.S coordinates. Finally, table 2.25 shows the primary objectives and key findings of the different literature studies.

Table 2.21. Literature Review Summary

Year	Name	Organization	Purpose of study
1987	Traffic Sign Retroreflectivity Measurements Using Human Observers	University of WA	Crew Validation
2001	Comparing Results of Night Time Visual Inspections With Applications of Minimum Retroreflectivity Values	TX A&M University	
1991	Service Life of Retroreflective Traffic Signs	FHWA	Sign Deterioration
2001	Factors Affecting Sign Retroreflectivity	OR	
2002	Analysis and Predictive Modeling of Road Sign Retroreflective Performance	LA State University	
2002	Sign Retroreflectivity Study	Purdue University	
1999	National Transportation Product Evaluation Program (NTPEP)	AASHTO	

Table 2.22. Sign Type, Sheeting, and Retroreflectometer Used in Literature

Organization	Retroreflectometer Model Used	Sign Type Studied	Sheeting Color Studied
University of WA	910F RetroTech	I	Stop and Yellow
TX A&M University	RetroSign 4500	I, III	White, Yellow, Green and Red
FHWA	920 SEL	I, III	White, Yellow, Green and Red
OR	RetroSign 4500	III	White, Yellow, Green and Red
LA State University	920 SEL	I, III	White, Yellow, and Green
Purdue University	920 SEL	III	White, Yellow, and Red
AASHTO	RetroSign 4500	All Sign Types	All Sign Colors

Table 2.23. Sign Cleaning and Sample Size for Literature

Organization	Sign Cleaning	Sample Size
University of WA	Uncleaned Data	130
TX A&M University	Uncleaned Data	49
FHWA	Uncleaned and Cleaned Data	6000
OR	Cleaned Data	137
LA State University	Uncleaned and Cleaned Data	237
Purdue University	Uncleaned and cleaned data	1341
AASHTO	Uncleaned data	-

Table 2.24. Deterioration Factors and Location Measurement

Organization	Deterioration Factors Considered				Measured G.P.S Coordinates
	Age	Orientation	Environmental Factors	Offset Distance to Road	
University of WA*	-	-	-	-	-
TX A&M University*	-	-	-	-	-
FHWA	Yes	Yes	Yes	No	No
OR	Yes	Yes	Yes	No	No
LA State University	Yes	Yes	Yes	Yes	No
Purdue University	Yes	Yes	Yes	Yes	Yes
AASHTO	Yes	Yes	Yes	No	No

* - These studies did not measure the deterioration factors mentioned in the above table. Rather, their purpose was only to assess inspector performance.

Table 2.25. Objectives and Key Findings from Literature

Organization	Objectives	Key Findings
University of WA	To determine the accuracy of trained observer in rating retroreflectivity of traffic signs	Observers correctly rated 75% of warning signs and 82% of stop signs based on visual observation
TX A&M University	To compare nighttime visual inspection with sign's retroreflectivity values	Factors other than retroreflectivity influence the effectiveness of signs at night such as uniformity or damage of the sign face and type of sheeting material
FHWA	To determine the factors affecting sign deterioration	Age variable was the dominant predictor of in service retroreflectivity and quantifies the impacts of other climate and geographic variables.
OR	To determine the effect of age and orientation on sign deterioration	Age cannot be considered as a factor for planning for sign replacement and there was not enough evidence to relate sign orientation to deterioration.
LA State University	To determine the factors affecting rate of sign deterioration and benefits of cleaning	Sign orientation and distance of sign from road had no significant effect on sign deterioration. Cleaning affected retroreflectivity by 33%.
Purdue University	To check if the 10 year replacement cycle is adequate and to find the effects of age, cleaning and orientation on sign deterioration.	Replacement cycle could be extended to 12 years. Orientation did not effect deterioration and cleaning did not have an effect on the retroreflectivity values
AASHTO	To provide quality and responsive engineering for the testing and evaluation of products, materials, and devices that are commonly used by the AASHTO Member Departments of Transportation.	Only three year's data available. No significant conclusion was made.

3.0 NCDOT NIGHTTIME SIGN INSPECTION PROCEDURES

In order to develop a data collection procedure for recording the nighttime inspection evaluation data, the nighttime sign inspection procedure used by NCDOT divisions had to be further defined. Based on feedback from NCDOT Divisions 4 and 8 as well as a visit with Division 6, the research group gained an understanding of how the nighttime sign inspection evaluation data are collected and recorded.

3.1 Logistics and Scheduling

There are 77,500 miles of NCDOT-maintained highways containing over one million road signs. The objective of the nighttime sign inspection is to identify the signs on the road that have inadequate retroreflectivity, legibility and/or installation. Typically, a set number of sign crews are assigned to each NC County based on the NCDOT road miles in that county. Within the county the sign crews have an area where they are responsible for nighttime sign inspections.

Nighttime sign inspection generally occurs between November and February because of the longer hours of darkness. The nighttime sign inspections are typically performed over a two-week to one-month period. The sign crews work usually from 2 pm to 10 pm, Monday night through Thursday night, during the nighttime inspection period. Signs located in interstate highways are inspected annually, while signs on primary roads are inspected every two years. The majority of NCDOT roads are secondary roads, and they are inspected every two to three years depending on how large an area each sign crew is responsible for. All sign inspection information is completed and submitted as a spreadsheet to the NCDOT State Road Maintenance Unit no later than March 15 of each year.

3.2 Inspection Procedure

The traffic sign erector, the erector's helper, and/or other personnel as determined by the Division sign crew leader conduct the nighttime sign survey. The two inspectors, with at least one being experienced, drive a car or truck on a predetermined route marked on an NCDOT county map. The sign crews follow the map and inspect all signs along the marked route. One person in the crew drives while the other person evaluates the signs and logs defective signs. Sign crews are trained for the nighttime sign inspection on the job or via a training video produced by the NCDOT.

The nighttime sign inspection is conducted at posted speed limits in the lane closest to the signs with the vehicle headlights as the light source. The inspection light needs to be bright enough to cause the sign sheeting to reflect, but not so bright as to cause the sheeting to be brilliantly illuminated. A flashlight is used when the car headlights do not light up a particular sign.

Nighttime sign inspection is a qualitative visual inspection with no assistance from any electric measuring devices, such as a retroreflectometer. The signs are inspected from the point at which the light is first reflected from the headlights, as the vehicle approaches and passes the sign. Vehicles do not typically stop at a certain distance and inspect the signs unless the sign is in question. The age of a questionable sign is often checked by one member of the sign crew exiting the vehicle and looking at the punched date sticker on the back of the sign or by the crew remaining in their vehicle and reading a large two-digit date, such as '98,' written or on a sticker affixed to the back of the sign. If a sign needs replacement, a dot is painted in its lower left hand corner. The color of the dot corresponds to the calendar year the sign was determined to need replacement.

3.3 Reporting Inadequate Signs

When the member of the sign crew that is visually inspecting signs determines that a sign needs to be replaced, the crew member enters that sign's information into the sign condition survey report. A sample sign condition survey report is shown in Figure 3.1.

Division 6   ***County*** Harnett   ***The county system work order #*** 5.54511   ***Date*** Nov.12,2004

Route	Sign Size	Message	Comment	Action Code	Date Corrected
US 401	48x48	Bicycle Sign -symbol	paintball	2	

Definition of Action Codes
- Code 1 [Red sign] : Stop, Yield, Wrong Way, Do Not Enter – Immediate action required
- Code 2 [Yellow sign] : Warning or diamond shape sign – Take action as soon as possible
- Code 3 [Other sign] : Take action whenever possible

Figure 3.1. Sample Sign Condition Survey Report

In the report, the location and size of the sign are noted, as well as the sign's message. Physical sign characteristics such as cleanliness, installation, orientation, and vandalism/damage are also evaluated during the nighttime sign survey in addition to the level of retroreflectivity. This information is recorded in the comment column. For example, in Figure 3.1 the comment column indicates that the bicycle symbol sign has been damaged by paintball. Vandalized/damaged signs are noted for replacement regardless of retroreflectivity levels. The more that a sign's message is obscured by damage the more likely it is for the sign crews to reject it. The sign crews will also check the cleanliness of the sign. If a sign can be cleaned and the retroreflectivity after cleaning is acceptable the sign is not replaced.

The NCDOT sign crews assign three Action Codes to deficient signs during the nighttime inspection. Code one signs, which are red and white sheeting signs (i.e. stop, do not enter, yield, wrong way), must be replaced immediately if supplies and conditions permit. Most sign crews will replace a code one sign if the sign has any noticeable mark or defect. Warning (yellow) signs are designated as code two, and should be replaced as soon as possible. All other signs, generally including signs having white, green, brown, and blue sheeting, are assigned code three and will be replaced as labor availability and budgets allow.

4.0 RETROREFLECTIVITY MEASUREMENT

The retroreflectivity of signs can be checked by human observers with or without the help of some devices. Our research project team examined the devices, which are called handheld retroreflectometers and mobile measurement systems, in this Section, focusing on practicality and functionality. Those two types are available in the market currently, but mobile measurement systems are still at their initial stages and need some more time to be ready for use with confidence.

4.1 Handheld Retroreflectometers

A handheld retroreflectometer is one of the most credible methods to measure retroreflectivity of traffic signs for nighttime drivers. We can assure retroreflectivity of each sign numerically in $cd/lx/m^2$. Figure 4.1 illustrates a handheld retroreflectometer.

Figure 4.1. A handheld retroreflectometer (RetroSign®4500)

By pressing a trigger, the device emits a beam toward the a sign sheeting and then it displays retroreflectivity in a few seconds. It has relatively small size of about 360 to 490 $inch^3$ and weighs about 4.2 to 5 pounds.

There are several models of hand-held retroreflectometer in the market, including the ZRS 5060R from GENEQ Inc., the 930C from Gamma Scientific Sales, the 920SEL Sign Master from Advanced Retro Technology, the SignInspector from Mechatronic, and the RetroSign®4500 from Delta Light & Optics. They all comply with the standard test method for measurement of retroreflective signs using a portable retroreflectometer as defined in ASTM-E 1709.

<u>4.1.1 Selection of Retroreflectometer for Study</u>

With the aid of the Signing Section of the Traffic Engineering Branch of the NCDOT, our project team obtained a RetroSign®4500 for use in the project. This is the same model used at the Correction Enterprises Sign Plant in Bunn, NC.

The basic function of the RetroSign®4500 follows the ASTM-E 1709 Standard, with an entrance angle of -4º, an observation angle of 0.2º, and a measuring of coefficient of retroreflection values from 0.1 to 1999.9 $cd \cdot lx^{-1} \cdot m^{-2}$ [Flint Trading, INC. 2006]. There are some other distinctive features of the RetroSign®4500:

- It measures all types of retroreflective materials and colors directly, with only one calibration unit and no need for correction factors,
- It compensates for stray light,
- It allows a user to identify and store up to 1,000 measurements,
- The Road Sensor Control (RSC) program provides an easy interface to the RetroSign®4500 instrument,
- Data can be exported to a spreadsheet, and
- It takes substantially less time to take readings with the RetroSign®4500 than with other traditional hand-held sign retroreflectometers.

The RetroSign®4500 has some accessory options, including a global positioning system (GPS) unit, an extension pole kit, an aperture reducer, and an extra battery that facilitates field inspection. The GPS unit identifies and displays the location of signs; the extension pole kit consists of an extension pole that can be extended 5 to 9 feet, a remote trigger, and a digital display; and the aperture reducer allows the operator to measure each letter without including any of the background material in the measurement. The research team used our own GPS unit to record sign locations. We purchased the extension pole kit from Flint Trading, Inc. for our field study. The price of a RetroSign®4500 retroreflectometer is $9,527.00. The RetroSign®4500 pamphlet and the price list are included in an appendix to this report.

Several retroreflectometers have been used in other studies. In the Washington State study (1987), the sign retroreflectivity measurement was done using a 910F Retro Tech retroreflectometer which is not available in the market anymore [Lagergren, et. al. 1987]. The biggest problem with that kind of old model was that the device had to be recalibrated for each color of sign sheeting. The RetroSign®4500 was used in the Oregon State study in 2001 [Kirk, et. al. 2001] and the Sign Master 920SEL from Advanced Retro Technology was used in the Purdue [Bischoff, et. al. 2002] in 2002. Both models are the latest versions of retroreflectometer and comply with the ASTM-E 1709 standard which defines the standard test method for measurement of retroreflectivity signs using a portable retroreflectometer.

Our research team decided to use the RetroSign®4500 which has not only the basic function of reading retroreflectivity without recalibration for changing colors but also has various options such as the extension pole. The company which caries the RetroSign®4500 model is also located in Thomasville, North Carolina, which made repairs convenient.

4.2 Mobile Retroreflectivity Measurement

Our research team decided to use a hand-held retroreflectometer to check exact retroreflectivity of signs but there are other devices to evaluate retroreflectivity. The most well known devices are the Sign Management and Retroreflectivity Tracking System (SMARTS) van from the Federal Highway Administration (FHWA) and the RetroView™ vehicle from Mandli. We also investigated these kinds of new technologies to see whether the NCDOT can adopt either of these systems in the near future.

4.2.1 FHWA Van

The FHWA developed the SMARTS van to measure the retroreflectivity of traffic signs efficiently, economically, and safely. SMARTS has distinctive capabilities such as measuring the retroreflectivity at highway speeds with an automatic tracking system and it also has significant safety advantages over hand-held devices. Four SMARTS vans were built by FHWA Resource Centers and one of them was evaluated by Alaska Department of Transportation in 2001 [Smith, et. al. 2001]. The SMARTS van is illustrated in Figure 4.2.

Figure 4.2. SMARTS Van [Smith, et. al. 2001]

The SMARTS Vans contained the following equipment:

- Regular length Ford Club Wagon with 2,000-watt inverter for AC power. Racks were installed inside the van to house associated equipment.
- Laser range finder with the capability of 1,000-ft range and 2-inch accuracy. It was safe to the naked eye.
- One color camera with the resolution of 768(H)×494(V). A 50-mm lens captured a picture with 1/60 to 1/10,000 sec shutter speed.
- Two black and white cameras with the same resolution as the color camera. One camera used a 50-mm lens and the other used a 75-mm lens. The shutter speed of black and white cameras was also 1/60 to 1/100,000 sec.
- A Xenon flash tube mounted on a turret of the van with the laser range finder and three cameras. It had 270,000 candelas of light intensity and 1 second flash recharge time.
- An Intel Pentium 200 MHz dual processor with 2 to 4 gigabyte internal hard drive and 2 gigabyte removable drive. It had a Windows NT 4.0 operating system.
- 13.8-inch LCD flat panel monitor with 1,024×768 resolution installed not to interfere with the driver's view of the side mirror.
- GPS unit with 10 channel sensor to record the location of signs.
- Two software programs to look for retroreflective signs and to analyze retroreflectivity data.

A driver and an operator are needed to check retroreflectivity of traffic signs using the SMARTS van. The driver operates the van at proper speed and the operator will manage the automatic tracking system using a computer mouse. The color camera is used to locate and track the signs. As the van approaches the minimum required distance (200 feet), the Xenon flash will be fired and the sign image will be captured by the black and white camera. The histogram from the sign image will be analyzed later to calculate the retroreflectivity of the signs. All picture data along with GPS coordinates will be stored in the internal hard drive first and then transferred to the removable drive to take to the office later.

The original intention of the SMARTS van was to allow highway agencies to have the sign retroreflectivity data necessary to schedule timely maintenance on a system wide basis. However a research project by the Alaska Department of Transportation in 2001 showed a different story. The conclusion of the research was that the van's performance was not acceptable. They checked the accuracy of van-collected data and typical sign capture rates under rural and urban conditions. For the accuracy of van-collected data, they used two methods. First, they measured the consistency of multiple retroreflectivity readings for the same signs. The difference in retroreflectivity values for two selected signs was 41 and 72 $cd/lx/m^2$, for example, which was not acceptable. The second method was to compare the retroreflectivity value recorded in the van with a reading from a hand-held retroreflectometer (a RetroSign®4500, the same device as our research team used, generally considered as among the most accurate types of available devices). The average differences for sign legends was 351 percent and on backgrounds was 297 percent, which were unacceptable. They also revealed that the sign capture rate, number of sign photos taken divided by number of target signs, was only 36 percent in an urban area and 64 percent in a rural area.

Based on the result of the Alaska DOT study and cost of the van, which was known to be $210,000, data collection with a hand-held retroreflectometer was deemed to be the best solution for our research at this time.

4.2.2 Mandli RetroView™ Vehicle

Mandli Communication Inc. has developed the RetroView™ mobile platform, which has the ability to collect the retroreflectivity of traffic signs in a single pass at posted road speeds. It is basically the same concept as the SMARTS van from FHWA but it is expected to show a better outcome than the SMARTS van in collecting data in the field. It can collect not only retroreflectivity data but also digital roadway imagery and GPS data with its Roadview6 software, high resolution color digital camera, engineer grade black and white digital camera, and GPS unit [Mandli Communications, Inc. 2005]. The RetroView™ vehicle is illustrated in Figure 4.3.

Figure 4.3. RetroView™ vehicle [Mandli Communications, Inc. 2005]

The company announced that over 5,000 signs per day could be measured with its RetroView™ mobile system at the 2005 Transportation Research Board Annual Meeting. However, the RetroView™ is also at initial stage in some pilot projects with the Tennessee and Texas DOTs and it needs some time to be verified as a cost-effective method to measure the retroreflectivity of signs.

5.0 FIELD STUDY SCOPE, EQUIPMENT, AND PROCEDURE

The research team initially developed a plan for the field study before going out in the field. One early and important part of the planning was to decide on the sign colors, sign types, and sheeting type to be measured as well as to decide the different geographic locations at which to collect data. Initially the team planned to do about 4 visits to 4 different NCDOT divisions. The reasons for visiting 4 divisions were to get a good sample of signs and to obtain samples from different geographic locations. Visits to the divisions were initially planned in the early spring of 2005 because that was the time most of the sign crews performed their inspections. The reasons for choosing certain geographic locations and sign attributes are discussed in the following sections.

5.1 Field Study Scope

Data is the backbone of this research. The more appropriate the sample size, the more accurate the results will be. Not only a better sample size but also samples from different geographic locations were expected to yield realistic sign deterioration rates. Hence the team planned to collect data samples from different geographic locations encompassing the coastal region, mountain region, and plains of NC. Within each geographic location, the team decided to collect a sample of signs on different roads including interstates, other primary roads, and secondary roads.

The first division visited was Fayetteville, which is located in flat terrain and is situated in Cumberland County NC. The team accompanied the NCDOT inspection crew on 2 night rides and measured the signs using a retroreflectometer the following day. The sign crew rode only secondary roads, hence the team measured signs only on those secondary roads.

The next visit was to Asheville, situated in the mountains in Buncombe County. At this location the research team had an opportunity to ride all of secondary, other primary, and Interstate roads. The trip to Asheville enabled the field ream to gather valuable data from a variety of road types.

Siler city was another important field study location. It is situated Chatham County NC, which also consists terrain like Cumberland County. The sign crews again rode only secondary roads in this county. Another field study trip was taken to Shelby. Shelby is also in the piedmont region in the southern part of NC in Cleveland County. In Shelby the sign crews rode both secondary roads and interstates. The research team's final trip was to Greenville, situated in Pitt County, which is a coastal region. The crew rode secondary and other primary roads in this county. Table 5.1 shows the different divisions in which the NCSU research team rode along with NCDOT sign crews and the road types on which data was collected in each division. Figure 5.1 shows the different NCDOT divisions on the NC map.

5.1.1 Sign Attributes

The research team decided to measure signs with red, yellow, green, and white backgrounds because they are important to safety. Signs with blue or brown backgrounds were not included in the study because they are not nearly as important to safety. In addition, FHWA had not proposed a minimum retroreflectivity standard for those colors at the time our study began. In this paper the minimum standards are compared with the retroreflectivity of signs observed by inspectors. The minimum standards were used as a base line against which to compare the inspector's visual observation of retroreflectivity of signs.

Orange signs are important to safety and FHWA has proposed a minimum standard for them. However, orange signs are used in temporary traffic control zones, are moved frequently, and in general receive much harsher treatment than permanent signs. In addition, orange signs are often located in such a way (in construction areas) that it was determined to be unsafe for the research team to stop and make measurements of them. For these reasons the team decided not to measure orange signs.

The research team placed more emphasis on the more important regulatory, warning, and guide signs in its data collection. The team decided not to take any measurements of 'No Parking' and 'Adopt a Highway Signs,' for example. These types of signs are usually the last to be replaced by the sign inspection crew depending on their budget, so decisions regarding the replacement of these signs are often quite different than others.

The research team decided to collect data on Type I and Type III sheeting. These are by far the most common sheeting grades used by the NCDOT. Other sheeting grades are very rare in NC and would not provide an adequate sample size from which to draw any meaningful conclusions.

During the daytime rides the team visited various divisions and took retroreflectivity measurements of signs with red, white, yellow, and green colors. The team did not measure signs with blue or brown colors as per the discussion above also because the signs crews did not evaluate the blue and brown signs. The team initially took readings of a couple of fluorescent school signs but then realized that fluorescent data is not required as per initial plan and thus did not measure any fluorescent signs further.

The team inspected all the signs along the road driven by the sign inspectors. The regulatory, warning and guide signs were the inspector's and research team's top priority.

The research team observed that most of the signs in the field were Type I signs but there were also quite a large number of type III signs. The team took measurements of both Type I and Type III signs with varying ages. The team was surprised when it discovered older signs with Avery Dennison Stimsonite® sign sheeting in the field. The team also measured these signs and took special note of them.

The research team collected data from a number of crews in a variety of settings. This helped us to come up with a fairly accurate estimate of crew validation. In the end, we collected data in 5 of the NCDOT's 14 divisions, including one in the coastal region (Division 2), two in the central Piedmont region (Divisions 6 and 8) and two in the mountain region (Divisions 12 and 13). Within each geographic region, the team decided to obtain samples from different roads including interstates, other primary roads, and secondary roads. Figure 1 shows the locations visited for data collection. These were centered in Greenville, Fayetteville, Siler City, Shelby, and Asheville which were in Divisions 2, 6, 8, 12, and 13 respectively.

Table 5.2 shows the division numbers of different counties where data was collected, the geographic terrain of those counties, the sign types measured in those counties, and the number of signs of each sign type measured.

Table 5.1. NCDOT Divisions and Road Types

Division Number	NCDOT Division Location	County	Geographic Terrain	Interstates	Other Primary	Secondary
2	Greenville	Pitt	Coastal		X	X
6	Fayetteville	Cumberland	Piedmont			X
8	Siler City	Chatham	Piedmont			X
12	Shelby	Cleveland	Piedmont	X		X
13	Asheville	Buncombe	Mountain	X	X	X

Table 5.2. Geographic Area and Sign Attributes

Division Number	County	Sign Sheeting Type			
		Type I	Type III	Other	Total
2	Pitt	102	20	-	122
6	Cumberland	232	82	2	316
8	Chatham	118	17	1	136
12	Cleveland	112	67	4	183
13	Buncombe	218	79	3	300
Total		**782**	**265**	**10**	**1,057**

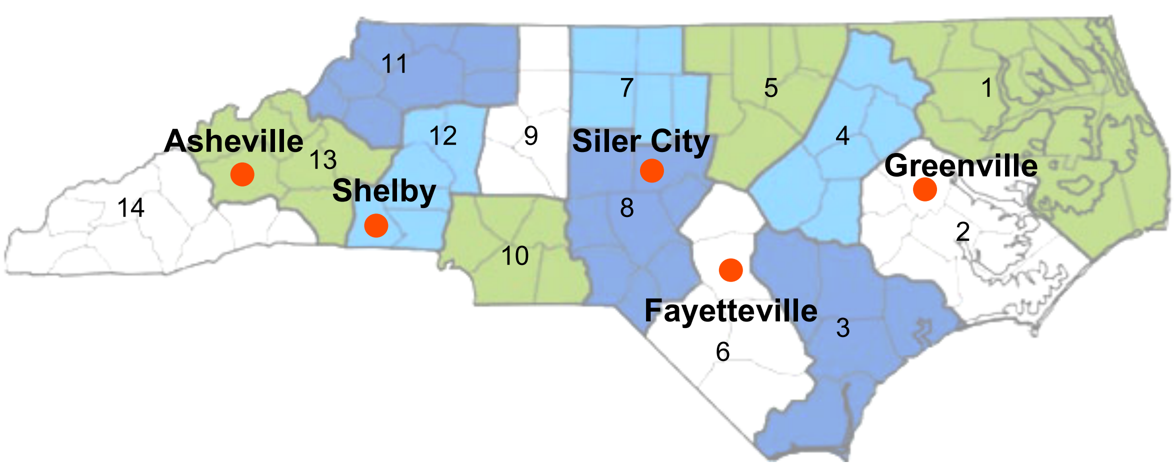


Figure 5.1. Locations Visited for Data Collection

5.2 Field Data Collection Equipment and Procedure

The most important part of the field data collection effort was the retroreflectometer measurement. A handheld retroreflectometer is one the most credible methods to measure retroreflectivity of traffic signs in the field. By pressing the trigger, a beam is emitted that reflects off the sign sheeting; the retroreflectometer displays the retroreflectivity value in about 4 seconds.

There are several models of hand-held retroreflectometer that comply with the standard test method for measurement of retroreflective signs using a portable retroreflectometer as defined by ASTM. For this study, we used the RetroSign®4500 [Flint Trading, Inc. 2005]. This is the same model used by the major sign manufacturer in NC (Correction Enterprises of Bunn, NC). This was also the model used in a previous study of sign deterioration by OR State University [Kirk, et. al. 2001]. The RetroSign®4500 was also advantageous because it does not have to be recalibrated when changing colors, it had various useful options such as an extension pole (with remote trigger and display), and we had access to a local dealer who could quickly make repairs when needed.

5.2.1 Nighttime Crew Ride Alongs

Data were collected from January through April of 2005. Sign inspection in NC is performed during the winter and early spring due to longer hours of darkness and because crews are busier with construction projects during the summer.

The field study consisted of two major parts. The first part was nighttime sign inspection with NCDOT sign crews. At least one of our team members rode in the same vehicle with sign crews and noted signs they declared deficient. The crews consisted of two experienced inspectors who were generally concerned for the safety of the traveling public and who were also aware of the budgetary limitations of the NCDOT. We asked to ride with typical crews—not the best in the division and not the worst—and tried to interfere with their usual routines as little as possible. The crews rode slowly along the roads being inspected in pickup trucks with standard headlights, occasionally deploying a bright flashlight to illuminate a sign of interest that the headlights could not reach. The sign crews noted signs to be replaced on a form, along with a reason for the rejection, and sprayed a small paint dot at the bottom of deficient signs to aid in later identification.

5.2.2 Field Team Retroreflectivity Measurement

The second part of the field study involved recording the retroreflectivity values of a portion of the signs that had been inspected the night before. Three retroreflectivity values for each reflective color were collected on most signs and the mean of these three was used in most of the results. However, some signs with irregular retroreflectivity values were encountered. In those situations, more than three retroreflectivity values were recorded to be able to compute a more representative mean value. Sign location (latitude and longitude using GPS), sign message, erection date, and sheeting type were recorded, and photos of each sign were taken. Not every sign the crews had inspected was measured. Rather, an emphasis was placed on rejected signs and sign types for which there were only small samples.

5.2.3 Field Study Problems

The sign erection date is critical to quantifying one of the assumptions of this paper. The sign erection date was generally located on a sticker on the back of each sign, although handwriting was also used to note the sign erection date in some divisions. However, for some signs the erection date could not be determined. For those signs, the date was read from the sign manufacture date that had been engraved on the back surface of the sign. But for some signs even the manufacture date could not be found. A further complication was that some signs were made up of double, or sometimes even triple, layers of aluminum, with the sticker or handwriting located inaccessibly in the middle of the "sandwich."

Weather was another concern during the daytime field study because the retroreflectometer could not accurately measure the retroreflectivity value of wet sign sheeting. Thus, all of the measurements needed to be made under dry conditions that sometimes resulted in delay.

The other problem was safety. It was relatively unsafe for the field survey team's vehicle to be stopped when driving on any road, but especially if the road has many curves. It was also difficult to stop on interstates. Where stopping conditions were unsafe the field team did not stop to take measurements and record data. This is one of the reasons why not all signs inspected by the NCDOT sign inspection crew were measured by the research team the next day.

5.2.4 Sign Crew Rejection Criteria

During nighttime inspections, NCDOT sign crews typically rejected signs due to low observed retroreflectivity or due to damage that obscured the sign message. Messages could be obscured by man-made causes (vandalism, gun shots, or paintball marks) or by natural causes (vehicle scrapes or accumulation of tree sap).

The NCDOT sign crews assign three numerical codes to deficient signs during the nighttime inspection. Code one signs, which are red and white sheeting signs (i.e. stop, do not enter, yield, wrong way, etc.), must be replaced immediately if supplies and conditions permit. Most sign crews will replace a code one sign if the sign has any noticeable mark or defect. Warning (yellow) signs are designated as code two, and should be replaced as soon as possible. All other signs, generally including signs having white, green, brown, and blue sheeting, are assigned code three and are to be replaced when possible.

6.0 FOLLOW-UP FIELD STUDY

In February and March of 2006, the signs in Divisions 2, 6, 8, 12, and 13 that had been measured for retroreflectivity a year earlier were re-inspected. The purpose of this data collection effort was to see what change in retroreflectivity, if any, had occurred over the course of approximately a year. The follow-up field study did not include nighttime sign crew ride-alongs because the goal of the follow-up study was to measure only the change in sign retroreflectivity in one year, not to evaluate sign inspector performance.

6.1 Data Collection Procedure

The data collection procedure for the follow-up study was similar to the field retroreflectivity measurement procedure followed in the original data collection effort, which was outlined in Section 5.2.3. The only difference between the original and follow-up data collection was that in the follow-up data collection pictures were not taken of the signs. Instead, each sign measured in the follow-up study was marked with a sign inventory number on the back of the sign using a permanent marker. This inventory number marking is intended to facilitate any future retroreflectivity measurement of the signs from this study by making the signs easier to identify.

6.1.1. Sign Identification

During the follow-up field study, the research team sought to locate each of the signs measured in the original field study. For most signs this was a straightforward process. However, for some the pictures of each sign's front, back, and date sticker that were taken during the original field study were necessary to confirm that it was the same sign measured in the original data collection effort. When a sign's approximate position along a road was unknown or when a picture match was inconclusive, the GPS coordinates of the sign gathered in the original field study were used to confirm the sign's location. Both sign pictures and sign GPS coordinates were very effective, especially in combination, in finding the signs measured the previous year. All but two of the 1057 signs measured in the original field data collection study were located in the follow-up study.

6.1.2. Missing Signs

However, the research team was unable to re-measure all of the signs measured in 2005 because approximately 20% of the signs had been replaced or removed by division sign crews between the original and follow-up field studies. When a replaced sign was encountered, the retroreflectivity of the newly installed sign was measured and its new installation date was recorded. It too was marked with a sign inventory number.

6.2 Problems Encountered

During the follow-up data collection, it was observed that for 198 signs in Division 6, the retroreflectivity values for 2006 were consistently much higher than the 2005 values. The cause of this discrepancy was a faulty retroreflectometer used for the measurement of these 198 signs in 2005. The faulty retroreflectometer, owned by NCDOT, stopped operating in the field after 198 signs were measured in Division 6 in February of 2005. At this point the retroreflectometer was taken to Flint Trading for repair and a loaned retroreflectometer was used to complete the data collection for the remaining 850 signs.

The 2006 re-inspection used the repaired NCDOT retroreflectometer, and all re-measured signs not in the group of 198 were found to have consistently similar or lower retroreflectivity measurements when compared with the original 2005 measurements performed by the loaned retroreflectometer. This discrepancy mandated a mathematical adjustment to the year 2005 retroreflectivity values for this group of 198 signs.

6.2.1 Expected One-Year Loss in Retroreflectivity

In order to adjust the year 2005 retroreflectivity values for the group of 198 signs, it was first necessary to determine the expected one-year loss in retroreflectivity from 2005 to 2006 for these signs. To do this the sign data from both years were divided into four groups:

A. Group A contained the 2005 retroreflectivity values for the approximately 850 signs that were measured correctly in 2005.
B. Group B contained the 2006 retroreflectivity values for the same 850 signs.
C. Group C contained the 2005 retroreflectivity values for the 198 signs measured with the faulty retroreflectometer in 2005.
D. Group D contained the 2006 retroreflectivity values for the same 198 signs.

The loss in retroreflectivity over one year was calculated by subtracting the Group B retroreflectivity value from the Group A retroreflectivity value for each individual sign. In other words, the one-year loss in retroreflectivity for the 198 incorrectly measured signs was based on finding the difference between the 2005 and 2006 correctly measured sign retroreflectivity data. For example, if a 2005 sign had an R_A value of 70 and in 2006 the same sign had an R_A of 64, the one year R_A loss value for this sign would be 70 – 64 = 6.

Since all of the 2005 signs were not re-measured exactly one year (365 days) later in 2006, the one-year loss in retroreflectivity calculated from Group B minus Group A had to be annualized. To do so the number of days between the 2005 and 2006 measurements in each division were calculated and then divided by 365 to produce a year correction factor, as shown in Table 6.1. This year correction factor assumes a proportional relationship between sign age and amount of sign retroreflectivity deterioration.

Table 6.1. NCDOT Division Data Collection Dates and Year Correction Factor

NCDOT Division	2005 Measurement Date	2006 Measurement Date	Difference (Days)	Year Correction Factor
2	April 22	February 10	294	0.8055
6	February 4	February 4	365	1.0000
8	February 25	February 17	357	0.9781
12	March 10	March 5	360	0.9863
13	February 9	March 3	387	1.0603

Next, the original one-year loss in retroreflectivity calculated from Group B minus Group A for each sign was divided by the year correction factor corresponding to the sign's NCDOT division in order to determine the expected one-year loss in retroreflectivity for each sign. These expected one-year loss in retroreflectivity values were averaged by a combination of sign type (I or III) and sign color (white, yellow, red, green) and are shown in Table 6.2.

Table 6.2. Average Expected One-Year Loss in Retroreflectivity

Sheeting Color	Type I	Type III
White	5.71	-2.32
Yellow	2.76	-6.48
Red	0.58	-5.39
Green	1.75	2.05

There are a number of observations that can be made about Table 6.2. The Type III white, yellow, and red signs show a slight increase, instead of decrease, in retroreflectivity over a one-year period. This slight increase is probably due to statistical noise and may indicate that there is a negligible change in the retroreflectivity of Type III signs over the course of one year. The small decrease in Type III green signs supports this conclusion. Given the high R_A values and long lifetimes of Type III sheeting this result is not surprising.

<u>6.2.2. Corrected 2005 Retroreflectivity Values for the 198 Signs</u>

The average expected one-year loss in retroreflectivity values calculated from the correctly measured signs (Groups A and B) were then added to the Group D (2006, 198 signs) individual sign retroreflectivity values based on the Group D sign's sheeting color and type. Adding the average expected one-year loss to the 2006 retroreflectivity values for the 198 signs (Group D) results in the expected 2005 retroreflectivity values for the 198 signs, or what is referred to as Group C*. For example, if a white Type I sign in the group of 198 had a 2006 R_A of 65, the expected 2005 R_A value (member of Group C*) would be 65+5.71=70.71. The actual 2005 measured value was 56. This clearly illustrates the error induced by the faulty retroreflectometer. Since the average expected one-year loss in retroreflectivity was assumed to be negligible for Type III signs, their corrected 2005 R_A (Group C*) values were equal to their 2006 (Group D) values.

However, some of the original 198 signs were not measured in 2006 because they were either removed or replaced. These signs were corrected using a modified procedure that calculated the total retroreflectivity correction from the signs in the group of 198 that were measured in 2006. For each of the signs measured in 2006, the Group C values were subtracted from the Group C* values to get the total retroreflectivity correction (TRC). The TRC values from the 2006 measured signs were then averaged to find the average total retroreflectivity correction (ATRC) for each sign type and color combination. This correction accounts for both the average expected one-year loss in retroreflectivity and the retroreflectometer error. The ATRC was then added to the Group C values of the signs not measured in 2006 to find the expected 2005-retroreflectivity values for these signs. For example, a white Type I sign (Sign X for example) in the group of 198 that was not re-measured in 2006 has a 2005 R_A of 60 measured with the faulty retroreflectometer. The ATRC found from the white type I signs measured in both 2005 and 2006 is 27.44. The corrected 2005 R_A for Sign X therefore is 60 + 27.44 = 67.44. Table 6.3 lists the ATRC values for each combination of sign type and color. Type III green signs do not have an ATRC value given because there are no Type III green signs in Group C.

The ATRC values in conjunction with the average expected one-year loss in retroreflectivity, can be used to calculate the average retroreflectometer equipment error. For each combination of sign type and color, the ATRC value minus the average expected one-year loss in retroreflectivity value equals the average equipment error (AEE). In the case of Type I white signs, the ATRC minus the average expected one-year loss in retroreflectivity would be 27.44 - 5.71 = 21.73. Table 6.3 gives the AEE values for each combination of sign type and color. The AEE is the portion of the ATRC due to the retroreflectometer and not the decrease in R_A over the course of a year. Generally, as the retroreflectivity of a sign increased, so did the AEE.

Table 6.3. Average Total Retroreflectivity Correction (R_A) and Average Equipment Error (R_A)

Sheeting Color	Type I		Type III	
	ATRC	AEE	ATRC	AEE
White	27.44	21.73	80.16	82.48
Yellow	21.58	18.82	64.42	70.90
Red	5.58	5.00	14.71	20.10
Green	3.08	1.33		

The 2005 measured retroreflectivity values for the 198 signs were converted to corrected values by incorporating the corrections mentioned in this section. Table 6.4 shows a summary of the 2005 average measured values for the 198 signs, aggregated by sign type and color. For comparison, Table 6.5 shows the average 2005 corrected values for the 198 signs by sign type and color. From Tables 6.4 and 6.5 the 2005 average correction can be observed by adding the correct ATRC value from Table 6.3 to the Table 6.4 values to get the Table 6.5 values.

Table 6.4. 2005 Average Measured Retroreflectivity (R_A) for the 198 Signs

Sheeting Color	Type I	Type III
White	45.01	177.76
Yellow	34.52	153.57
Red	9.67	42.04
Green	7.67	

Table 6.5. 2005 Average Corrected Retroreflectivity (R_A) for the 198 Signs

Sheeting Color	Type I	Type III
White	72.46	257.91
Yellow	56.09	217.99
Red	15.25	56.76
Green	10.75	

6.3 2005 to 2006 Sign Replacement Rates

During the 2006 follow-up field study, several signs measured in the 2005 field study were found to have been removed entirely or replaced with new signs. Most of the sign replacement was expected because many of the signs rejected by the sign crews in 2005 should have been replaced one year later.

6.3.1 Sign Removal

Approximately 2.4% of the signs measured during the 2005 field study were found to have been removed entirely from the field in 2006. Table 6.6 shows the number of signs removed by NCDOT Division.

Table 6.6. Number of Signs Removed and Percentage of 2005 Total Measured Signs

NCDOT Division	Number of Signs Removed
2	0
6	8
8	6
12	3
13	8
Total Removed	25
Number of Signs NOT located (missing)	3
Total Number of Signs NOT Measured (removed + missing)	28
Number of Signs Measured in 2006	1057-28= 1029
Removed Signs Percent of 2005 Total	25/1057=2.37%

The reasons for a sign's removal was generally unknown, except for cases where an obvious change in traffic control necessitated a change in signage. This occurred at an intersection in Division 6 that was converted from stop control to signal control. In total, 25 signs measured in 2005 were removed by 2006. The locations of three signs measured in 2005 could not be found during the 2006 follow-up field study, and therefore, these three signs were not measured. A total of 28 signs that were measured in 2005 were not measured in 2006, resulting in a total number of signs measured in 2006 of 1029. In 2005, a total of 1057 signs were measured.

6.3.2 Sign Replacement

A total of 187 signs measured in 2005 were replaced with new signs by the time of the 2006 follow-up field study. Table 6.7 shows the number of signs replaced by each NCDOT Division and by sign sheeting type. Most Divisions are replacing Type I signs with Type III signs (the Type I to Type III column), with a few exceptions, such as Divisions 8 and 13 where at least 25% of Type I signs were replaced with Type I. Reasons for this are unknown. It may be the case that these Divisions still had inventories of Type I signs they were trying to exhaust in 2005-2006. Divisions 2, 6, and 12 are replacing at least 90% of their Type I signs with Type III sheeting. Across all five Divisions, 89% of signs are being replaced with Type III sheeting. This is just over 10% short of the NCDOT goal of 100% Type III replacement.

Table 6.7. Number of Signs Replaced and Sheeting Type Used by Division

Division	Total Number of Signs Replaced	Type I to Type I	Type I to Type III	Type III to Type III	Type I		Type III	
					No. of Type I	%	No. of Type III	%
2	13	2	11	0	2	15.38	11	84.62
6	111	4	99	8	4	3.60	107	96.30
8	28	9	17	2	9	32.14	19	67.86
12	19	1	13	5	1	5.26	18	94.74
13	21	6	12	3	6	28.57	15	71.43
Total	192	22	152	18	22	11.46	170	88.54
Replaced Signs as a Percent of 2005 Total					192/1057=18.16%			

Sign replacement can also be examined in terms of sheeting color. Table 6.8 shows the number of signs replaced by sheeting color and type. Yellow and red signs were replaced about 95% of the time with Type III sheeting, while white and green signs are replaced about 65% of the time with Type III. It is likely that the higher Type III replacement rate for yellow and red signs may be due to these signs having a higher replacement priority due to their having an NCDOT Action Code of either 1 or 2.

Table 6.8. Number of Signs Replaced and Sheeting Type Used by Sheeting Color

Color	Number of Signs Replaced	Type I to Type I	Type I to Type III	Type III to Type III	Type I		Type III	
					No. of Type I	Percent	No. of Type III	Percent
White	29	10	19	--	10	34.48	19	65.52
Yellow	129	8	118	3	8	6.20	121	93.80
Red	26	1	12	13	1	3.85	25	96.15
Green	8	3	3	2	3	37.50	5	62.50
Total	192	22	152	18	22	11.46	170	88.54

As a result of almost 90% of all replaced signs being replaced with Type III sheeting between 2005 and 2006, the ratio of Type I to Type III sheeting in the field changed. In 2005, 72% of the measured signs were Type I and 28% were Type III. In 2006, approximately 60% of the measured signs were Type I and 40% were Type III. Table 6.9 shows the number of Type I and III signs categorized by NCDOT Division. Division 6 is the only Division listed in Table 6.9 that has at least 50% Type III signs in the measured sample.

Table 6.9. Type I vs. Type III Sign Distribution in 2006

Division	Total Signs*	Type I		Type III		Other Type	
		No. of Type I	Percent	No. of Signs	Percent	No. of Type III	Percent
2	122	91	74.59%	31	25.41%	0	0.00%
6	308	131	42.53%	174	56.49%	3	0.97%
8	130	95	73.08%	34	26.15%	1	0.77%
12	179	97	54.19%	79	44.13%	3	1.68%
13	290	199	68.62%	91	31.38%	0	0.00%
Total	1029	613	59.57%	409	39.75%	7	0.68%

** Total signs does NOT include removed and not measured signs*

6.3.3 Replacement of Rejected Signs

In 2005, all signs were either rejected or not rejected by NCDOT sign crews during the nighttime inspection process. Looking at whether these signs were replaced in 2006 can shed light on how NCDOT replaces signs.

Table 6.10 shows the number of signs rejected in 2005 and their replacement status in 2006. The number of signs rejected is shown by NCDOT Division and by NCDOT Action Code within each division. NCDOT assigns Action Codes to rejected signs to indicate their replacement priority, with '1' being the most urgent. The Action Codes are defined as follows:

- Code 1 [Red sign]: Stop, Yield, Wrong Way, Do Not Enter – Immediate action required.
- Code 2 [Yellow sign]: Warning or diamond shape – Take action as soon as possible.
- Code 3 [All Other signs]: Take action whenever possible.

The numbers in parenthesis in Tables 6.10 and 6.11 are the total number of rejected/not-rejected signs when the signs removed by 2006 or not measured in 2006 are included in the totals.

Given these the Action Code definitions, one would expect that nearly 100% of all Code 1 signs would be replaced within one year of their identification. This was the case in Divisions 6, 12, and 13, as shown in Table 6.10. Division 2 did not have any Code 1 rejections and Division 8 replaced 40% of their Code 1 rejected signs. Overall, 80% of Code 1 signs were replaced within one year. Also following from the Action Code definitions, 62% of Code 2 and 38% of Code 3 signs were replaced. A total of 57% of rejected signs in 2005 were replaced by 2006.

Although one would initially expect that signs that were not rejected would not be replaced within one year, data from the 2006 follow-up field study shows that 11% of signs not rejected in 2005 were replaced by 2006. Table 6.11 shows the number of signs by Division not rejected by NCDOT signs crews in 2005 and whether these signs were replaced or not replaced. Division 6 replaced twice the average amount (22%) of not rejected signs and Division 8 replaced 19%. The replacement of not rejected signs is possibly due to sign crews upgrading all signs on the same support structure to Type III sheeting or replacing all older signs, not just rejected signs, along a road corridor.

Table 6.10. Number of Signs Rejected in 2005 and Replacement Status in 2006

Division	Action Code	Total number of Signs Rejected, 2005	Signs Replaced, 2006		Signs NOT Replaced, 2006	
			No.	Percent	No.	Percent
2	1	0	0	0.00%	0	0.00%
	2	8	1	12.5%	7	87.5%
	3	2	1	50.0%	1	50.0%
	TOTAL	10	2	20.0%	8	80.0%
6	1	3 (4)	3	100.0%	0	0.0%
	2	59 (61)	48	81.4%	11	18.6%
	3	15	8	53.3%	7	46.7%
	TOTAL	77 (80)	59	76.6%	18	23.4%
8	1	5	2	40.0%	3	60.0%
	2	18	5	27.8%	13	72.2%
	3	6 (7)	2	33.3%	4	67.7%
	TOTAL	29 (30)	9	31.0%	20	69.0%
12	1	6	6	100.0%	0	0.0%
	2	14	9	64.3%	5	35.7%
	3	12	1	8.3%	11	91.7%
	TOTAL	32	16	50.0%	16	50.0%
13	1	1	1	100.0%	0	0.0%
	2	13 (15)	6	46.2%	7	53.8%
	3	15 (17)	7	46.7%	8	53.3%
	TOTAL	29 (33)	14	48.3%	15	51.7%
All Divisions	1	15	12	80.0%	3	20.0%
	2	112	69	61.6%	43	38.4%
	3	50	19	38.0%	31	62.0%
	TOTAL	177 (185)	100	56.5%	77	43.5%

Table 6.11. Number of Signs NOT Rejected in 2005 and Replacement Status in 2006

Division	Total Number of Signs NOT Rejected, 2005	Signs Replaced, 2006		Signs NOT Replaced, 2006	
		No.	Percent	No.	Percent
2	112	10	8.9%	102	91.1%
6	233 (236)	52	22.3%	181	77.7%
8	101 (106)	19	18.8%	82	81.2%
12	147 (151)	4	2.7%	143	97.3%
13	261 (267)	7	2.7%	254	97.3%
All Divisions	854 (872)	92	10.8%	762	89.2%

6.3.4 Summary

Every year some signs in the field are replaced, while others are completely removed due to changes in traffic control or the elimination of excessive signage. The 18% one-year replacement rate translates into every sign being replaced every 5.5 years. However, since 5.5 years is less than the lifetime of both Type I and Type III signs, the 18% one-year replacement rate may be artificially high for 2005-06 due to aggressive Type III upgrades in the Divisions. Supporting this assertion is the fact that 48% of signs replaced between 2005 and 2006 were not rejected by sign crews in 2005 (92/192 = 48%).

Another indicator of aggressive Type I to Type III replacement and upgrade is that in one year, the percent of Type III signs in the field increased from 28% to 40%. However, 44% of signs that were rejected by sign crews were not replaced within a one-year time frame. The follow-up study found that a sign is more likely to be replaced if it has a lower Action Code number, which follows NCDOT policy. Unexpectedly, 11% of signs not rejected in 2005 were replaced by 2006. This replacement can be attributed to additional sign damage occurring after the 2005 field study, to Type III blanket upgrades along a road corridor, and to the upgrading of all signs on a support.

7.0 FIELD STUDY RESULTS

The research team sought to determine results for sign deterioration, sign damage, and sign crew validation based on the data collected in the field. In order to determine sign deterioration rates the research team plotted the field data with five different curves in order to come up with the best fit curve for each sign color and type. To determine sign damage rates in NC the research team was informed by the NCDOT that the sign on interstates, other primary and secondary roads are measured every one, two, and three years respectively. Another important result that was obtained from our research was related to crew performance. The research team compared the visual results of signs observed by sign inspectors with the retroreflectivity values measured by the research team using the retroreflectometer. This helped the research team make important conclusions about the sign inspector accuracy.

7.1 Sign Deterioration Rates

Signs, like everything else, deteriorate with age. The relationship between a signs retroreflectivity and its age determines the rate at which a sign deteriorates. In order to determine this deterioration rate the research team plotted the measured retroreflectivity values against the age of each sign on a graph. Retroreflectivity was plotted on the Y - axis and age was plotted on the X – axis for each sign type and color. This research focuses on four sign colors and two sign types. Hence the sign deterioration rates were obtained for eight combinations of sign color and type. In this section deterioration curves are proposed that are based only on NCSU data. However in chapter 8.0 our research team combined the NCSU data with data from literature to derive a final deterioration curve.

<u>7.1.1 Type I</u>

Type I sheeting is classified by ASTM as a medium intensity retroreflective sheeting and is typically constructed using an enclosed sheet of glass bead lenses. About 75% of the signs measured by the research team are of Type I sheeting. Hence signs with Type I sheeting play an important role among all sign types on the road and it is important to determine their deterioration rate. Knowing the deterioration rate will help the DOT in planning for sign replacement and in estimating the cost of replacement.

7.1.1.1 White

In order to properly fit different curves the research team combined the data of all the Type I white signs and also the white retroreflectivity readings from red and white signs, and the green and white signs. This helped the research team get more data for Type I white signs. Hence the data consists of all the signs except the signs for which we did not have the sign combined age. Without knowing the age of the sign it is not possible to come up with a deterioration rate.

Figure 7.1 shows the different curves plotted to the NCSU data for Type I white signs. The different curve forms plotted are Linear, Logarithmic, Polynomial, Exponential, and Power. The graph of retroreflectivity versus age for Type I white signs shows a cloud of points with no particular trend. All the different plotted curves give very low R^2 values. This means that there is no significant correlation between the age and the retroreflectivity of the signs. Also, the FHWA proposed retroreflectivity minimum for Type I white is 50. The Figure shows that about

42% of the Type I white signs are below the proposed minimum standard. Based on the scatter and low R^2 values shown in the figure, no trend can be concluded in the obvious certainty.

7.1.1.2 Yellow

Yellow color signs are warning signs. They are one of the most important signs on the roads. In order to determine best fit curves the research team combined the data of all the Type I yellow signs and also the yellow retroreflectivity readings from red and yellow signs like stop ahead signs.

Figure 7.2 shows the different curves plotted with the NCSU data for Type I yellow signs. The curve forms plotted are Linear, Logarithmic, Polynomial, Exponential, and Power. Type I yellow signs seem to lose retroreflectivity quicker than Type I white signs. Nearly 70% of Type I yellow signs were below the FHWA proposed retroreflectivity minimums. The correlation between retroreflectivity and age of sign (R^2) is better than that for white signs but is very low. The best correlation was for a polynomial curve whose R^2 value is 0.24. The graph for Type I yellow signs also shows a cloud of points without any clear deterioration trend. Linear, Polynomial, and Exponential are the curves that have the highest R^2 values and can be considered to be the best fit for Type I yellow curves based on the NCSU data.

7.1.1.3 Red

Red signs are regulatory signs and considered as the most important sign color by the NCDOT. NCDOT personnel try to quickly replace any red sign that does not meet their inspection standards. The retroreflectivity readings of red signs were also plotted against their respective age and graphs were plotted for the five curves discussed earlier.

Figure 7.3 shows the different curves plotted with the NCSU data for Type I red signs. The data showed a clear deterioration trend with good R^2 values with over 35% correlation. Based on this correlation the age at which the sign's retroreflectivity falls below the proposed minimums or hits zero can be calculated. The proposed minimum for Type I red signs is 7. About 40% of the signs are below the proposed minimums for Type I red signs. Linear, Polynomial, and Exponential curves seem to best fit the NCSU data for Type I red signs.

7.1.1.4 Green

Green signs are guide signs. These play an important directional role, mainly on interstates. The retroreflectivity readings of green signs were plotted against their respective age and the graphs were plotted for the five curves.

Figure 7.4 shows the different curves plotted with the NCSU data for Type I green signs. The correlation between retroreflectivity and age was not very good but the R^2 values were better than the R^2 value for white and yellow signs. A Polynomial curve had the highest R^2 value that was about 0.36. Linear and Polynomial curves seem to best fit the NCSU data for Type I green signs.

7.1.2 Type III

Type III is a much more retroreflective material than Type I. It is typically made up of an encapsulated glass bead retroreflective or prismatic material. This sheeting is more expensive than type I sheeting. Cost data for signs is shown in Table 7.1. Here the cost difference between Type I and Type III signs can clearly be seen. Notice that the second and third columns represent the manufactured cost of the sign. The fourth, fifth, and sixth columns represent the miscellaneous material, labor, and equipment required to install it. The total column represents the total budget cost for an in place sign in the field.

The NCDOT have started replacing Type I sheeting with Type III and are no longer installing any Type I sheeting. Thinking ahead, it is important to also plan for the replacement of Type III sheeting because these sheeting are more expensive. The research team noticed that the all colors of Type III sheeting were performing very well for the first 15 years of their service life for which we have data.

7.1.2.1 White

Figure 7.5 shows the different curves plotted with the NCSU data for Type III white signs. The graph of retroreflectivity versus age for Type III white signs shows a cloud of points with no proper trend. All the plotted curves give very low R^2 values, meaning there is no correlation between the age and retroreflectivity. The FHWA proposed retroreflectivity minimum for Type III white is 50. Figure 7.5 shows that every sign is well above the minimum standard. Every sign meets the proposed minimums. Based on NCSU data for only 15 years, it is difficult to conclude that Type III white signs deteriorate.

7.1.2.2 Yellow

Figure 7.6 shows the different curves plotted with the NCSU data for Type III yellow signs. Almost all of the retroreflectivity values shown are above the FHWA proposed minimums, which is 50 for Type III yellow signs. The polynomial curve for Type III yellow signs showed an R^2 value of about 0.09. Based on the NCSU data, polynomial curves seem to best fit the Type III yellow sign deterioration data.

7.1.2.3 Red

Figure 7.7 shows the different curves plotted with NCSU data for Type III red signs. All of the retroreflectivity values shown are above the FHWA proposed minimums, which is 7 for Type III red signs. The curves plotted showed good R^2 values of around 0.48 for a polynomial curve which is very good considering that other sign colors did not have such high R^2 values. Linear, polynomial, and exponential curves seem to best fit the NCSU data for Type III red sign deterioration data.

7.1.2.4 Green

Figure 7.8 shows the different curves plotted with NCSU data for Type III green signs. All of the retroreflectivity readings of these signs are above the FHWA proposed minimums, which is 7 for Type III green signs. Only a polynomial curve seemed to fit the NCSU green Type III sign data with an R^2 value of 0.11.

7.1.3 Summary

Table 7.2 shows a summary of the deterioration curves based on the NCSU data for the eight sign color and type combinations. The best-fit curve recommendations are obtained only from NCSU data. Due to low R^2 values and inconsistent best fit curves, the NCSU research team decided to compare the best fit curves from NCSU data with the best fit curves from other studies as reported in literature. Based on the comparison, the NCSU research team decided to give its final conclusion about best-fit curves. These are presented in Chapter 8.0.

Table 7.1. Cost Data for Type I and III Signs

Sign and Size	Type I	Type III	Labor	Equipment	Materials	Total
BOW 24" x 30"	25.49		17.46	7.69	10.13	60.77
BOW 24" x 30"		41.53	17.46	7.69	10.13	76.81
RED - Stop - 36"	40.16		17.46	7.69	11.33	76.91
RED - Stop - 36"		65.01	17.46	7.69	11.33	101.76
Yellow - 36" x 36"	23.63		17.46	7.69	11.33	60.38
Yellow - 36" x 36"		48.66	17.46	7.69	11.33	85.41
WOG - 54" x 24"	75.92		34.92	15.38	28.44	154.66
WOG - 54" x 24"		103.77	34.92	15.38	28.44	182.51

Table 7.2. Best Fit Curves Based on NCSU Data

Sign Type	Sign Color	Best Fit Curves
I	White	None
	Yellow	Linear, Polynomial, Exponential
	Red	Linear, Polynomial, Exponential
	Green	Linear, Polynomial
III	White	None
	Yellow	Polynomial
	Red	Linear, Polynomial, Exponential
	Green	Polynomial

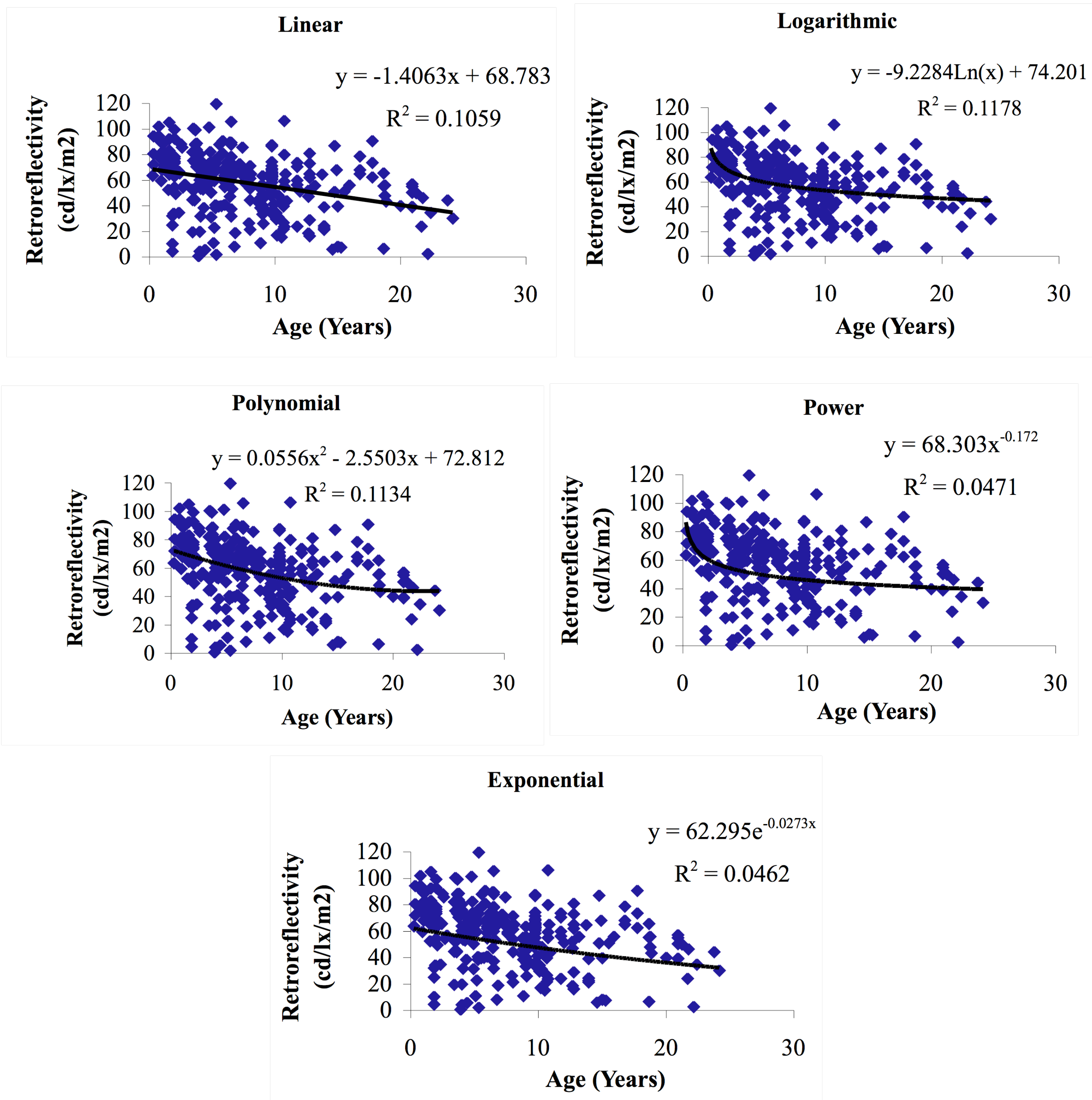


Figure 7.1. Deterioration Curves for Type I White Signs

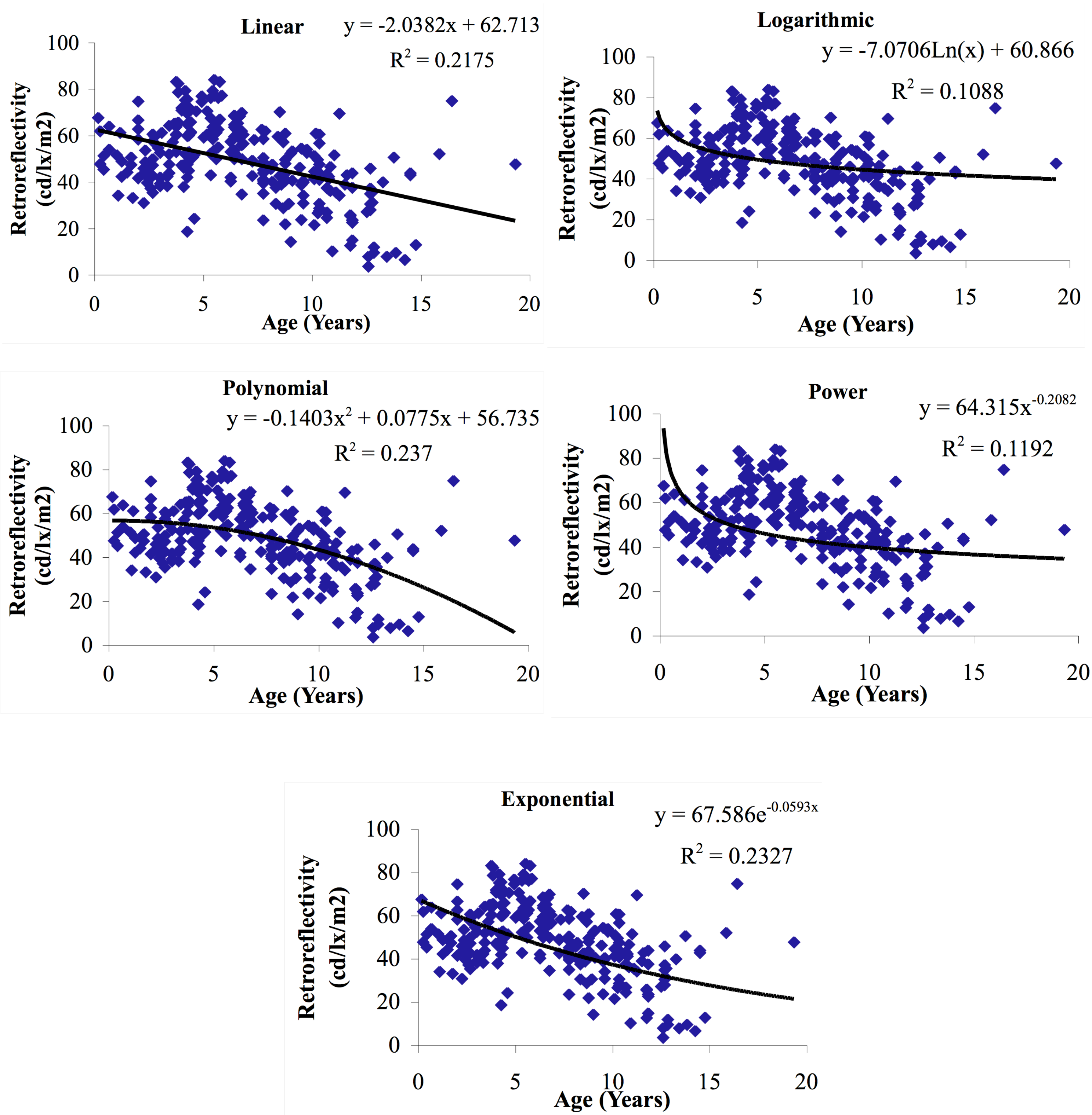


Figure 7.2. Deterioration Curves for Type I Yellow Sheeting

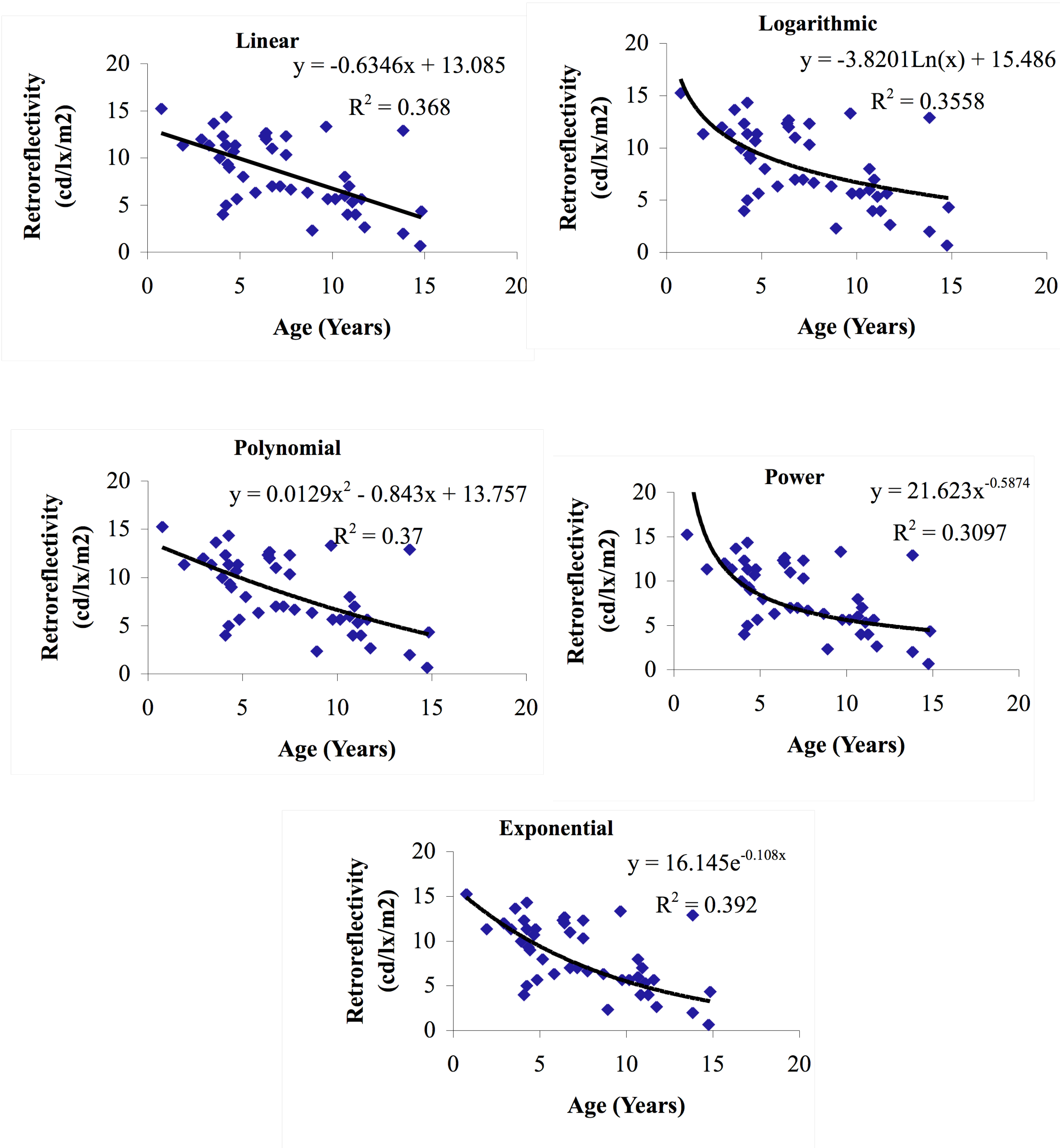


Figure 7.3. Deterioration Curves for Type I Red Signs

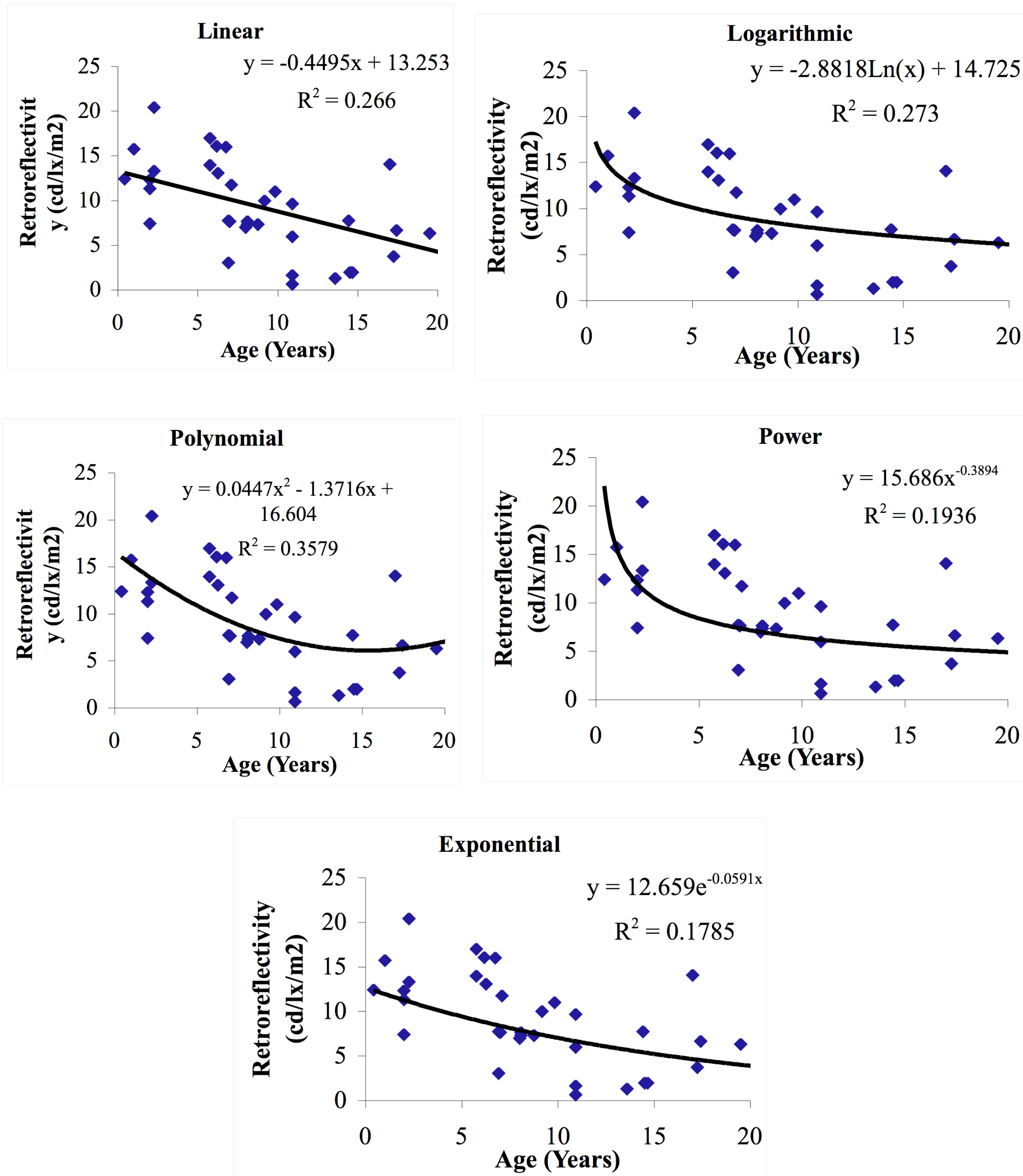


Figure 7.4. Deterioration Curves for Type I Green Signs

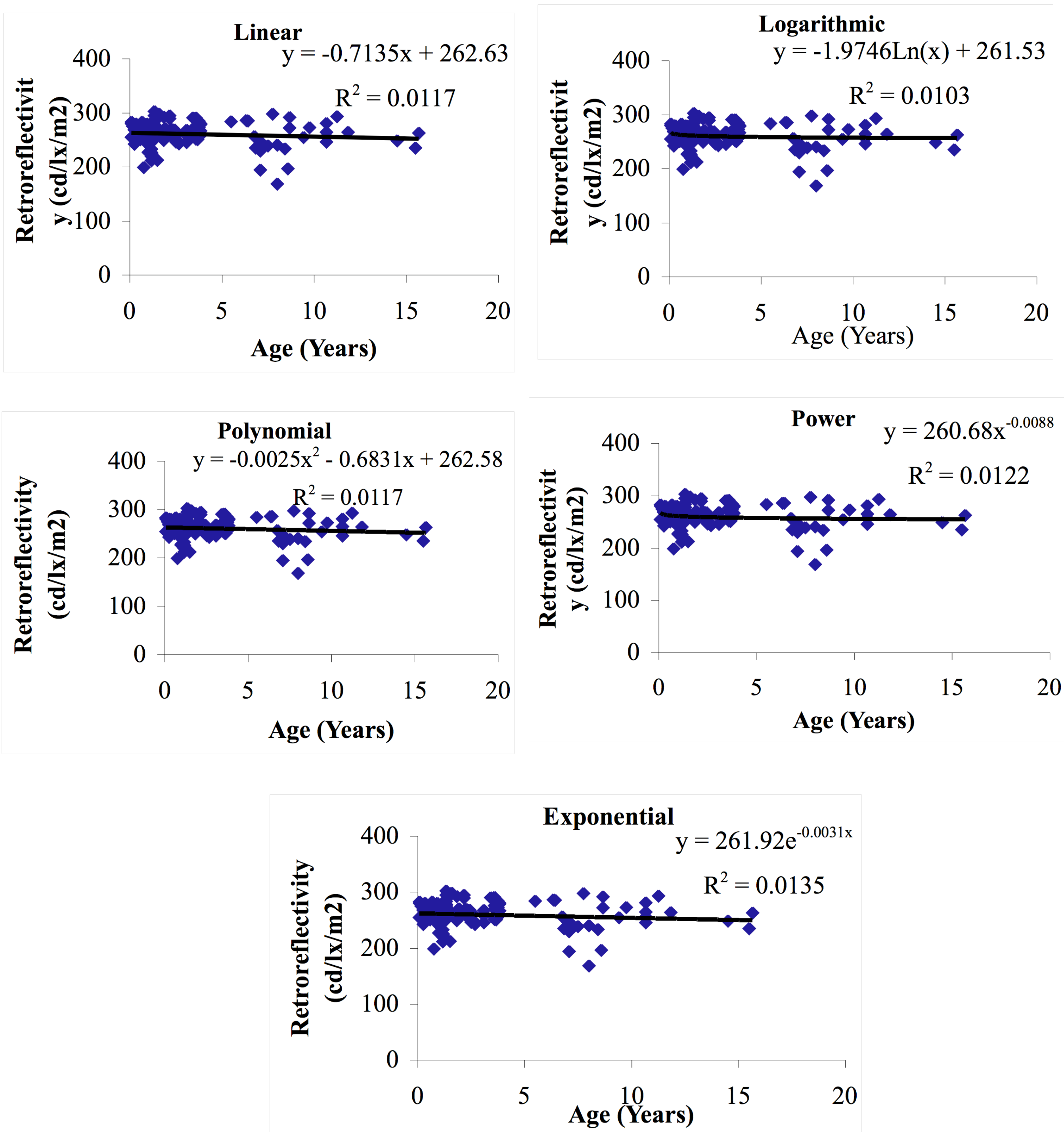


Figure 7.5. Deterioration Curves for Type III White Signs

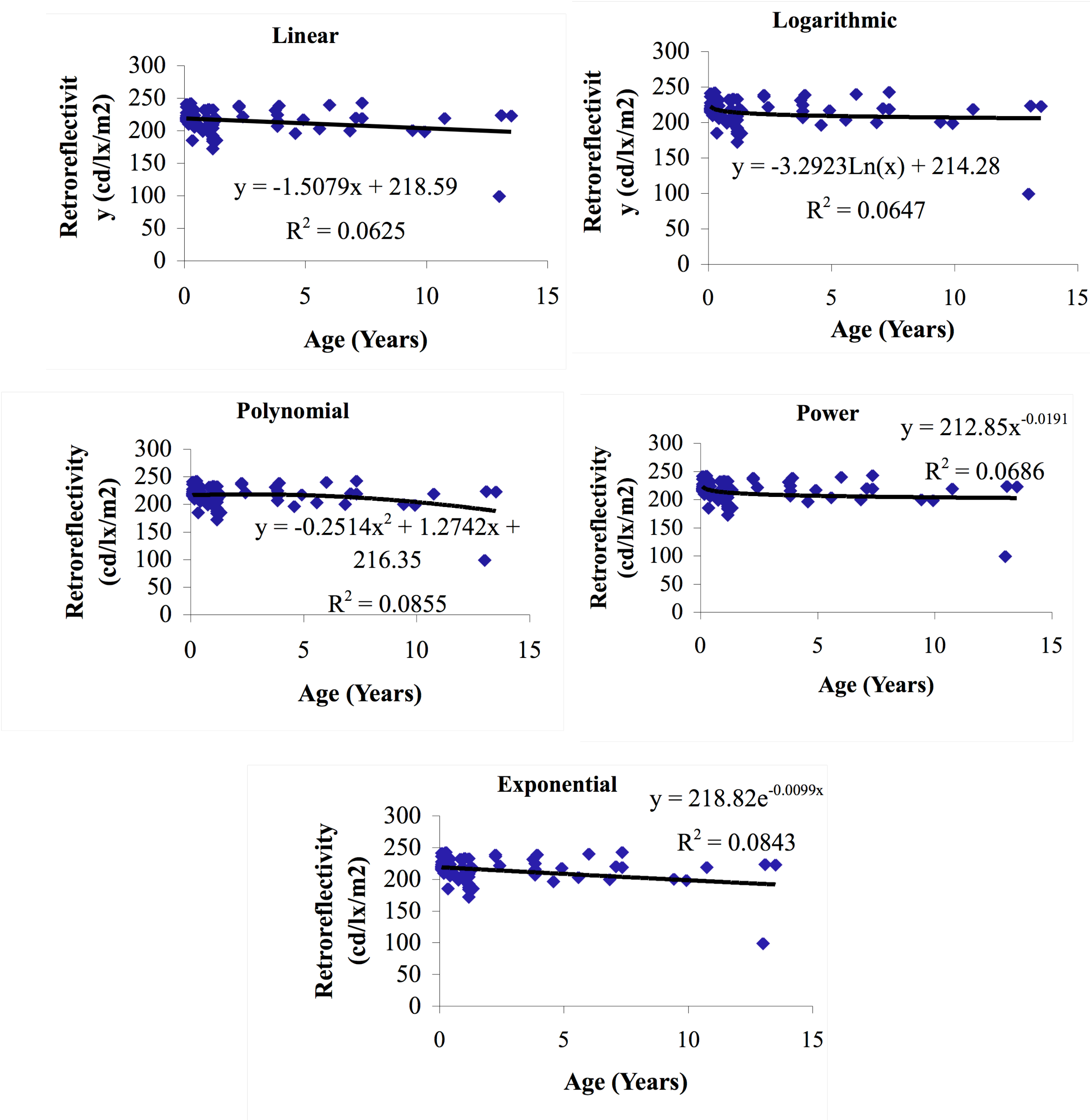


Figure 7.6. Deterioration Curves for Type III Yellow Signs

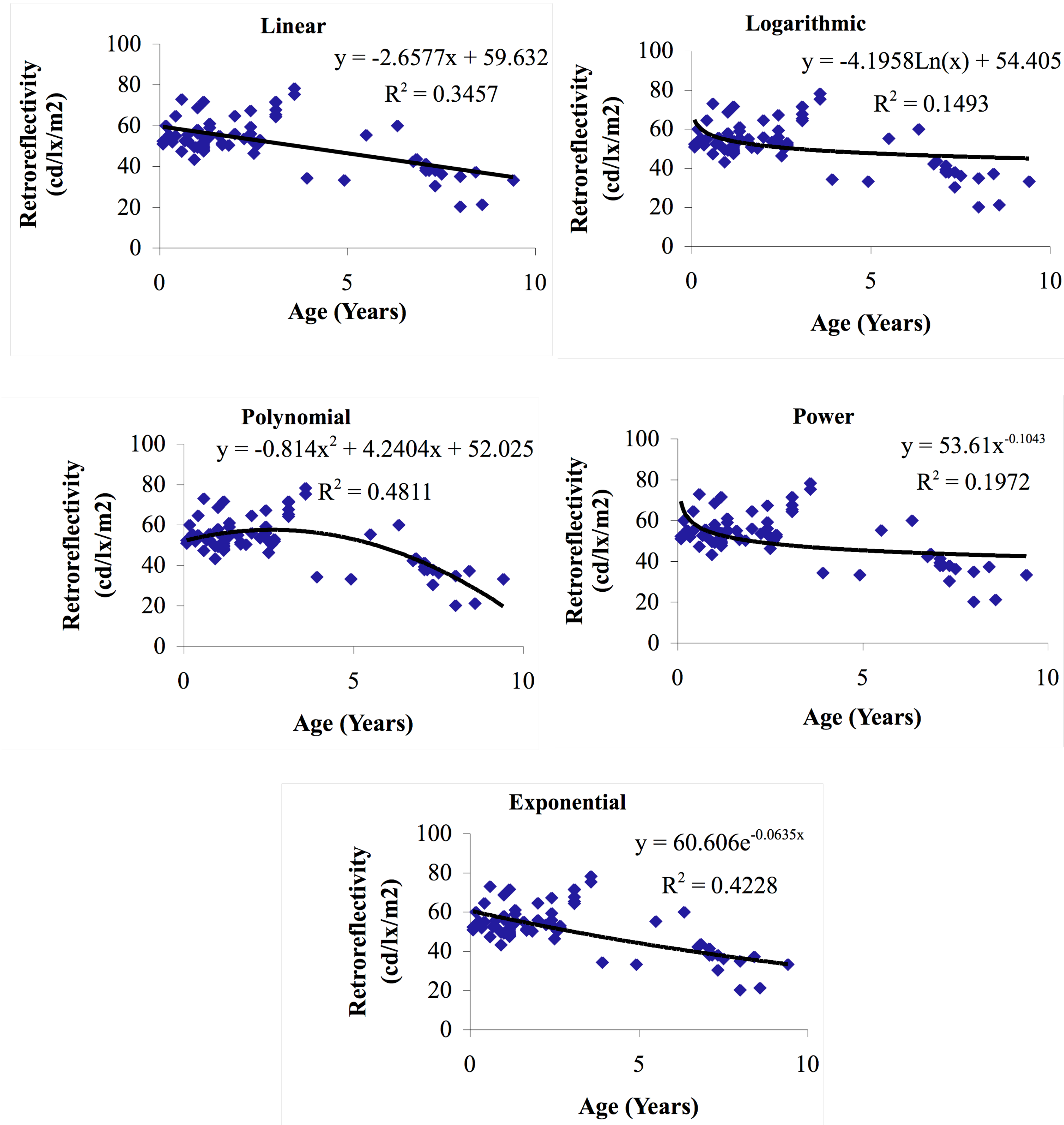


Figure 7.7. Deterioration Curves for Type III Red Signs

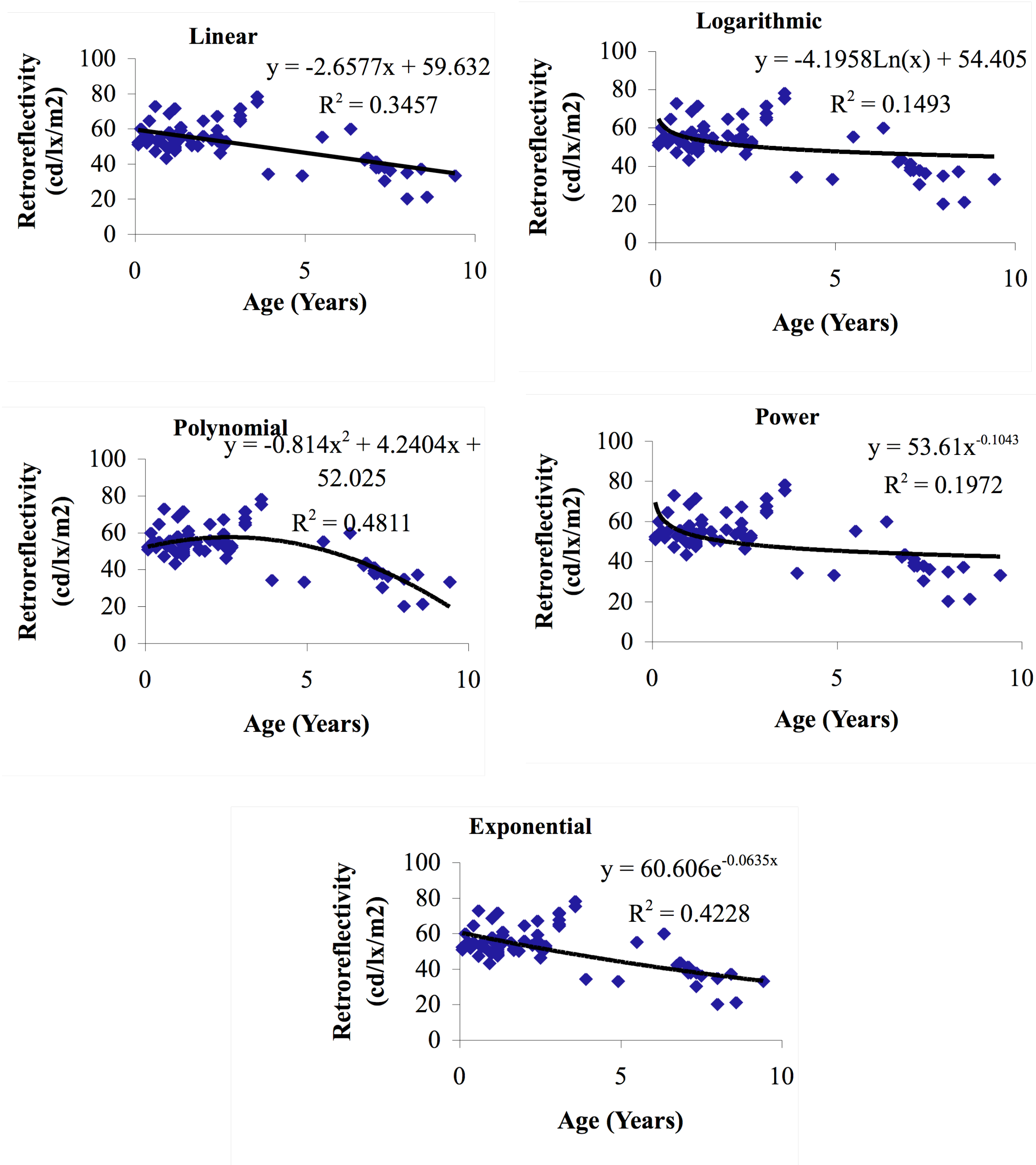


Figure 7.8. Deterioration Curves for Type III Green Signs

7.2 Sign Damage

There is very little previous research on the rate at which signs are damaged beyond usefulness based on either natural or man-made causes. An FHWA study noted that vandalism was more prevalent in rural areas and that cracking of sign sheeting was observed to be more prevalent in engineering grade signs [Black, et. al. 1991]. Using NCDOT accounting system data, our previous study had assumed an average of five percent of signs lost to damage each year, but we had no validation of that estimate and had also run simulations assuming damage rates ranging from 0 to 10 percent. No factual data was available on the types of damages and also on whether certain types of signs (ages, color, messages, etc.) were damaged more often than others. No other sign damage data were available.

7.2.1 Types of Damage

There are three main kinds of damage caused to signs in NC. The first type of damage is that which is intentionally caused by humans; this damage is referred to as vandalism. Vandalism seriously degrades the reflectivity of signs. Some people spray paint on signs, some shoot them with paint balls and guns, and some throw eggs at signs. While these are not the only causes of human sign damage they are by far the most prevalent deliberate causes. One additional type of deliberate damage is theft where signs are stolen and the sign is missing.

The second type of damage is that caused by nature. This includes damage to signs because of tree sap, scratches on signs from tree branches, water damage, etc. Water damage is caused when water enters the space between the sandwiched layers of the sign and destroys a part of the sheeting. These types of damage are unintentional and, to a large extent they are unavoidable

There are a few other types of damage caused by humans that are not deliberate. One of them is damage caused by mowing equipment striking signs and damaging them. This kind of damage occurs mostly during the mowing season, which is during summer and early fall. Another type of non-deliberate human damage is due to knockdowns. Knockdown damage occurs when a vehicle hits a sign post, bending or even breaking it. This type of damage does not occur often. Typically, knockdowns are replaced by the NCDOT when they are discovered. Mower damaged signs are primarily replaced seasonally in the early to late fall. (Gunshot damaged signs are also replaced seasonally – usually in early winter during hunting season). Since our data were collected during the late winter and spring, neither mowing nor gunshot damage was evident because most of these signs had already been replaced.

7.2.1.1 Vandalism

One of the important kinds of damage caused to signs is that caused by humans. Humans abuse signs and this abuse destroys their retroreflectivity. Vandalism occurs mostly on deserted roads or roads with less traffic. Signs on secondary roads are more prone to vandalism compared to signs on primary roads or interstates. Some of the common types of vandalism include shooting signs with paint balls or guns killing the retroreflectivity of signs, throwing eggs or black substances on the sign that will obscure the message of the sign, and spraying paint on signs. Another kind of vandalism is missing signs. Some signs are missing due to theft. The Figures 7.9, 7.10, and 7.11 show examples of the different kinds of vandalism found in NC.

Figure 7.9 shows a sign that has been vandalized with a paint ball, egg, and also has a sticker added onto the bottom sign. The message on the sign cannot be read at night (left side of figure). The paint ball kills the retroreflectivity of the sign sheeting. Even during day time (right side of figure) the paint ball mark looks prominent but the message is somewhat visible.

Figure 7.10 shows the night and day (left and right) appearance of a stop sign with black paint on it. The sign looks equally bad both during daytime and at night. The lower right part of the sign looks black both at night and daytime.

Figure 7.11 shows a stop sign that was shot with a gun. The sheeting is totally damaged and the sign has clearly visible holes in its bottom from the gunshots.

7.2.1.2 Nature Damage

The other important kind of damage caused to signs in is due to natural causes. This includes damage caused to signs because of tree sap, scratches from tree branches, water damage, etc. Natural damage is unintentional and unavoidable to a large extent. Figures 7.12, 7.13, and 7.14 show some damaged signs that were encountered during data collection. Note that dirty signs can be cleaned and will recover much of their reflectivity if this is done. Also note that water damaged signs were quite readable by day but did a poor job of conveying information at night. That is one reason that it is crucial to conduct inspections during the night.

Water damage is caused when water creeps in between the sandwiched layers of the sign and destroys a part of the sheeting. Figure 7.12 shows the way a water damaged sign looks at night (left) and in daylight (right). The water-damaged sign has its message nearly completely obscured at night. The water has percolated into the sheeting material of the sign and damaged the sheeting of sign. This sign looks pretty normal during daytime.

Figure 7.13 shows a very dirty sign. This sign is from NCDOT Division 8, which is located in Siler City, NC. This county had a lot of agricultural feed mills. The transportation of feed to and from the mills creates a lot of airborne feed dust that sticks to the signs. The research team decided to check the retroreflectivity of the signs by cleaning the sign with a regular glass cleaner and napkins. In the Figure the dirty sign is shown and then beside it is the portion of the sign that was partly cleaned. There was a large difference between the retroreflectivity of this sign before and after cleaning.

Figure 7.14 shows a sign in Division 13, situated in the mountains of Ashville, NC. This mountainous region has a lot of sign damage from the tree sap. The tree sap sticks to the sign, obscures its message, and makes the sign difficult to read. Tree sap, unlike dirt, cannot be cleaned and thus the sign has to be replaced. Figure 7.14 shows the day/night comparison of a sign with tree sap sticking to it. A sign damaged from tree sap is equally difficult to read both at night and during daytime.

7.2.2 Nighttime Inspection Damage Rates

In order to determine the percentage of damage caused to signs due to vandalism and natural damage, the NCSU research team compared the number of damaged signs in each division with the total number of signs inspected by sign crew in those divisions. Table 7.4 shows the percentage of signs rejected due to vandalism and natural damage in the five NCDOT divisions during the nighttime inspection process. The overall damage rate was 2.37 percent of signs per year. This damage rate was derived on the basis of the assumption that signs on interstates, other primary roads, and secondary roads are inspected by the sign inspectors every one, two, and three years respectively. This assumption matches the inspection rates followed by the sign crews in NC.

The number of vandalized signs per year was higher than the number of signs damaged by natural causes per year. A few signs, in fact, had both types of damage. Hence these signs were classified as having both. The data also suggests large differences between damage in different divisions. Division 8 had many signs that were bent due to natural causes (apparently a severe storm). Division 8 also had a lot of vandalism, especially from paint balls. However, Division 2 in the coastal region of NC had very few signs rejected for vandalism or for natural damage. Inspectors in Division 2 seem to be replacing damaged signs quicker than in Division 8. The reason for this may be due both to differences in the standards used by inspectors and to budgetary constraints.

We found the number of damaged signs to be high on secondary roads. There were 93 signs damaged on secondary roads out which 27 were damaged due to natural causes, 58 signs due to vandalism, and 8 signs were damaged due to both natural damage and vandalism. However in our sign count we only counted the total number of signs in a division but did not count the number of signs on each road type and hence we do not have a denominator to determine the damage rate per road type.

Among the damage caused by humans, paint balls, gunshots, and eggs were the most common. About 66% of vandalized signs were damaged by paint balls, while about 26% were damaged by gun shots, and about 8% by eggs. More vandalism was found on secondary roads and yellow signs were found to be more prone to vandalism than other colors.

Among the signs that were damaged due to natural causes, the dirty signs are a special category. These signs are not permanently damaged and hence they do not need to be replaced. They are just dirty and can be cleaned. Hence the dirty signs are not included in the natural sign damage count.

7.2.3 Overall Damage Rates

This study establishes a firm rate for natural damage and vandalism. However, this rate does not fully account for mowing damage, gunshot damage, knockdowns, and theft. Until these damage causes are addressed an accurate overall rate cannot be determined. Unfortunately there are no sources of data for these damage types and they are not addressed in the literature.

While no field data, in terms of damage counts, has been identified, there is an alternative way that is available in NC to estimate an overall damage rate. Kirtley and Palmquist [Kirtley, et. al. 2001, Palmquist, et. al. 2002] were successfully able to determine the number of signs in NC on state maintained roads for various colors of signs (blue, brown, green, orange, red, white, yellow, and stop), for all classifications of roads (interstate, US, NC, and secondary), and for urban and rural locations. Their data establishes the number of signs in place in the field. Table 7.3 shows the results of the Kirtley and Palmquist studies.

On an annual basis, the NCDOT tracks the cost of sign replacement through the use of a separate sign budget code. Thus, actual expenditures for sign replacement are known. Given an average replacement cost per sign, the research team determined that the number of signs replaced in 2005 (for whatever reason) was 67,000. This is 6.9 percent of the signs owned by the NCDOT from Table 7.3. After accounting for sign replacement initiated by inspectors, the research team was able to estimate with confidence that about 2.4 percent of all signs each year are replaced outside the inspection process; almost all of these are due to damage caused by humans. The overall sign replacement rate due to damage, whether replacement is initiated by inspectors or others, is then 4.7 percent of all signs per year.

Table 7.3. Total Number of Signs in NC

	Blue	Brown	Green	Orange	Red	White	Yellow	Stop	Totals
I, US, NC	26,702	3,523	39,247	10,405	19,746	161,735	88,233	1,548	351,139
RAs,VCs,and WCs	294	0	21	0	378	970	50	23	1,736
Truck Weigh Stations	32	0	96	0	58	292	76	40	594
Primary Total	27,028	3,523	39,364	10,405	20,182	162,997	88,359	1,611	353,469
Secondary Total	12,336	2927	27,885	10,025	6,113	220,524	285,559	51,067	616,436
All Total	39,364	6,450	67,249	20,430	26,295	383,521	373,918	52,678	969,905

Note- RA – Rest Area, VC – Visitor Centre, WC – Welcome Centre.

Figure 7.9. Night and Day Time Comparison of Sign Damaged with Paint Ball, Egg, and Sticker

Figure 7.10. Night and Day Time Appearance of Sign with Paint

Figure 7.11. Sign Shot with a Gun

Figure 7.12. Night and Day Time Comparison of a Water Damaged Sign

Figure 7.13. Dirt on Sign from Feed Mill (Before and After Cleaning)

Figure 7.14. Sign Damaged Due to Tree Sap

Table 7.4. Annual Damage Percentages by Division

Division	# of Signs Rejected for Vandalism	# of Signs Rejected for Natural Damage	# of Signs Rejected for Vandalism and Natural Damage	Total # of Signs Damaged	Total Number of Signs Inspected by Sign Crew	Damage as a Percentage of Total Inspected Signs
2	0	0	0	0	122	0.00
6	9	2	2	13	581	2.24
8	4	4	0	9	159	5.66
12	6	2	0	7	344	2.13
13	3	7	1	11	475	2.21
Total	22	15	3	40	1681	2.37

7.3 Sign Crew Validation

One goal of the research team was to determine if NCDOT sign inspectors were accepting or rejecting signs at the level of the FHWA minimum proposed standards. In order to compare the visual accuracy of the NCDOT inspectors with retroreflectivity measurements the NCDOT research team performed the following analysis. During the nighttime sign inspections the research team noted the signs that were observed to have low retroreflectivity in the field by the sign inspectors. During the daytime sign inspections the research team rode the same route that was driven by the sign inspectors and measured both the signs that were observed to have low retroreflectivity by the sign crew as well as the signs that were not observed to have low retroreflectivity. Based on this information, the research team conducted an analysis and compared the findings with the literature.

In order to model the performance of the sign inspection crews the inspectors' judgments on signs during the nighttime rides was compared to the retroreflectivity measurements of those same signs a day or two later. In viewing these results, it should be noted that the data sample is slightly biased towards signs that appeared bad. The reason for this is that the sample contains almost all of the signs that were marked to have low retroreflectivity by the sign crew but does not have all the signs that were observed to be good by the sign inspectors. In other words, the data focuses on how well the inspectors did with bad signs rather than how well they did with good signs.

7.3.1 Findings by Other Researchers

Our early simulation modeled sign inspector performance based on a study conducted in the state of WA in 1987 [Lagergren, et. al. 1987]. The WA study was based on 17 observers' ratings of warning and stop signs in a laboratory setting, a controlled highway setting, and an uncontrolled highway setting. Warning and stop signs were chosen because of their "high relative importance" and because they are commonly used on the roads. The uncontrolled highway setting included two road types, a rural highway containing 76 signs and an urban highway containing 54 signs. The observers in the WA study rated the retroreflectivity of signs based on their visual judgments using a scale of 0 to 4, where any signs rated 0 or 1 would be replaced and signs receiving a rating of 2, 3, or 4 would remain in place. Although the observers in the study received only limited amounts of training the "inconsistency among observers was averaged in the median decision" [Lagergren, et. al. 1987].

For warning signs, the researcher found a 74% overall accuracy, with 50% being the correct decision not to replace a sign (correct negative) and 24% being the correct decision to replace a sign (correct positive). Of the 26% inaccuracy, 6% of the signs should have been replaced and were not (false negative) and 20% of the signs should not have been replaced and were (false positive). Overall, the observers erred on the safer side. Stop signs had similar rates.

In an effort to gain a better understanding of the relationship between the FHWA research recommendations for minimum retroreflectivity and nighttime visual inspections of sign retroreflectivity, researchers at the TX Transportation Institute compared the results of visual sign evaluations to the minimum retroreflectivity values. In the evaluation, TxDOT sign crews evaluated 49 signs on a five-mile closed course. The results of the evaluations were then compared to an application of the FHWA minimum values. The results show that while only one sign did not meet the FHWA minimum values, the average ratings for the TxDOT sign crews indicated that 26 signs were not acceptable. The researchers identified several factors that were found to impact the average rating of signs. These factors included the uniformity of the sign face, the type of sheeting material, and the retroreflectivity [Hawkins, et. al. 2001].

7.3.2 Findings of the NCSU Field Study

Based on the data collected for the signs inspected that were observed to have low retroreflectivity and the retroreflectivity of signs measured using a retroreflectometer, the research team developed a table showing the number of signs inspected by the sign inspectors categorized by their retroreflectivity values. Table 7.5 shows one such table for white, yellow, red, and green signs with Type I sheeting. In this Table the sign which were measured to have a certain retroreflectivity value were placed in the row corresponding to the retroreflectivity range under which it belonged. The first column shows the retroreflectivity range. The second and fourth columns show the total number of undamaged signs observed by sign inspector. The third and fifth column show the percentage of signs which appeared with low retroreflectivity to sign inspectors. For example there were 10 white signs with retroreflectivity less than 20 and greater than or equal to 10. Sign inspectors found that 60 percent of these 10 signs have low retroreflectivity (based on their training). This implies that the sign inspectors deemed 4 of these 10 signs to have good visibility. The FHWA proposed minimum retroreflectivity standard for Type I white color sign is 50.

Comparing the above example with the FHWA proposed minimum standard it can be seen that the 4 signs which were observed to have good visibility had a retroreflectivity of less than 20 which is 30 units below the proposed minimum standards. The reason could be either an error on the part of the sign inspectors for not rejecting signs that have reflectivity value less than the FHWA proposed minimum standards or the other reason for not rejecting white signs may be the lack of budget and since white color does not has as much importance as yellow and red, some signs that are not very bad are left in the field.

Table 7.5 shows the sign inspector validation data for Type I white and yellow signs, for which there was the largest sample sizes. The totals in this table do not match the totals in Tables 1 and 2 because Table 6 includes dirty signs, but does not include signs rejected due to damage only. The highlighting identifies retroreflectivity levels below the FHWA proposed minima (R = 50 for Type I white and yellow signs). Type I red and green signs showed similar trends, while the data for Type III signs were not helpful because none of those signs were near the point in age where retroreflectivity was an issue. It is simply difficult to get long term data of any kind for Type III signs because so few have been in the field over a long period of time.

Table 7.5 shows that there is a significant reduction in rejection percentage as the retroreflectivity increases, which means that the sign inspectors were discerning retroreflectivity fairly well. However, the sign inspectors did not reject a fairly high number of signs that had retroreflectivity values below the proposed minimum standards. This may be due to the inspectors being unaware of the standard, to their having no training regarding the standard, or to their being influenced by tight budgetary constraints. The table also shows that the inspectors rejected very few signs with good retroreflectivity values — there were far more false positives than false negatives.

On the whole, the study found the inspector accuracy (based on the proposed minimums for Type I signs) to be 67% for white, 51% for yellow, 74% for red, and about 63% for green signs. The inspector accuracy for the different divisions was 63% for Division 2, 54% for both Divisions 6 and 8, 83% for Division 12, and 80% for Division 13.

This can be further illustrated with a pie chart. Figure 7.15 shows the number of correct and incorrect decisions by the sign crew. The pie chart shows that the sign inspectors observed 94% of signs to have good retroreflectivity. Of this 94%, retroreflectivity of 61% of signs were above the proposed minimum standards and hence it is a correct decision. The remaining 33% of the signs had their retroreflectivity values below the proposed minimums and thus, this is an incorrect decision. Similarly 6% of the signs were observed by the sign inspectors to have low retroreflectivity. Virtually all of the signs observed by the sign inspector had their retroreflectivity values below the minimum retroreflectivity standards and hence this was a correct decision by the sign inspectors. Overall, the sign inspectors rated 67% of the sign with Type I white color correctly.

Figure 7.16 illustrates the crew accuracy compared to the FHWA minimum standards for yellow Type I sheeting. The pie chart shows that the sign inspectors observed 78% of signs to have good retroreflectivity. Of this 78%, retroreflectivity of 31% of signs were above the proposed minimum standards and hence it is a correct decision. The remaining 47% of the signs had their retroreflectivity values below the proposed minimums and thus, this is an incorrect decision. Similarly 22% of the signs were observed by the sign inspectors to have low retroreflectivity. 20% of the signs observed to have low retroreflectivity had their retroreflectivity below the minimum retroreflectivity standards and hence this was a correct decision by the sign inspectors. The remaining 2% of the signs observed to have low retroreflectivity were above the minimum standards and hence this was an incorrect decision. Overall, the sign inspectors rated 51% of the signs with Type I yellow color correctly.

Similarly, Figure 7.17 shows the crew to be about 74% correct with their observations of Type I red color sheeting. Of these 74% of signs, 20% were correctly observed as having low retroreflectivity. Figure 6.3.4 shows the pie chart for Type I green sheeting. The sign crew observed 63% of the signs correctly, of which 5% of the signs were correctly observed to have low retroreflectivity and 58% were correctly not observed to have low retroreflectivity.

7.3.3 Comparison of Field Study Findings to Literature

The NCDOT results can be directly compared with the results of the WA Study. As mentioned earlier the WA study found that observers rated 74% of the warning signs and 82% of stop signs correctly (See Section 2.3.1.1). This 74% can be directly compared to the Type I yellow sheeting and Type I red sheeting of the NCSU study. Tables 7.6 and 7.7 show the comparison of the NCSU research with the WA Study results for Type I yellow sheeting and Type I red sheeting respectively.

For Type I yellow sheeting (Figure 7.16) the major difference between the two studies is for the incorrect decisions for observing the sign with low retroreflectivity (2-20) and incorrect decisions for not observing the sign with low retroreflectivity (47-6). The sign crew in the NCSU research incorrectly observed only 2% of the signs as having low retroreflectivity and 47% of the signs as not having low retroreflectivity whereas the WA observers incorrectly observed 20% of the signs as having low retroreflectivity and 6% of the signs as not having low retroreflectivity. The reason for the high incorrect rate is that the NCDOT sign crews in the NCSU study were bound by their annual budget, which hinders them from rejecting all bad sign. The sign NCDOT inspectors reject only signs that are very bad, and further, reject signs based on their safety priority (Red and Yellow). The observers in the WA study were not bound by any budget and received good training prior to evaluation. This may be the reason for them having a low number of incorrect observations.

For Type I red sheeting (Figure 7.17) there does not seem to be any major difference between the NCSU and WA studies. The main reason could be the sign inspectors consider red signs as the most important and any sign observed with low retroreflectivity is replaced quickly. The reason for the small percentage for the signs that were correctly observed as having low retroreflectivity is that the total percentage of signs with low retroreflectivity was only 24% and the sign inspectors correctly observed 20% of these, which is a very good percentage relatively. The WA study observers correctly observed 43% of the signs as having low retroreflectivity out of 50% which is similar to the NCSU rate. Overall, the sign inspectors in the NCSU study have done equally well compared with WA State Study observers.

The WA Study did not consider Type III sheeting and hence the NCSU data cannot be compared to theirs. However there were very few signs of Type III sheeting that were rejected by the NCDOT sign crew and almost all of these that were rejected were due to damage. The purpose of the crew validation was to check the sign inspector performance in rejecting signs which had low retroreflectivity and hence our analysis numbers do not contain damaged signs. Almost all of the signs with Type III sheeting had their retroreflectivity values very high and about 3 to 4 times the minimum standard.

Table 7.5. Sign Inspector Validation for White, Yellow, Red, and Green Type I Signs

	White Type I		Yellow Type I	
Retroreflectivity	**Total Number of Undamaged Signs Observed by Sign Inspectors**	**% of Signs which Appeared to Have Low Retroreflectivity to Sign Inspectors**	**Total Number of Undamaged Signs Observed by Sign Inspectors**	**% of Signs which Appeared to Have Low Retroreflectivity to Sign Inspectors**
0 ≤ R < 10	8	50	34	68
10 ≤ R < 20	10	60	32	72
20 ≤ R < 30	19	21	26	23
30 ≤ R < 40	35	9	39	10
40 ≤ R < 50	48	4	66	5
50 ≤ R < 60	56	2	45	7
60 ≤ R < 110	133	0	51	4
Total	307	7	293	22
	Red Type I		**Green Type I**	
0 ≤ R < 7	19	47	15	13
7 ≤ R < 10	10	20	14	7
10 ≤ R < 20	16	0	12	8
Total	45	24	41	10

Table 7.6. Comparison of NCSU Study with Literature for Type I Yellow

Inspector Observation	NCSU (%)	WA Study (%)
Correctly observed with low retroreflectivity	20	24
Incorrectly observed with low retroreflectivity	2	20
Correctly not observed with low retroreflectivity	31	50
Incorrectly not observed with low retroreflectivity	47	6

Table 7.7. Comparison of NCSU Study with Literature for Type I Red

Inspector Observation	NCSU (%)	WA Study (%)
Correctly observed with low retroreflectivity	20	43
Incorrectly observed with low retroreflectivity	4	7
Correctly not observed with low retroreflectivity	54	32
Incorrectly not observed with low retroreflectivity	22	18

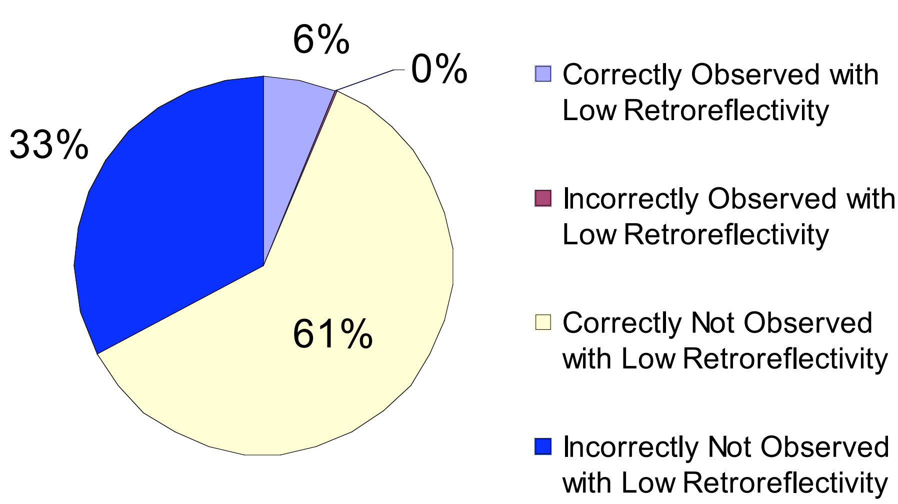


Figure 7.15. Type I White Sheeting

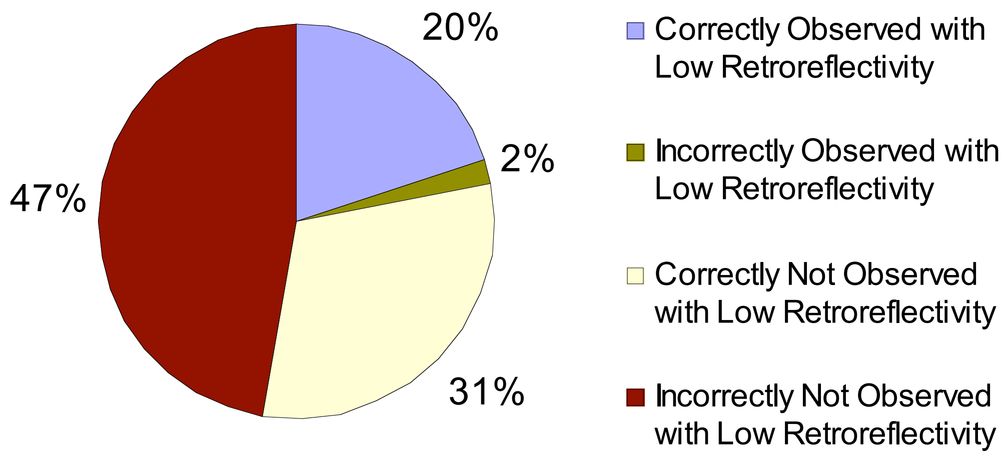


Figure 7.16. Type I Yellow Sheeting

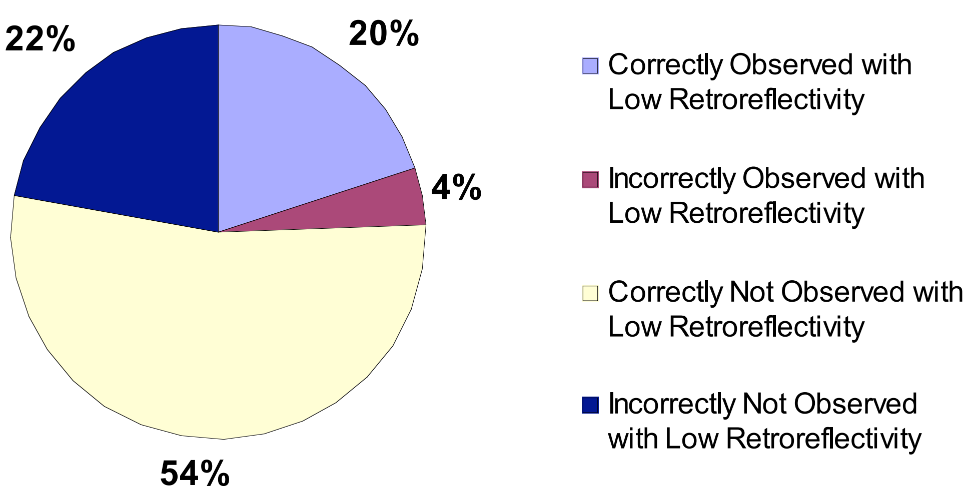


Figure 7.17. Type I Red Sheeting

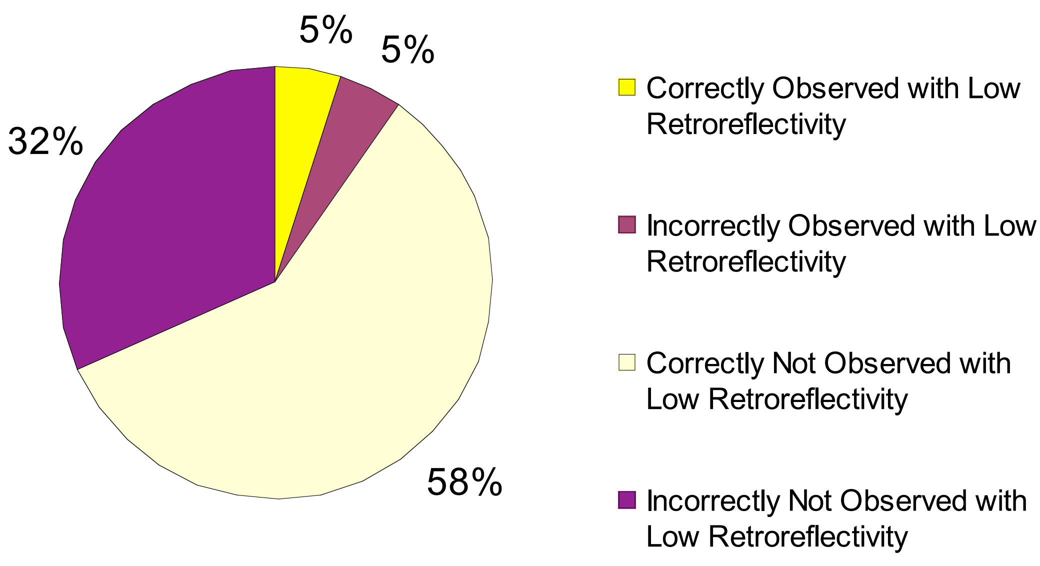


Figure 7.18. Type I Green Sheeting

8.0 DETERIORATION RATE ANALYSIS

The NCSU research team was not satisfied with the curves fitted to the NCSU data. The low degree of correlation of all the curves with the data introduced great uncertainty about which curve fit best. As a result it was decided to plot curves for all of the data from the various literature studies. To do so the NCSU research team decided to extract data from the graphs of retroreflectivity versus age from all the research studies that modeled the best-fit curves of retroreflectivity versus age. The studies from which data was extracted were as follows:

- Purdue Study (Section 2.3.2.1),
- OR Study (Section 2.3.2.2),
- LA Study (Section 2.3.2.3), and
- FHWA Study (Section 2.3.2.4).

The section numbers in the brackets show the location in this report where the study was previously extensively discussed. The data could not be extracted from the FHWA study due to the poor quality of the graph in the report. Because of this legibility problem the best fit curve recommended by the FHWA researchers was used and the R^2 values obtained by the researchers were used directly. The FHWA researchers found a linear curve to be the best fit curve for sign Types I and III and sign colors white, yellow, red, and green.

Using the data from the four studies, five different curve types (linear, polynomial, logarithmic, exponential, and power) were tried on the data and the R^2 values were obtained. The R^2 values provided a good indication of the extent to which the curve fit the data. When analyzing the data we noticed that some of the curves had their tail pointing in a direction heading upward. This meant that the retroreflectivity of signs would start increasing after a certain age. Also some of the curves were horizontal implying when extrapolated they would last for over 80 years.

Based on these observations the research team decided finalize the best-fit curve after analyzing four aspects of the data from both the literature and the NCSU data. The four aspects considered in their order of priority as follows:

1. R^2 values (indicating degree of fit),
2. The age at which a sign hits zero retroreflectivity when curve is extrapolated,
3. The age at which a sign hits zero retroreflectivity when a tangent is drawn to the curve at the end, and
4. The age at which a sign hits zero retroreflectivity when a tangent is drawn to the curve at any point based on engineering judgment.

Clearly, the first two aspects are the most important. If a clear solution did not present itself based on these the research team considered the next two aspects.

8.1 Type I

One of the problems with the data in the literature was that only two studies other than the NCSU study had data for Type I signs. These were the LA and the FHWA studies which both had data for both Type I signs and Type III signs. The remaining studies had data only for Type III signs. Hence for Type I signs only three studies were analyzed.

8.1.1 White

For Type I white signs the NCSU data had very poor R^2 values and the NCSU research team was unable to predict a best fit curve as discussed earlier in section 7.1.1.1 of this report. The LA study had very high R^2 values with over a 70% correlation. Although the research team was happy with the curves it was decided not to consider the LA study because its data was for cleaned signs. The LA study mentioned finding about a 33% increase in retroreflectivity readings after cleaning. Our research team believes that cleaning the signs has caused the scatter to reduce and correlation to increase. However, these cleaned signs are not what the motorist sees in the field and were not the target sought herein.

As shown in Table 8.1 the FHWA study, using a linear curve, showed good correlation with an R^2 value of 0.52. The extrapolated curve showed an age of 24 years (Table 8.3) at which the Type I white signs would hit zero retroreflectivity. Since the linear curve was the best-fit curve, and was also identified to be so by the FHWA study, the NCSU research team decided that the linear curve would be used as the best-fit curve for Type I white signs.

8.1.2 Yellow

For Type I yellow signs the R^2 values obtained from plotting curves on NCSU data were a maximum of about 0.24 (Table 8.1), which implies a lower correlation. The LA study, because of the cleaning factor, was again not considered by the NCSU research team in the analysis for best-fit curves. The linear curve from FHWA study had a significant R^2 value of 0.39 (Table 8.1) for Type I yellow signs. The extrapolated sign showed an R^2 value of 26 years (Table 8.3). Based on the R^2 value and based on the extrapolated sign life it was concluded that a linear curve was the best-fit curve for Type I yellow sign also.

8.1.3 Red

For Type I red signs the R^2 values of the NCSU data curves were around 0.40 (Table 8.2), which was higher than the R^2 values of the FHWA study. Three curves had similar R^2 values, linear, polynomial, and exponential. The NCSU research team decided to consider the linear curve as the best fit curve in order to maintain consistency among the different colors among Type I signs.

8.1.4 Green

For Type I green signs, the polynomial curve had the highest R^2 value (0.36 from Table 8.2) among all the curves plotted for green signs in the NCSU data set. However, this polynomial trended upwards over time. As a result, the FHWA linear curve was selected as the best fit curve for Type I green signs, with an R^2 values of 0.31. Also note that the lifetime of these signs as predicted by the FHWA data of Table 8.4 is approaching 29 years.

8.2 Type III

All the studies discussed above in Section 8.0 other than the NCSU study had data for Type III signs. As mentioned before, the data from FHWA study could not be obtained and the LA data was not considered in the analysis.

8.2.1 White

For Type III white signs the NCSU data had very poor R^2 values and it was not possible to predict a best fit curve as discussed in Section 7.1.2.1 of this report.

The FHWA study, with linear curve, showed good correlation with an R^2 value of 0.19. Although the R^2 value was low, this was relatively higher than data from other studies. The extrapolated curve showed an age of 67 years at which the Type III white signs would hit zero retroreflectivity. Based on engineering judgment it was concluded that the Type III white signs deteriorate in a linear fashion for up to 30 years and at which time the sign sheeting drops below acceptable retroreflectivity levels.

8.2.2 Yellow

For Type III yellow signs the polynomial curve plotted from the Purdue study data had an R^2 value of 0.26 and an extrapolated life of 26 years. The linear curve plotted from the FHWA study data had a slightly better R^2 value of 0.31 and an extrapolated sign life of 77 years. Based on the extrapolated sign life, the research team concluded that the polynomial curve best fits the Type III yellow sign data. The NCSU research team also suggested using the polynomial when only the NCSU data was analyzed.

8.2.3 Red

For Type III red signs the polynomial curve plotted from the NCSU study has the highest R^2 value (0.48), however the predicted sign life of 11 years was determined to be too short. The polynomial curve from the Purdue study (R^2 = 0.36) trends upward over time. The polynomial and exponential curves plotted from the NCSU data also had good R^2 values but the NCSU research team chose the linear curve based on the extrapolated sign life, which was 45 years for an exponential curve and 17 years for a polynomial curve. The 22-year sign life from the NCSU linear curve is similar to the Type I red sign life. None of the other studies had comparatively good R^2 values.

8.2.4 Green

For Type III green signs only the FHWA study had a good R^2 value for the linear curve. All the other studies had low R^2 values for all the different curve types plotted to their data. The FHWA linear curve had an extrapolated life of 30 years which was similar to the Type I green extrapolated sign life.

8.3 Summary

The R^2 values of different curves plotted using data from all available studies has been compiled into tables and the selected curves have been highlighted in each table. Tables 8.1 and 8.2 show the R^2 values from the different studies for white, yellow, red, and green signs and Tables 8.3 and 8.4 show the extrapolated sign life using the best fit equations. The extrapolated life shows the age at which the retroreflectivity of a sign hits zero. Table 8.5 summarizes the selection criteria for signs (based on the analysis) that were discussed in Sections 8.1 and 8.2. All the curves plotted using the data of the different studies can be found in the appendix of this report. The age at which the retroreflectivity of signs hit zero has been slightly adjusted for consistency.

In summary a linear curve fit works better than any other curve over the full range of data, studies, colors, and types. As to age, the data shows that signs will last 20 to 30 years before reaching zero retroreflectivity.

Table 8.1. R^2 Values of Deterioration Curves Based on Best Fit Equations for White and Yellow Signs

Study	R^2 Values					R^2 Values				
	Lin	Log	Poly	Pow	Exp	Lin	Log	Poly	Pow	Exp
Type I Signs										
FHWA	0.52	-	-	-	-	0.39	-	-	-	-
NCSU	0.17	0.18	0.19	0.13	0.14	0.22	0.11	0.24	0.12	0.23
Type III Signs										
FHWA	0.19	-	-	-	-	0.31	-	-	-	-
OR	0.01	0.01	0.01	0.01	0.00	0.08	0.09	0.09	0.05	0.05
Purdue	0.01	0.00	0.03	0.00	0.01	0.17	0.07	0.26	0.07	0.17
NCSU	0.01	0.01	0.01	0.01	0.01	0.06	0.07	0.09	0.07	0.08
All w/o FHWA	0.00	0.00	0.02	0.00	0.00	0.08	0.01	0.19	0.01	0.07
OR and NCSU	0.01	0.18	0.01	0.02	0.01	0.01	0.02	0.05	0.00	0.01

Table 8.2. R^2 Values of Deterioration Curves Based on Best Fit Equations for Red and Green Signs

Study	R^2 Values					R^2 Values				
	Lin	Log	Poly	Pow	Exp	Lin	Log	Poly	Pow	Exp
Type I Signs										
FHWA	0.21	-	-	-	-	0.31	-	-	-	-
NCSU	0.37	0.36	0.37	0.31	0.40	0.27	0.27	0.36	0.19	0.18
Type III Signs										
FHWA	0.17	-	-	-	-	0.48	-	-	-	-
OR	0.12	0.06	0.20	0.07	0.13	0.00	0.01	0.09	0.01	0.00
Purdue	0.34	0.34	0.36	0.24	0.28	-	-	-	-	-
NCSU	0.35	0.15	0.48	0.20	0.42	0.06	0.02	0.11	0.02	0.06
All w/o FHWA	0.34	0.32	0.36	0.23	0.29	0.00	0.06	0.22	0.07	0.00
OR and NCSU	0.27	0.18	0.27	0.21	0.20	0.00	0.06	0.22	0.07	0.00

Legend	
-	No Data
Lin	Linear curve
Log	Logarithmic curve
Poly	Polynomial curve
Pow	Power curve
Exp	Exponential curve

Note: W-White signs; Y-Yellow signs; R-Red signs; G-Green signs

Table 8.3. Extrapolated Sign Life Using Best Fit Equations for White and Yellow Signs

Study	Deterioration Age of Sign (Years)									
	White					Yellow				
	Lin	Log	Poly	Pow	Exp	Lin	Log	Poly	Pow	Exp
Type I Signs										
FHWA	24	-	-	-	-	26	-	-	-	-
NCSU	45	>80	↑	>80	>80	31	>80	20	>80	>80
Type III Signs										
FHWA	67	-	-	-	-	77	-	-	-	-
OR	>80	>80	↑	>80	>80	42	>80	↑	>80	75
Purdue	>80	>80	38	>80	>80	61	>80	26	>80	>80
NCSU	>80	>80	>80	>80	>80	>80	>80	32	>80	>80
All w/o FHWA	>80	↑	37	↑	>80	>80	>80	26	>80	>80
OR and NCSU	↑	↑	64	↑	↑	>80	↑	21	>80	>80

Table 8.4. Extrapolated Sign Life Using Best Fit Equations for Red and Green Signs

Study	Deterioration Age of Sign (Years)									
	Red					Green				
	Lin	Log	Poly	Pow	Exp	Lin	Log	Poly	Pow	Exp
Type I Signs										
FHWA	24	-	-	-	-	29	-	-	-	-
NCSU	21	58	32	>80	>80	29	>80	↑	>80	>80
Type III Signs										
FHWA	↑	-	-	-	-	30	-	-	-	-
OR	42	>80	18	>80	>80	↑	↑	17	↑	↑
Purdue	25	>80	↑	>80	60	-	-	-	-	-
NCSU	22	>80	11	>80	>80	↑	↑	35	↑	↑
All w/o FHWA	26	>80	↑	>80	65	↑	↑	22	↑	↑
OR and NCSU	26	>80	21	>80	>80	↑	↑	23	↑	↑

Note: The ↑ symbol indicates that the curves are heading in the upward direction after a certain age, which is absurd.

Table 8.5. Selection Criteria of the Deterioration Curves for Different Sign Color and Type Combinations

Sign Type and Color	Possible Options	Selection Criteria
Type III White (Linear – 30)	• FHWA linear curve • All w/o Purdue	Only the FHWA linear curve had significant R^2 value and a reasonable deterioration age while Purdue had too high a deterioration age.
Type I White (Linear – 25)	• FHWA linear	Only the FHWA linear curve had a reasonably high R^2 value.
Type III Yellow (Polynomial – 25)	• FHWA linear • Purdue polynomial • NCSU polynomial	FHWA linear curve had a very high age at which the curve hit zero retroreflectivity and the NCSU polynomial hit zero Ra at 32 years. These were too large so both of these options were eliminated. The Purdue polynomial had retroreflectivity hit zero at 26 years. This was similar to a Type I yellow deterioration age and hence was selected.
Type I Yellow (Linear – 25)	• FHWA linear	The FHWA linear curve had a relatively good R^2 value and year (26) for which retroreflectivity hit zero.
Type III Red (Linear – 20)	• NCSU polynomial • NCSU linear	The NCSU polynomial had a very low value for the year in which retroreflectivity hits zero (11) for its extrapolated curve. This is also less than the deterioration age of Type I red signs. The NCSU linear curve had retroreflectivity hit zero at 22 years which was similar to Type I red signs and hence was selected.
Type I Red (Linear – 20)	• NCSU exponential • NCSU polynomial • NCSU linear	The exponential curve had a very high year for which retroreflectivity hits zero. The polynomial curve had retroreflectivity hit zero at age 32. But, for consistency among Type I and Type III red signs, the linear curve with whose retroreflectivity hit zero at 21 years was chosen.
Type III Green (Linear – 30)	• FHWA linear	The FHWA linear curve was the only curve with good R^2 values and its retroreflectivity hit zero at 30 years.
Type I Green (Linear – 30)	• FHWA linear	The FHWA linear curve was the only one with good R^2 values and its retroreflectivity hit zero at 29 years which is similar to the Type III green sign.

9.0 SIGN INVENTORY MANAGEMENT SYSTEM SIMULATION

The sign inventory management system simulation uses an excel spreadsheet to model sign condition in the field over time using actual factors such as sign deterioration rate, replacement rate, and damage rate. The simulation factors were obtained from North Carolina sign data and the simulation results were validated by matching them with current field sign data and sign financial data from the NCDOT.

The sign inventory management simulation program enables various sign management scenarios to be analyzed in order to predict how NCDOT can minimize sign costs while maintaining safety on state roads.

9.1 Simulation Algorithm

The basic sign management system simulation algorithm is explained in this section using a simplified example. To understand the simulation process, there are several concepts to be clarified at the start.

In the simulation, signs existing in the field can be grouped based on either their age or retroreflectivity. Table.9.1 shows an example of how a population of 100 signs can be grouped by age for use in the age-based simulation..

Table 9.1. Example of 100 Signs Grouped by Age

Sign Age (Year)	Under 1	1 to 2	2 to 3	3 to 4	Over 4	Total
Number of Signs in Group	20	20	20	20	20	100

In Table 9.1, the 100 signs are grouped by age into 5 groups because a five-year sign lifetime is assumed in this example. The grouping results in each age group containing 20 signs. All of the signs in each age group are considered to have the same age in the simulation. New signs are placed into the first group (Under 1), age less than 1 year old. These signs move to the second group, age one to less than two years old, when the age-based simulation advances by one year. Finally, signs move to the final group (Over 4), greater than 4 years old.

In the retroreflectivity-based simulation, the same population of 100 signs can be grouped by their retroreflectivity values, as shown in Table 9.2. In Table 9.2, there are 20 signs which have retroreflectivity values greater than 80.0 cd/lx/m^2 placing them in the first group (Over 80.0) and there are another 20 signs which have retroreflectivity values between 50.0 to 80.0 in the second group (80.0 to 50.0).

The important concept to be gathered from Table 9.2 is that each retroreflectivity group represents the expected retroreflectivity value range for signs of the same age group. For example, a sign that is less than two years old but greater than one year old is expected to have a retroreflectivity value in the range 80 to 50. This means that the first 20 signs in the greater than 80.0cd/lx/m^2 group will move to the 80.0 to 50.0 (cd/lx/m^2) group next year and at the same time, 20 signs in the 80.0 to 50.0 (cd/lx/m^2) group will move to the 50.0 to 40.0 (cd/lx/m^2) group and so on.

Table 9.2. Example of 100 Signs Grouped by Retroreflectivity

Sign Retroreflectivity (cd/lx/m^2)	**Over 80.0**	**80.0 to 50.0**	**50.0 to 40.0**	**40.0 to 30.0**	**Under 30.0**	**Total**
Number of Signs in Group	20	20	20	20	20	100

Hence the number of groups in Table 9.2 is analogous to the assumed five-year sign lifetime. By grouping signs by retroreflectivity, the retroreflectivity-based simulation can represent both sign lifetime and sign retroreflectivity range for each age group.

Once signs are grouped by either age or retroreflectivity, the next step in the simulation algorithm is to incorporate the sign replacement rate from the NCSU field data. In the field study, data was collected about what signs were allowed to remain in place and what signs were rejected by NCDOT sign crews. For all signs, sign age and retroreflectivity value were recorded.

With the information from the field study, the sign replacement rate can be calculated by either age or retroreflectivity separately as expressed in Table 9.3.

Table 9.3. Example of Sign Replacement Rate

Sign Age (Year)	**Under 1**	**1 to 2**	**2 to 3**	**3 to 4**	**Over 4**	**Total**
Sign Retroreflectivity (cd/lx/m^2)	Over 80.0	80.0 to 50.0	50.0 to 40.0	40.0 to 30.0	Under 30.0	Total
Number of Signs in Group	20	20	20	20	20	100
Number of Signs Replaced by Sign Crews	0	0	2	4	10	16
Replacement Rate (%)	0	0	10	20	50	16

In Table 9.3, the third group (2 to 3 years) has a 10 percent replacement rate because 2 signs were rejected out of 20 signs in the group. Similarly, the last group (Under 30.0 retroreflectivity) has a 50 percent replacement rate because 10 signs were rejected out of 20 signs in the group. In this example, only signs rejected for low retroreflectivity are included in the replacement rate.

The annual sign damage rate was also included in the simulation algorithm. For example, if the team found 10 damaged signs out of 100 total inspected signs, the damage rate would be 10 percent. However, if the signs were located on secondary roads where sign inspection happens every 3 years, the damage rate of 10 percent was divided by 3 and the result, 3.3 percent, was stated as the annual sign damage rate.

Table 9.4 shows how sign lifetime, replacement rate, damage rate, and inspection frequency influence the sign simulation results. Note that Table 9.4 uses the replacement rates from Table 9.3, a 10 percent damage rate, and assumes that signs are inspected annually. The signs are grouped by their retroreflectivity in Table 9.4.

Table 9.4 calculates the number of signs in place, replaced due to low retroreflectivity, not replaced, and damaged. The simulation starts with 'Year 1' signs for each sign category and then 'Year 2' and so on. It ends in 'Year n' when the number of signs in place in each retroreflectivity range group is exactly the same as the number of signs in place in 'Year n+1'.

In Table 9.4, the simulation begins with an even distribution of in place signs for each retroreflectivity range group. A total of 100 signs were distributed equally in 'Year 1' so each retroreflectivity group has 20 signs. Later, the equally distributed signs will be adjusted year by year to account for replacement rate and damage rate.

The next step in the Table 9.4 calculation is to calculate how many signs are replaced each year due to low retroreflectivity using the replacement rates in Table 9.3. The first retroreflectivity group, 'Over 80.0', in 'Year 1' has zero signs replaced due to low retroreflectivity because the replacement rate for that retroreflectivity group is zero percent (20.0 × 0 % = 0.0). The second retroreflectivity group, '80.0 to 50.0', also has no signs replaced due to low retroreflectivity, but in the third group, '50.0 to 40.0', there are 2 signs replaced due to low retroreflectivity because 20 signs in the group were multiplied by a 10 percent replacement rate from Table 9.3 (20 × 10 % = 2.0). All of the number of signs replaced due to low retroreflectivity values in Table 9.1.4 follows the same calculation procedure.

'The number of signs not replaced' is calculated by subtracting 'the number of signs replaced each year due to low retroreflectivity' from 'the number of signs in place' for each retroreflectivity group. For example, there are 20 not replaced signs in the first (Over 80.0) and second (80.0 to 50.0) retroreflectivity groups for 'Year 1' (20 – 0 = 20). In the third retroreflectivity group (50.0 to 40.0), there are 18 signs not replaced in year 1 because 2 signs in the group were replaced due to low retroreflectivity.

The final step in 'Year 1' is to calculate the number of damaged signs assuming a 10 percent damage rate. Sign damage occurs regardless of sign age or retroreflectivity so 10 percent of signs that are not replaced will become damaged. For example, in the first retroreflectivity group, 'Over 80.0', and the second group, '80.0 to 50.0', 2 signs were damaged in 'Year 1' (20 × 10 % = 2.0). In the third group, '50.0 to 40.0', 1.8 signs were damaged in 'Year 1' because 10 percent of the not replaced signs in that retroreflectivity group for 'Year 1' is 1.8 (18 × 10 % = 1.8). The other numbers of damaged signs for each retroreflectivity group in 'Year 1' were calculated following the same procedure.

Table 9.4. Example of Simulation

Number of Signs	Year	Retroreflectivity Range (cd/lx/m^2)					Total
		Over 80.0	80.0 to 50.0	50.0 to 40.0	40.0 to 30.0	Under 30.0	
In Place (1)	1	20.0	20.0	20.0	20.0	20.0	100.0
	2	24.4	18.0	18.0	16.2	23.4	100.0
	…						
	n-1	23.7	21.3	19.1	15.5	20.4	100.0
	n	23.7	21.3	19.2	15.5	20.3	100.0
	n+1	23.7	21.3	19.2	15.5	20.3	100.0
Replaced Due to Low Retroreflectivity (2)	1	0.0	0.0	2.0	4.0	10.0	16.0
	2	0.0	0.0	1.8	3.2	11.7	16.7
	…						
	n-1	0.0	0.0	1.9	3.1	10.2	
	n	0.0	0.0	1.9	3.1	10.2	
	n+1	0.0	0.0	1.9	3.1	10.2	
Not Replaced (1) – (2)	1	20.0	20.0	18.0	16.0	10.0	84.0
	2	24.4	18.0	16.2	13.0	11.7	83.3
	…						
	n-1	23.7	21.3	17.2	12.4	10.2	84.8
	n	23.7	21.3	17.2	12.4	10.2	84.8
	n+1	23.7	21.3	17.2	12.4	10.2	84.8
Damaged (10 % of Not Replaced per Year)	1	2.0	2.0	1.8	1.6	1.0	8.4
	2	2.4	1.8	1.6	1.3	1.2	8.3
	…						
	n-1	2.4	2.1	1.7	1.2	1.0	8.5
	n	2.4	2.1	1.7	1.2	1.0	8.5
	n+1	2.4	2.1	1.7	1.2	1.0	8.5

Once the numbers of signs in each category were calculated for ’Year 1’, the next step in the calculation was to compute the number of signs in place for the first group, ‘Over 80.0’, in ‘Year 2’. In the second year, the number of signs in place in the first group are new signs installed in

‘Year 2’ and the number of new signs can be obtained from the total number of signs replaced the previous year, ‘Year 1’. In ‘Year 1’, 16 signs were replaced due to low retroreflectivity and 8.4 signs were replaced because of damage. Hence 24.4 signs should be new signs in ‘Year 2’ and this value became the number of in place signs in ‘Year 2’ for the first retroreflectivity group, ‘Over 80.0’.

The number of signs in place in the second retroreflectivity group, ‘80.0 to 50.0’, in ‘Year 2’ is calculated from the number of signs in place in the first retroreflectivity group, ‘Over 80.0’ in ‘Year 1’ because the signs in the first group in ‘Year 1’ will move to the second retroreflectivity group, ‘80.0 to 50.0’, in ‘Year 2’. However, not all signs in place moved to the next group because some of them were replaced due to low retroreflectivity or damage.

In the first retroreflectivity group in ‘Year 1’, the 20 in place signs should have moved to the second retroreflectivity group in ‘Year 2’ but only 18 of these signs were actually in place in ‘Year 2’ because 2 signs in the first retroreflectivity group were replaced due to damage in ‘Year 1’. In the third retroreflectivity group, ‘50.0 to 40.0’, in ‘Year 2’, 18 signs were also in place because 2 damaged signs were subtracted from the original 20 signs in place in the second retroreflectivity group in ‘Year 1’. In the fourth retroreflectivity group, ‘40.0 to 30.0’, in ‘Year 2’, 16.2 signs were in place instead of 20 because 2 signs were replaced due to low retroreflectivity in the third retroreflectivity group in ‘Year 1’ and 1.8 signs were replaced due to the number of signs damaged in the third retroreflectivity group during year ‘Year 1’ (20 – 2 – 1.8 = 16.2).

The signs in place in the fourth and fifth, ‘Under 30.0’, retroreflectivity groups in ‘Year 1’ moved together to the fifth group for ‘Year 2’. Out of a total of 40 original in place signs in the fourth and fifth groups in ‘Year 1’, 5.6 signs were replaced due to low retroreflectivity (4 signs) and damage (1.6 signs) from the fourth group in ‘Year 1’ and 11 signs were replaced due to low retroreflectivity (10 signs) and damage (1 sign) from the fifth group in ‘Year 1’. Hence 23.4 signs (40 – 5.6 -11) were in place in the fifth retroreflectivity group, ‘Under 30.0’, in ‘Year 2’.

The numbers of signs replaced due to low retroreflectivity in ‘Year 2’ were calculated with the same procedure using Table 9.3. The numbers of signs not replaced and damaged were also calculated using the same method explained previously.

The simulation repeated these calculation procedures until ‘Year n+1’ which is when the number of signs in place in ‘Year n’ and ‘Year n+1’ are equal. This meant the sign data were stabilized for replacement and damage rate. As long as the simulation factors are kept the same, the number of signs in place after ‘Year n’ will be the same for each following year.

This stabilized distribution of signs should match the current sign condition in the field because signs in the field have been installed and managed long enough to have reached a stabilized state. The simulation results, once stabilized, should reflect the current North Carolina sign conditions if the sign replacement and damage rates from actual NCDOT sign management practices are used.

9.2 Factors Affecting Simulation Results

There are several key factors directly affecting simulation results and they are replacement rate, damage rate, and inspection frequency. Following the purpose of the project, those factors were all acquired from North Carolina sign inventory and NCDOT nighttime sign inspection system to deduce reliable simulation results.

When the factors are obtained properly and applied in the simulation, the results of simulation should be close enough to be used directly for sign inventory management system for NCDOT.

9.2.1 Replacement Rate

The replacement rate in this report means the proportion of signs replaced by sign crews because of low retroreflectivity to the total number of signs inspected for each either age or retroreflectivity group of signs. The basic concept of replacement rate calculation was explained in Section 9.1.

Three type of replacement rate, 'Raw', 'Modified', and 'High-level', were examined and two of them, 'Modified' and 'High-level', were used in the simulation for the study.

Type I yellow sign replacement rate grouped by retroreflectivity value from NCSU field study was expressed in Table 9.5.

Table 9.5. Type I Yellow Sign Replacement Rate

Retroreflectivity Range ($cd/lx/m^2$)	**Over 67.0**	**67.0 to 60.7**	**60.7 to 53.0**	**53.0 to 48.0**	**48.0 to 43.0**	**43.0 to 40.0**	**40.0 to 34.3**	**Under 34.3**	**Total**
Inspected and Undamaged Sign Number	24	24	27	28	27	23	27	79	259
Replaced Signs Due to Low Retroreflectivity	0	0	2	0	1	0	2	36	41
Replacement Rate (%)	0.0	0.0	7.4	0.0	3.7	0.0	7.4	45.6	15.8

There are total 259 Type I yellow undamaged signs inspected by signs crews and they are grouped by their retroreflectivity value with 8 years lifetime in Table 9.5. Note that damaged signs were not considered here because they were calculated separately in the simulation with the title of damage rate.

The 'Raw' replacement rate is straightforwardly from the rate in Table 9.5 and Figure 9.1 shows the graph of 'Raw' replacement rate.

In Figure 9.1, it is natural to see that the lower retroreflectivity value of signs is the higher replacement rate is. However, some group of signs showed abnormal pattern of rate. For example, in the sixth group (43.0 to 40.0), the replacement rate was zero even though previous retroreflectivity group (48.0 to 43.0) had 3.7 percent of rate.

So, the team made 'Modified' replacement rate using trend line created in the spreadsheet and it was expressed in Figure 9.2.

In Figure 9.2, 'Modified' replacement rate was created based on the 'Raw' replacement rate using polynomial trend line expressed as dashed line in Figure 9.2. and its equation. Using the equation of the polynomial trend line, 'Modified' replacement rate table was created and it was expressed in Table 9.6.

In Table 9.6, considering peculiar property of polynomial trend line, the rates from the first (~67.0) to the fourth (53.0~48.0) group became zero other than original results expressed in parentheses from the equation to prevent distortion of rates. The 'Modified' replacement rate always guarantees lower retroreflectivity range group of signs has higher replacement rate than any other higher retroreflectivity group of signs.

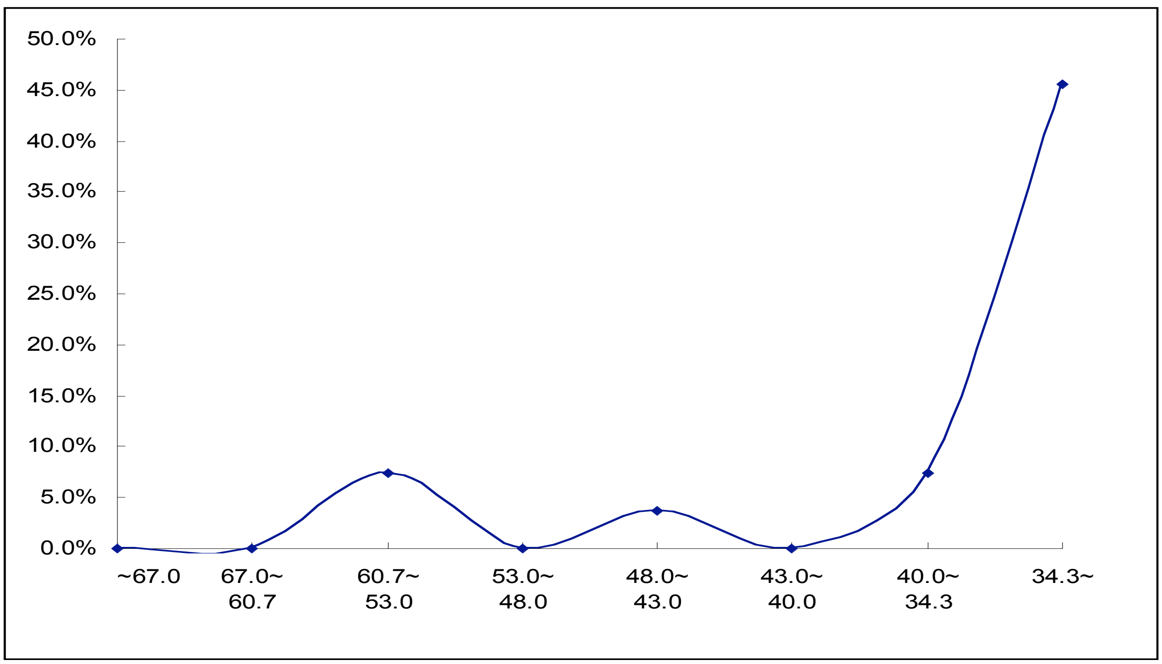


Figure 9.1. Raw Replacement Rate for Type I Yellow Signs

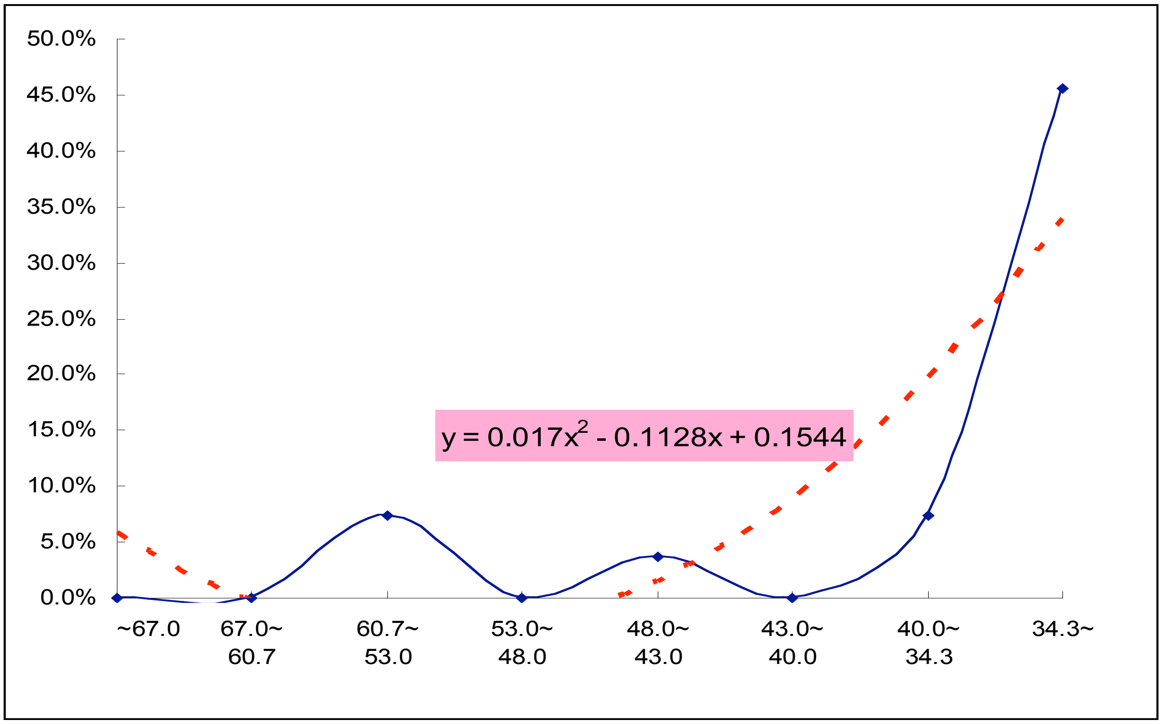


Figure 9.2. Modified Replacement Rate for Type I Yellow Signs

Table 9.6. Modified Replacement Rate for Type I Yellow Sign

Retroreflectivity Range ($cd/lx/m^2$)	**Over 67.0**	**67.0 to 60.7**	**60.7 to 53.0**	**53.0 to 48.0**	**48.0 to 43.0**	**43.0 to 40.0**	**40.0 to 34.3**	**Under 34.3**
Replacement Rate (%)	0.0 (5.9)	0.0 (-0.3)	0.0 (-3.1)	0.0 (-2.5)	1.5	9.0	19.8	34.0

'High-level' replacement rate was also made from 'Raw' replacement rate and it was expressed in Table 9.7 for Type I yellow sign.

Table 9.7. Modified Replacement Rate for Type I Yellow Sign

Retroreflectivity Range ($cd/lx/m^2$)	**Over 67.0**	**67.0 to 60.7**	**60.7 to 53.0**	**53.0 to 48.0**	**48.0 to 43.0**	**43.0 to 40.0**	**40.0 to 34.3**	**Under 34.3**
Raw Replacement Rate (%)	0.0	0.0	7.4	0.0	3.7	0.0	7.4	45.6
High-level Replacement Rate (%)	0.0	0.0	7.4	7.4	7.4	7.4	7.4	45.6

The basic idea of 'High-level' replacement rate is for any retroreflectivity group of signs to have at least same or higher level of replacement rate than previous higher retroreflectivity group of signs. For example in Table 9.7, the 'Raw' replacement rate of the fourth group (53.0 to 48.0) is zero and it is lower rate than previous group (60.7 to 53.0), so the replacement rate of the fourth group is adjusted to have at least same, 7.4 percent, rate with the previous third group (60.7 to 53.0) of signs. The replacement rates of the fifth and sixth group were also adjusted with same method.

'Modified' and 'High-level' replacement rates were applied to various simulation programs later to decide which type of rates deduce better results in the simulation.

9.2.2 Damage Rate

Within the context of this research project, the reasons for sign replacement have been categorized as low retroreflectivity, natural damage, and vandalism. A combined rate of natural damage and vandalism is called a damage rate throughout the study. In the beginning, to calculate the damage rate, only the field data collected by the research team during the regular nighttime sign inspection (performed by the sign crews in five divisions statewide) was used. Table 9.8 shows the annual replacement rates calculated from the field data.

An overall 4.1 percent replacement rate per year and 2.4 percent damage rate per year were calculated based on the inspection process.

Table 9.8. Annual Replacement Rate from NCSU Field Data

<table>
<tr><th>Replacement Reason</th><th>Number of Signs Replaced Per Year</th><th>Total Number of Signs Inspected</th><th>Annual Replacement Rate</th></tr>
<tr><td>Low Retroreflectivity</td><td>29</td><td rowspan="3">1,681</td><td>1.7 %</td></tr>
<tr><td>Natural Damage</td><td>16</td><td>1.0 %</td></tr>
<tr><td>Vandalism</td><td>24</td><td>1.4 %</td></tr>
<tr><td>Total</td><td>69</td><td>1,681</td><td>4.1 %</td></tr>
</table>

However, it was subsequently determined that, in addition to the inspection process, the NCDOT also replaces signs through other inspection checks that are outside the systematic nighttime inspection system. Thus, overall, the true damage and replacement rates should be higher than were calculated with the field data. To determine those other rates of replacement, sign manufacture cost, financial codes from the NCDOT, and a previous sign count study from NCSU were used. These were analyzed to calculate and verify an actual sign damage rate to be used in the simulation program. The process of calculating the overall replacement rate consists of the following 6 steps:

1. Examine the total number of signs statewide by sign color.

2. Calculate a weighted average manufacture cost per sign.
3. Calculate the number of signs replaced based on financial codes for low retroreflectivity, natural damage, and vandalism.
4. Calculate the replacement rate for each type of reason.
5. Compare the results from Step 4 with the rate from the NCSU field data.
6. Confirm the damage rate to be used in the simulation program.

Step 1 consisted of assembling the data in Table 9.9 which consists of the total number of signs in NC by sign color and based on sign count studies conducted by NCSU [Kirtley, et. al. 2001, Palmquist, et. al. 2002].

Table 9.9. Total Number of Signs in NC

Sign Color or Type	White	Yellow	Stop	Green	Others	Total
Sign Number	383,521	373,918	52,678	67,249	92,539	969,905

Note that 'Stop' signs were used as a category rather than all red signs in Table 9.9. In doing so this table conforms to the sign manufacture cost data. The total number of 969,905 signs was used in the remaining calculation steps.

Table 9.10 shows the number of white, yellow, and stop signs extracted from Table 9.9. The values shown in Table 9.10 will be used in the calculation of the weighted average manufacture cost per sign in Step 2.

Table 9.10. Total Number of White, Yellow, and Stop Signs NC

Sign Color or Type	White	Yellow	Stop	Total
Sign Number	383,521	373,918	52,678	810,117
Percent of Signs	47.3 %	46.2 %	6.5 %	100.0 %

Green and other signs were not considered in Table 9.10 because information from the NCDOT showed that the likelihood of replacement of those signs was extremely low. Green guide signs, in particular, are often mounted very high on busy roads. Thus, they are not easily accessible and are generally not subject to most damage. Additionally, the budget of the excluded sign colors was managed separately from the financial code used in the calculations below.

Table 9.11 shows the individual sign manufacture costs. These were obtained from the NC Department of Corrections, which makes most signs in NC.

To calculate the weighted average total manufacture cost of Table 9.12 (0.473 × 41.50 + 0.462 × 48.70 + 0.065 × 50.20 = $45.39), it was necessary to compute the weighted sign average manufacture cost as shown in Table 9.11 using the percentages of colors from Table 9.10.

Table 9.11. Weighted Average Sign Manufacture Cost for Type III Signs

Sign Color or Type	Sign Size	Type III Manufacture Cost ($/sign)	Average Cost ($/sign)	Weighted Average Cost ($/sign)
White	24” × 30”	41.53	41.53	52.83
Stop	30”	38.72	48.66	
	36”	58.59		
Yellow	30”	51.91	65.01	
	36”	78.10		

For step 3, NCDOT financial code data was used to calculate the total number of signs replaced in 2005 for any reason. According to the financial code data, signs replaced by vandalism were assigned to code 4301 and those replaced for low retroreflectivity and natural damage were both assigned to code 4302. Table 9.12 shows how many signs were replaced in 2005 in NC using sign expenditures from NCDOT.

Table 9.12. Sign Expenditures in 2005

Financial Code	Replacement Reason	Total Manufacture Cost ($)	Weighted Average Sign Cost ($)	Total Number of Signs Replaced
4302	Low Retroreflectivity and Natural Damage	1,580,515	52.83	29,917
4301	Vandalism	1,506,487		28,516

The total statewide sign expenditures reported in financial codes 4301 and 4302 (Table 9.12) were divided into the total number of signs in NC (Table 9.10) to find the total number of signs replaced statewide.

A total of about 29,000 signs were replaced because of vandalism and about 30,000 signs were replaced because of low retroreflectivity and natural damage.

To achieve step 4 of the calculation process, the total number of signs replaced (Table 9.12) was divided by the total number of signs in NC (Table 9.9) for the percentage replacement rate. These values are shown in Table 9.13.

Table 9.13. Sign Replacement Rate

Financial Code	Number of Signs Replaced	Total Signs in NC	Replacement Rate per Year
4302	29,917	969,905	3.1 %
4301	28,516		2.9 %
Total	58,433		6.0 %

Table 9.13 shows that the vandalism rate coded by 4301 was about 2.9 percent per year. The low retroreflectivity and natural damage rates combined (code 4302) were 3.1 percent per year. To separate the replacement rate from financial code 4302 into individual low retroreflectivity and natural damage rates, the ratio from the field data shown in Table 9.8 was applied. That is, out of 45 replaced signs because of natural damage and low retroreflectivity (16+29) it was found that 16/45 were damaged naturally and 29/45 had low retroreflectivity. The resulting annual replacement rates are shown in Table 9.14.

Table 9.14. Actual Sign Replacement Rate in NC

Replacement Reason	Replacement Rate (% per year)
Low Retroreflectivity	2.0
Natural Damage	1.1
Vandalism	2.9
Total	6.1

In step 5, the replacement rate from the NCSU field data was compared to the results calculated using the NCDOT financial codes. Table 9.15 shows the comparison. It makes sense that the largest increase between the field study (inspectors) and the financial data (all sources) was for vandalism. Vandalism is a type of instantaneous and catastrophic damage and it is the damage type that occurs continuously during the year at times other than during nighttime inspections.

Table 9.15. Comparison of Sign Replacement Rates

Replacement Reason	NCSU Field Study	Calculation Using Financial Data and Sign Counting Study
Low Retroreflectivity	1.7 %	2.0
Natural Damage	1.0 %	1.1
Vandalism	1.4 %	2.9
Total	4.1 %	6.0

The research team determined that the rate of signs replaced in 2005 (for whatever reason) was 6.0 percent. After accounting for sign replacement initiated by inspectors, the research team was able to estimate that about 1.9 percent (6.0 - 4.1) of all signs each year are replaced outside the nighttime inspection process; among the 1.9 percent, about 80 percent of these replacements ((2.9 – 1.4) / 1.9) are due to damage caused by human vandalism.

The overall sign replacement rate due to damage, whether replacement is initiated by inspectors or others, is then 4.0 percent (1.1 + 2.9) of all signs per year. Note that 2.0 percent replacement in Table 9.15 happens because of not damage but natural low retroreflectivity rejected by sign crews.

Table 9.16 is used to estimate damage rates that can be used in the simulation program. This table complies the annual damage rate by sign type and color from all sources. This rate was determined to be proportional to the annual damage rate found by the inspectors.

In summary, we initially estimated the damage rate as 2.4 percent and then adjusted it to 4.0 percent based on studying the actual sign replacement financial codes from NCDOT and based on a previous sign count study from NCSU. This percentage increase of 1.6 percent signs represents those signs replaced outside the nighttime inspection process and these rates will all be valuable in the simulation program, allowing it to more accurately represent true replacement rates.

Table 9.16. Converted Annual Damage Rate

Type	Color	Number of Signs Inspected	Number of Damaged Signs per Year	Annual Damage Rate From Inspection	Converted Annual Damage Rate From All Sources
I	White	530	11	2.0%	3.5%
	Yellow	445	22	4.9%	8.2%
	Red	115	2	1.5%	2.5%
	Green	120	2	1.5%	2.7%
	Total	1,210	36	2.9%	5.1%
III	White	90	0	0.4%	0.6%
	Yellow	188	2	1.0%	1.7%
	Red	106	2	1.6%	2.8%
	Green	87	0	0.0%	0.0%
	Total	471	4	0.8%	1.4%
Total		1,681	40	2.4%	4.0%

9.2.3 Inspection Frequency

Under the current NCDOT nighttime sign inspection policy, inspection frequency varies according to road type. Signs on Interstate have been inspected every year, signs on primary road have been inspected once every two years, and signs on secondary road have been inspected once every three years. To satisfy the different inspection frequency, different formation of simulation has been created.

First, to simulate signs on Interstate, in case of inspect signs every year, total 1,000 signs were used in the simulation to represent total signs in the field and the stabilized sign distribution from 'In Place Sign Number' was regarded as the result of simulation. This way of simulation was already explained in Section 9.1.

Second, to simulation signs on primary road, in case of inspect signs once every two years, total 1,000 signs were also used in the simulation but they were divided in two groups, 500 signs each. And then, each 500 signs were simulated by same factors such as replacement and damage rate. Note that each group of signs was inspected alternate years in the simulation to satisfy the inspection frequency, inspect every two years. After all, each group of signs were combined together to make total 1,000 signs that stands for total signs in the field.

Finally, to simulate signs on secondary road, in case of inspect once every three years, total 1,000 signs were divided in three groups, 333 signs each. Each group of signs was also simulated by same factors and then combined together to make total 1,000 signs.

Used same simulation factors, three different results came up according to inspection frequency and the results of simulation made sense because the more often signs were inspected the more new signs were shown in the results. Figure 9.3 shows not only new sign number but also 'above' and 'below the minimum standard' sign number in the results of simulation. Note that according to the minimum retroreflectivity value proposed by FHWA, signs were categorized either 'above' or 'below the minimum standard' in the results of simulation.

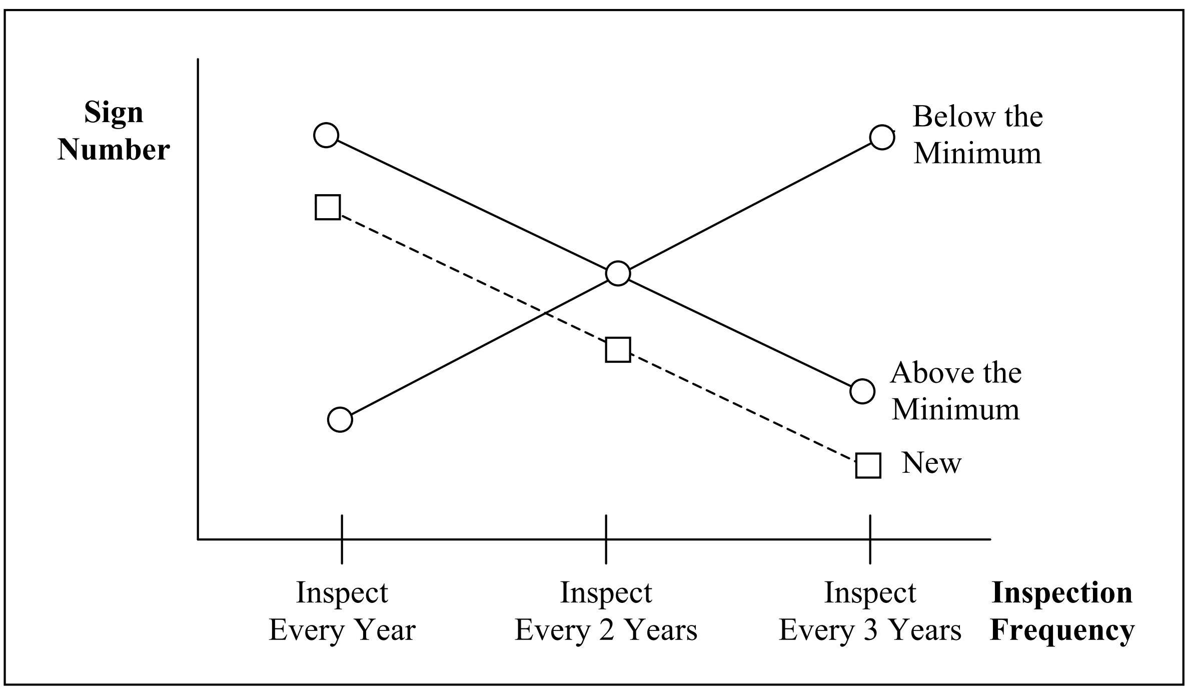


Figure 9.3. Simulation Results Variance According to Inspection Frequency

In Figure 9.3 a total of 1,000 signs were used for each simulation with different inspection frequency and they categorized either 'above' or 'below the minimum standard' signs according to their retroreflectivity value expected in the results of simulation. Note that 'new' signs were included in the 'above the minimum' signs.

'Above the minimum' signs decreases as the inspection frequency changes from inspect every year to every three years because it is logical for signs to stay longer in the field that is likely to have lower retroreflectivity under the fewer inspection. 'Below the minimum standard' signs have totally opposite idea to the 'above the minimum' signs.

Next step was to examine NCSU field data to know accrual inspection frequency of signs in the field. Because the field data was collected statewide, the actual inspection frequency could be calculated by checking the road type of signs. Table 9.17 shows inspection frequency of NCDOT calculated by the field data.

Table 9.17. Nighttime Sign Inspection Frequency of North Carolina DOT

Sign Type	Sign Color	Total Number of Signs Inspected	Inspected Sign Number			Inspection Frequency
			Interstate	Primary	Secondary	
I	White	335	1	151	183	2.54
	Yellow	351	0	59	292	2.83
	Red	50	0	1	49	2.98
	Green	46	0	18	28	2.61
	Total	782	1	229	552	2.70
III	White	56	11	19	26	2.27
	Yellow	79	3	30	46	2.54
	Red	84	4	2	78	2.88
	Green	46	13	32	1	1.74
	Total	265	31	83	151	2.45
Total		1047	32	312	703	2.64

To calculate inspection frequency in Table 9.17, signs on Interstate were multiplied by one, signs on primary road were multiplied by two, and signs on secondary road were multiplied by three and then the numbers combined all together were divided by total number of signs inspected. For example of Type I white signs, combined number of 852 was calculated by multiplying of road type number ($1\times1 + 151\times2 + 183\times3 = 852$) and the combined number was divided by total sign number inspected to calculate inspection frequency, 2.54 years ($852 / 335 = 2.54$).

Once the inspection frequency for each type and color was obtained, the result of simulation was expressed following the inspection frequency for each type and color of signs. For example, in case of Type I white sign, the final result of simulation with the inspection frequency of once every 2.54 years was acquired from between the results of inspect every two years and every three years corresponding linear ratio of inspection frequency.

9.3 Design of Spreadsheet Simulation

Signs can be grouped by either their age or retroreflectivity value for simulation program. According to the group, two types of simulation, age and retroreflectivity based, were created to find the optimum sign inventory management system for North Carolina DOT.

9.3.1 Age-Based Simulation

As an initial step, the research team used the previous simulation program based on sign age which had the replacement rate from the Washington DOT study. In this simulation, signs were grouped and simulated by their age and the age of sign was a reason to distinguish signs as deficient or not.

In the sign age-based simulation, sign age is the only criterion regardless of retroreflectivity to identify signs whether it is good or not. Hence, signs are grouped by their age to have replacement rate for each group to be used in the simulation program and the results of the simulation are also stated by the age of signs.

Warranty periods suggest maximum Type I sign useful life is 7 years and the maximum Type III sign useful life is 12 years. For example, if a Type III stop sign was 10 years old it would be 'OK' and a 14-year old Type III warning sign would be 'deficient' in this sign-age based simulation.

Our field data collection from five different divisions showed that many Type I signs were still in the field beyond 7 years of their warranty time. Table 9.18 and Figure 9.4 show that around 47% of studied Type I signs were more than 7 years old.

Table 9.18. The Number of Type I Signs Studied by Age

Sign Color / Sign Age	White	Yellow	Red	Green	Total
Less than 7 years old	150	188	26	18	382
More than 7 years old	139	158	23	25	345
No date information	46	5	1	3	55
Total	335	351	50	46	782

For this reason, not only 7 years warranty period but also 12 years lifetime Type I sign simulations for each color were also created to analyze signs in the field.

9.3.1.1 Type I with 7-year Lifetime

In this Type I with 7-year lifetime simulation, signs were grouped by their age and each replacement rate of the groups was calculated to be used in the simulation. Because damage rates were already fixed for each sign color as sated in Section 9.2.2, the replacement rate was the only factor to be obtained for the age-based simulation which was made for each color of signs, white, yellow, red, and green.

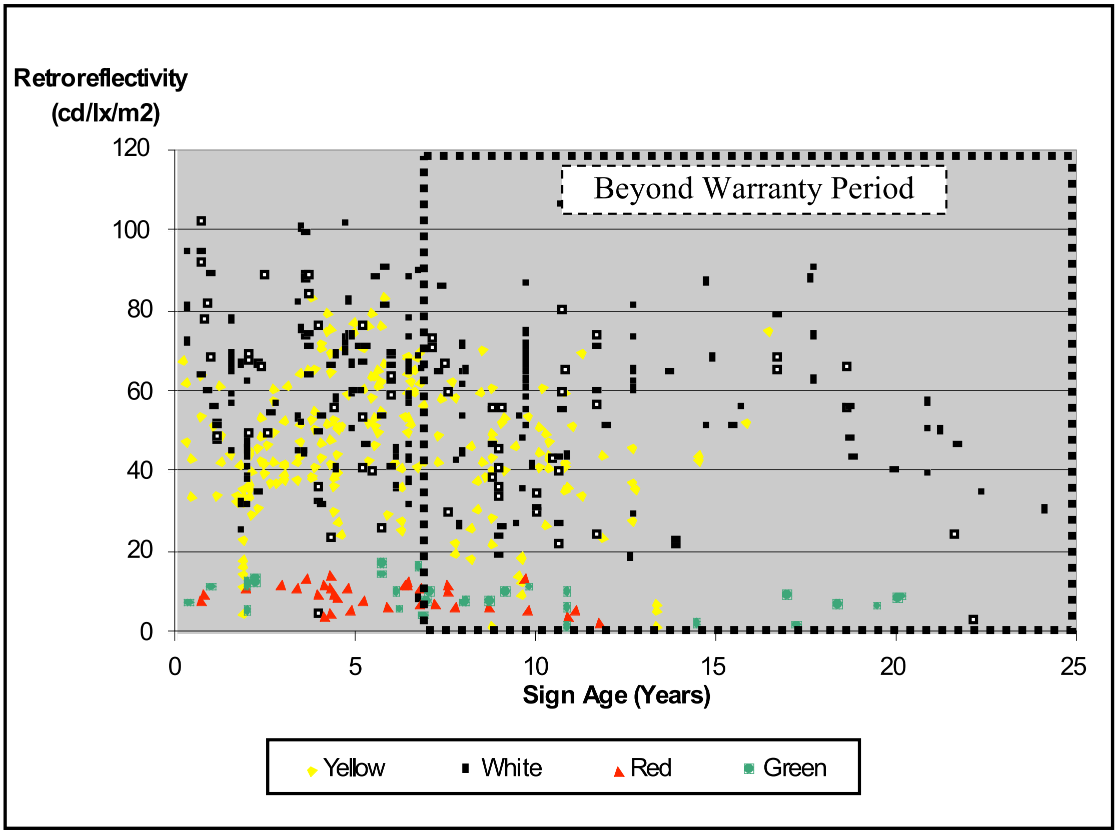


Figure 9.4. Type I Sign Data Distribution

The team arranged Type I white sign data first along with sign age which was from the sign erection date sticker or hand writing on the back of the sign, signs inspected and undamaged, signs rejected due to low retroreflectivity, and raw replacement rate as expressed in Table 9.19.

Table 9.19. Type I White Sign Data

Sign Age (years)	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	Over 7
Inspected and Undamaged Sign Number	10	21	21	20	27	21	30	139
Replaced Signs Due to Low Retroreflectivity	0	2	0	1	1	3	2	10
Raw Replacement Rate (%)	0.0	10.5	0.0	5.6	3.8	16.7	7.1	8.1

As the raw replacement rate in Table 9.19 for Type I white sign showed irregular increase by the age group of signs, the modified replacement rate was created using a polynomial trend line expressed in Figure 9.5.

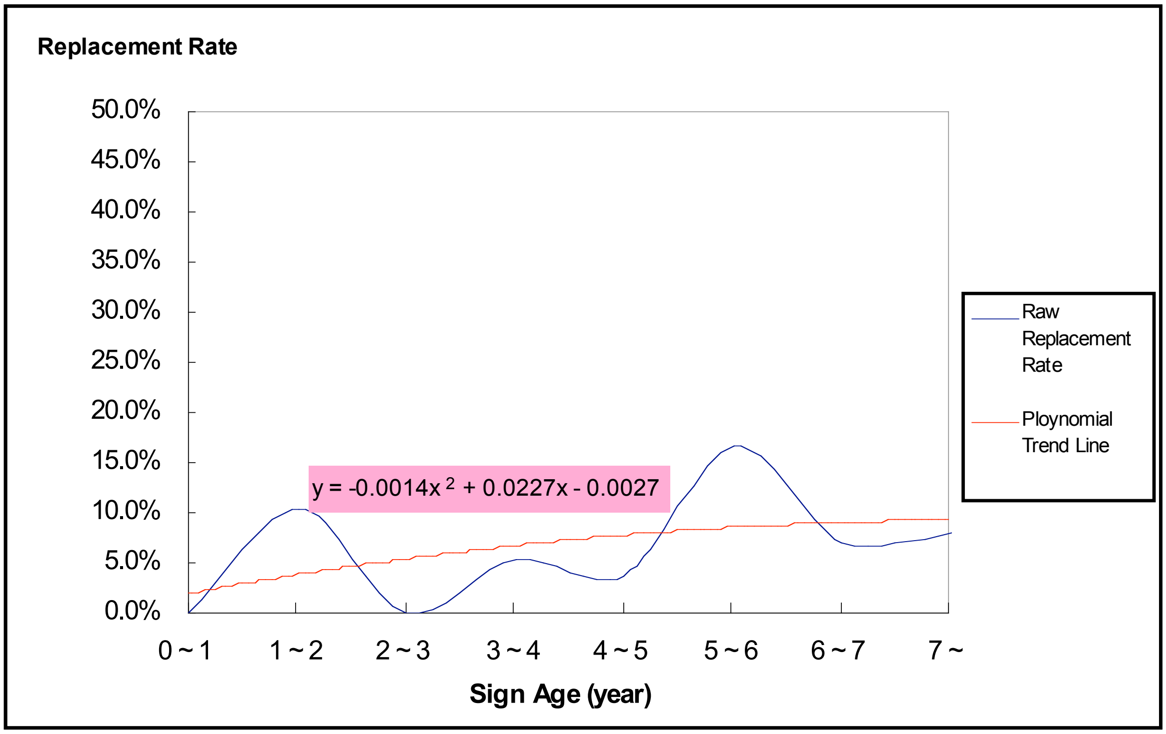


Figure 9.5. Type I White Sign Modified Replacement Rate

The equation created by the polynomial trend line in Figure 9.5 was used to make modified replacement rate for Type I white sign and it was expressed in Table 9.20.

Table 9.20. Modified Replacement Rate for Type I White Signs

Sign Age (years)	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	Over 7
Modified Replacement Rate (%)	1.9	3.7	5.3	6.6	7.6	8.3	8.8	8.9

Using the modified replacement rate from Table 9.20 and 4.1 percent damage rate in Table 9.16, Type I white signs were simulated following the same algorithm explained in Section 9.1. The result of simulation separated by inspection frequency is shown in Table 9.21.

As a result of simulation in Table 9.21, 1,000 Type I white signs were distributed by their age and the signs in the last group (Over 7) were regarded as deficient because they exceed warranty period. For example, 198 signs in case of inspect every year inspection frequency are expected to be deficient under the simulation factors discussed above. Note that deficient signs increases as the inspection frequency decreases like from every year to every three years because sign inspection brings more chances to replace signs, especially deficient signs.

Table 9.21. Result of Simulation for Type I White Signs

Sign age (years) / Inspection Frequency	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	Over 7	Total
Every year	176	162	125	115	92	76	55	198	1000
Every two years	141	129	105	97	81	72	57	317	1000
Every three years	117	108	96	88	78	71	56	386	1000

Following the same process explained above for Type I white signs, other color of signs, yellow, red, and green, were also simulated and the result of simulation is expressed in Table 9.22.

Table 9.22. Result of Simulation for Type I Yellow, Red, and Green Signs

Sign Color	Sign age (years) / Inspection Frequency	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	Over 7	Total
Yellow	Every year	301	234	152	109	78	55	34	36	1000
	Every two years	270	211	148	111	83	62	43	73	1000
	Every three years	254	198	147	111	84	64	45	96	1000
Red	Every year	168	151	136	122	105	86	67	166	1000
	Every two years	134	120	108	97	86	76	63	315	1000
	Every three years	111	104	96	89	80	73	63	384	1000
Green	Every year	137	128	119	108	95	82	69	263	1000
	Every two years	111	104	96	89	80	73	63	384	1000
	Every three years	100	93	87	80	73	67	59	442	1000

As a result of the simulation expressed in Table 9.21 and Table 9.22, all color of Type I signs except yellow have about three to four hundreds deficient signs out of 1,000 under the current inspection frequency, once every 2.64 years explained in Section 9.2.3, that is close but not quite satisfactory numbers compare to 47 percent of more than 7-year old signs based on the NCSU field study expressed in Table 9.18 and Figure 9.4.

However, the difference of results between the field study and simulation was expected because signs were grouped by age in the age-based simulation to have replacement rate for each group but actually, in the nighttime sign inspection, deficient signs were rejected by sign crews due to not age but low retroreflectivity that meant signs should be grouped by their retroreflectivity to deduce proper result of simulation.

9.3.1.2 Type I and III with 12-year Lifetime

As a next step, the research team completed 12-year life time simulation spreadsheet for both Type I and Type III signs. Basically, it has the same process with 7-year simulation except the life time is extended from 7 to 12 years, which means that signs more than 12 years old will be regarded as deficient in the result.

In the case of Type I signs, the real state of the field was considered as half of the Type I signs had the age of more than 7 years. The Type I signs with the age from 7 to 12 years were around 31% according to our field data and the simulation was expected to express more realistic result with the extension of Type I sign life time.

Generally, Type III signs have 12 years warranty period for the high intensity sheeting. The team assumed that Type III signs also make longer their lifetime more than 12 years but they were installed relatively recently, so only 12-year lifetime was considered for the Type III signs in the age-based simulation. Only 5 percent of Type III signs had the age of more than 12 years in the field data.

First, Type I signs were examined and Table 9.23 shows raw and modified replacement rates for each sign color obtained by the same process with 7-year Type I sign simulation.

Using the modified replacement rates above and damage rates in Table 9.16, Type I sign 12-year lifetime simulation were created for each sign color and the results of simulation separated by inspection frequency was expressed in Table 9.24.

Table 9.23. Replacement Rates for Type I Signs with 12-year Lifetime

Sign Color	Replacement Rate	Sign Age (year)												
		0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	Over 12
White	Raw	0.0	10.5	0.0	5.6	3.8	16.7	7.1	0.0	9.1	0.0	12.5	0.0	15.6
	Modified	4.0	4.4	4.7	5.1	5.5	5.8	6.2	6.6	6.9	7.3	7.7	8.1	8.4
Yellow	Raw	0.0	0.0	8.7	0.0	5.9	4.5	27.3	50.0	32.0	16.7	40.0	50.0	44.0
	Modified	0.0	0.0	4.2	8.5	12.8	17.1	21.4	25.8	30.1	34.4	38.7	43.0	47.4
Red	Raw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.7	0.0	80.0	33.3	100
	Modified	0.0	0.0	0.0	1.4	8.1	14.8	21.5	28.2	34.9	41.6	48.3	55.0	61.7
Green	Raw	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	36.4
	Modified	0.0	0.3	1.3	2.3	3.4	4.4	5.4	6.4	7.4	8.5	9.5	10.5	11.5

Table 9.24. Results of Simulation for Type I Sign with 12-year Lifetime

Sign Color	Inspection Frequency	Sign Age (year)												
		0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 t 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	Over 12
White	Every year	123	110	98	87	77	68	60	52	46	40	34	30	174
	Every two years	97	89	81	74	67	61	55	50	45	41	36	33	271
	Every three years	88	81	75	68	63	58	52	48	44	39	36	33	316
Yellow	Every year	245	199	162	126	93	66	44	28	17	10	5	3	2
	Every two years	226	183	149	119	91	70	51	37	26	18	11	8	11
	Every three years	217	176	143	114	90	70	53	40	30	21	15	11	20
Red	Every year	176	158	142	128	113	93	71	50	32	19	10	5	3
	Every two years	159	142	128	115	102	89	72	60	43	34	21	15	19
	Every three years	149	134	120	108	97	85	70	60	50	36	28	22	40
Green	Every year	115	107	99	91	82	74	66	58	51	43	37	31	147
	Every two years	97	90	84	77	71	65	59	54	48	43	38	34	239
	Every three years	89	83	77	71	66	61	55	51	46	42	38	34	286

After comparison with the results of 7-year lifetime Type I sign age-based simulation, several comments were made for the results of 12-year lifetime Type I sign simulation.

- Type I white signs showed very little difference between 7 and 12 years simulation. They still had big number of deficient signs in the 12-year simulation and the reason was the replacement rate of Type I white signs from 7 to 12 years did not change drastically. Sign crews rejected those signs without significant variation because white signs had biggest retroreflectivity value among other colors and they had very flat-like deterioration rate of retroreflectivity in the field data.
- Type I yellow signs showed very small number of deficient signs in the 12 simulation because sign crews rejected many 7 to more than 12 years old signs with the reason of low retroreflectivity.
- Type I red sign showed biggest difference of result between 7 and 12 years simulation. The deficient sign number was 166 in the 7-year simulation but it became 3 in the 12-year simulation with the inspection frequency of every year. It means that sign crews judged very aggressively for the Type I red signs with the age from 7 to more than 12 years because most red signs were very critical on the roads.
- In the case of Type I green sign, the deficient sign number reduced a lot but the result of 12 years simulation still had 147 deficient signs out of 1,000 with the inspection frequency of every year. The first reason why there were so many deficient signs in the 12-year simulation was from the peculiar kind of green signs on the roads. In the data, many green

signs were project signs on the Interstate or primary roads and the rest were usually county boundary or similar signs. For project signs, it was assumed that the cost to change those signs was very high and it influenced the replacement rate. The other green signs were not critical to nighttime drivers so it was imagined that sign crews did not give high priority to changing those signs.

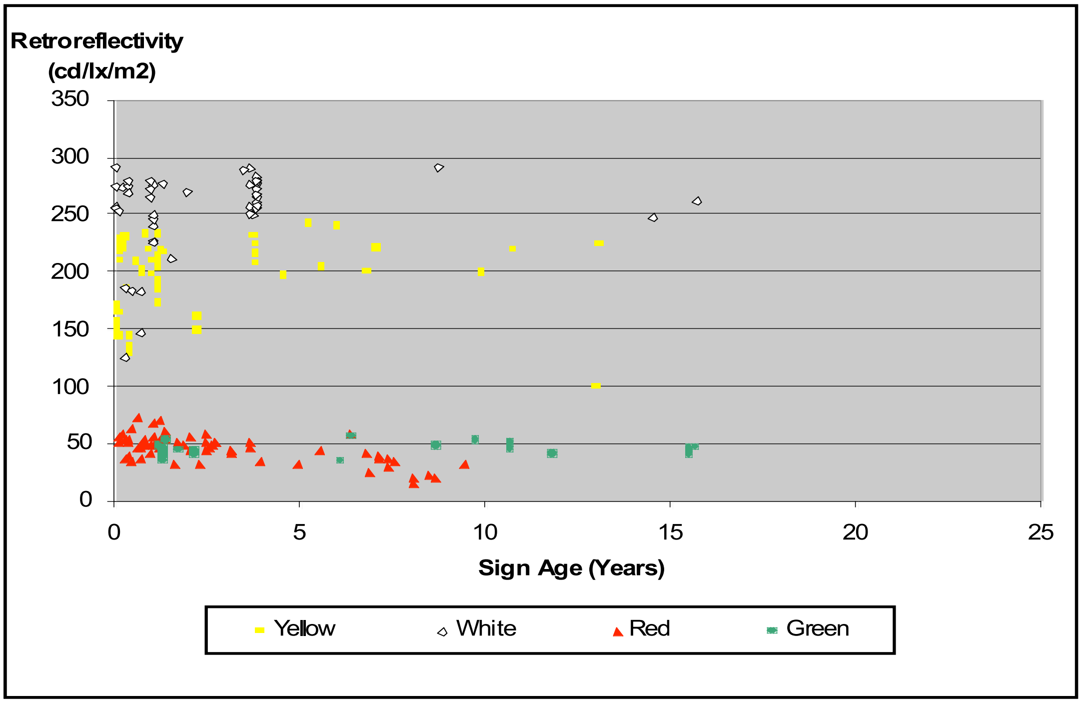


Figure 9.6. Type III Sign Data Distribution

The research team also examined Type III signs with the same procedure of 12-year Type I sign age-based simulation. Before the results of the Type III sign 12-year age-based simulation, some special condition of Type III signs in North Carolina should be explained from the NCSU field data collected statewide.

The team collected 265 Type III sign data in the five NCDOT Divisions but less than 3% of the signs were rejected by signs crews in our data with the reason of low retroreflectivity. The reason why we had somewhat small number of low retroreflectivity reason rejected signs could be explained in Figure 9.6.

As shown in Figure 9.6, Type III signs in NC have been installed in recent years. Around 72% of Type III signs were installed within 5 years and only 6% of Type III signs had the age of more than 10 years from the field data. Hence, they have very low replacement rates due to low retroreflectivity.

It was difficult to expect accurate result of the simulation with the partial portion of the data but the team simulated them with the same procedure used for Type I signs to see general tendency of Type III signs. The result of Type III signs 12-year age-based simulation was expressed in Table 9.25.

Table 9.25. Results of Simulation for Type III Sign with 12-year Lifetime

Sign Color	Inspection Frequency	Sign Age (years)												
		0 to 1	**1 to 2**	**2 to 3**	**3 to 4**	**4 to 5**	**5 to 6**	**6 to 7**	**7 to 8**	**8 to 9**	**9 to 10**	**10 to 11**	**11 to 12**	**Over 12**
White	Every year	118	104	92	81	71	63	56	49	43	38	34	30	222
	Every two years	109	97	87	77	69	61	55	49	43	39	34	31	250
	Every three years	106	95	85	76	68	61	54	48	43	39	35	31	261
Yellow	Every year	73	70	68	66	64	62	59	56	52	48	44	40	297
	Every two years	57	55	53	52	50	49	47	45	42	41	38	36	436
	Every three years	50	48	47	45	44	43	41	39	38	36	34	33	502
Red	Every year	83	76	70	64	59	54	49	45	42	38	35	32	352
	Every two years	60	57	53	50	47	44	41	39	36	35	32	31	477
	Every three years	52	49	47	44	42	40	37	36	34	32	30	29	528
Green	Every year	125	109	96	84	73	64	56	49	43	38	33	29	201
	Every two years	113	100	89	79	70	62	55	49	43	38	34	30	239
	Every three years	108	97	86	77	69	61	54	49	43	39	34	31	252

As expected, the result of simulation showed many deficient, more than 12-year old signs because of very low replacement rate for all color of signs. However, if the condition for Type I signs to continue their retroreflectivity beyond warranty period and Figure 9.6 are considered, it is assumed that Type III signs would also hold their valid retroreflectivity beyond the warranty period, 12-year, in the field. As a result, it is not appropriate to say that the Type III signs with the age of more than 12 years are all deficient.

The research team hoped to analyze Type III signs with more data in the future.

9.3.2 Retroreflectivity-Based Simulation for Type I Signs

The research team approached the retroreflectivity-based simulation differently than sign age-based simulation. Retroreflectivity is the major factor sign crews use to determine whether signs are deficient or not, so this simulation assumes that replacement rates are based on retroreflectivity.

The team created two different models, the “collapse” and the “best-curve”, for the retroreflectivity-based simulation program. The application of replacement and deterioration rates differs between the two models. Generally speaking, the collapse model groups signs based on the NCSU field data but the best-curve model uses data from previous other studies to group signs. Note that after retroreflectivity deterioration and replacement rates are applied, both models follow the basic algorithm of simulation explained in Section 9.1.

The following section explains how the team analyzed Type I sign data collected in the field to simulate nighttime sign inspection on the basis of retroreflectivity.

9.3.2.1 Collapse Model

The collapse model was created to simulate Type I signs based on their retroreflectivity. Signs were grouped according to their retroreflectivity, and each group has its own replacement rate calculated from our own field sign data. Hence, to have proper replacement rates for sign retroreflectivity groups is a key to simulating signs by the collapse model.

Figure 9.7 shows that one could group the Type I white signs that were observed in five NCDOT divisions by either age or retroreflectivity. In Figure 9.7, signs can be grouped either vertically or laterally. The vertical groups expressed with a small letter names like ‘a’ or ‘b’ were created by sign age and they were used for age-based simulation. On the other hand, the lateral groups expressed with capital letter names like ‘A’ or ‘B’ were used for retroreflectivity-based simulation.

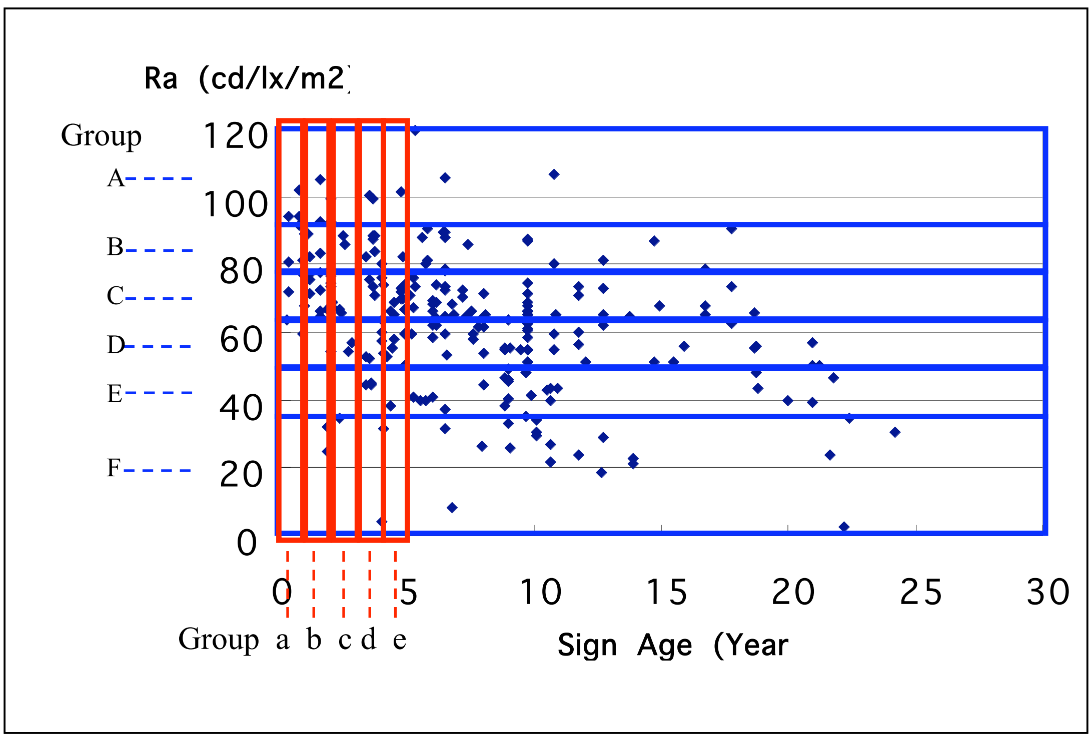


Figure 9.7. Group of Type I White Signs

To simulate signs according to their membership in a retroreflectivity group, two prerequisites must be determined: the number of retroreflectivity groups and retroreflectivity range for each group. Our idea was that the number of retroreflectivity groups should correspond to the general lifetime of signs in years so that each group contains one year's range of retroreflectivity, or cohort, of signs. From Figure 9.7, Table 9.26 was created to explain the meaning of retroreflectivity group in the simulation.

Table 9.26. Sign Retroreflectivity Groups

Sign Group	A	B	C	D	E	F
Sign Age (Years)	1	2	3	4	5	6
Retroreflectivity Range (cd/lx/m^2)	> 88	88 - 77	76 - 66	65 - 54	53 - 30	< 30

In the example in Table 9.26, new signs will be included in group 'A' for their first year in the field and in the next year the signs move to group 'B'. The signs in group 'B' in the year 'n' move to group 'C' in the year 'n+1'. Accordingly, signs in Table 9.26 move from group 'A' to 'F' throughout their lifetime, which would be six years.

To estimate the appropriate lifetime of signs to be used in the retroreflectivity-based simulation, the team examined field data. Figure 9.8 was constructed to show how the number of retroreflectivity sign groups was determined for Type I white signs.

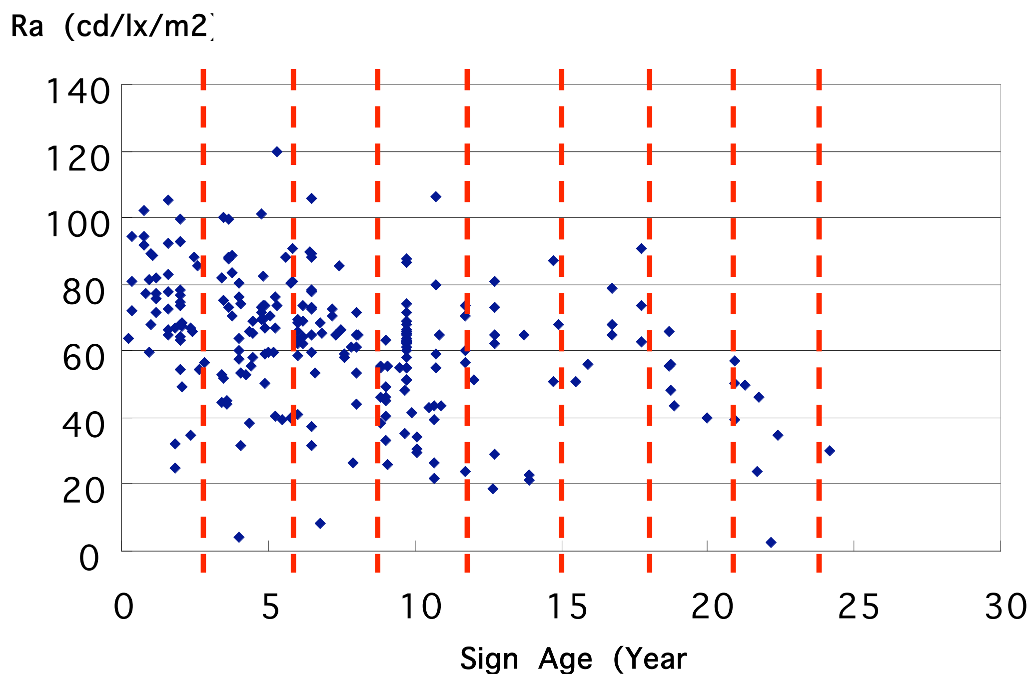


Figure 9.8. Separation of Type I White Signs

In Figure 9.8, Type I white signs were separated into 3-year groups and the number of signs in each group was counted. For example, the first range (0 to 3 years) has 48 signs and the second range (3 to 6 years) has 56 signs. The other age ranges were 6 to 9 years, 45 signs etc. The figure shows a fairly constant number of signs until after 12 years; the number of signs decreases drastically after that.

Table 9.27 was based on data like those presented in Figure 9.8. When we validated the simulation model, we also examined two or three other possible sign lifetimes as shown.

Table 9.27. Lifetime of Type I Signs

Sign Color	Sign Age with Greatest Population Decrease (Years)	Other Sign Lifetimes Tested (Years)
White	12	15, 18
Yellow	12	8, 10
Red	9	8, 10, 12
Green	12	10, 15

The next step in developing the collapse model was to decide on the retroreflectivity range for each group of signs. This is the range of retroreflectivity readings expected to correspond to a one-year cohort of signs; this idea was expressed earlier in Table 9.26.

Figure 9.9 shows how retroreflectivity groups were determined for Type I white signs. In Figure 9.9, 12 retroreflectivity groups were generated assuming a 12-year lifetime for undamaged Type I white signs. Second, we considered only signs that had retroreflectivity values of more than 20 $cd/lx/m^2$. This was because NCDOT sign crews rarely left any white sign in the field below 20 $cd/lx/m^2$; signs under 20 $cd/lx/m^2$ were regarded as exceptional data that distort the simulation result.

Next, we made the key assumption that NCDOT has had a stable sign maintenance system for years. Thus, we can further assume that the number of signs installed each year is fairly constant. The number of undamaged signs in each retroreflectivity group will thereafter be the same throughout the sign lifetime.

In Figure 9.9, a total of 238 signs was separated into 12 groups and each group has same number of signs, 20 (238 / 12 = 19.9).

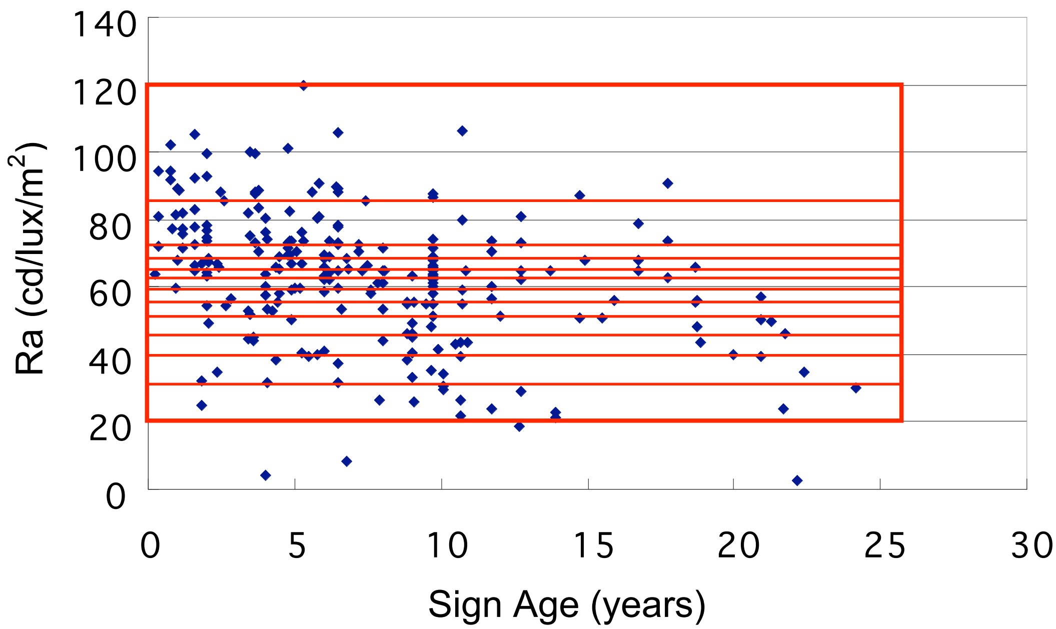


Figure 9.9. Retroreflectivity Group for Undamaged Type I White Signs

The retroreflectivity ranges necessary to produce these 12 equal-sized groups are shown in Table 9.28. In Table 9.28, Type I white signs with the age from zero to one year have a retroreflectivity value more than 87.0 cd/lx/m^2 and signs with the age from one to two years have a range of 87.0 to 73.8 cd/lx/m^2, and so forth.

Table 9.28. Retroreflectivity Ranges for Type I White Sign with 12-Year Lifetime

Sign Age (Years)	**0 to 1**	**1 to 2**	**2 to 3**	**3 to 4**	**4 to 5**	**5 to 6**	**6 to 7**	**7 to 8**	**8 to 9**	**9 to 10**	**10 to 11**	**11 to 12**
Retroreflectivity Range (cd/lx/m^2)	Over 87.0	87.0 to 73.8	73.8 to 69.3	69.3 to 66.0	66.0 to 63.7	63.7 to 59.7	59.7 to 55.3	55.3 to 50.3	50.3 to 45.0	45.0 to 39.7	39.7 to 31.7	Under 31.7

Table 9.29 shows how replacement rates were developed for Type I white signs using the collapse model. Note that undamaged and rejected signs were used to calculate replacement rates for each group of signs.

For some colors, modified and high-level replacement rates were also obtained and tested as explained in Section 9.2.1. The damage rates developed in Section 9.2.2 were in the simulation. Note that the collapse model simulation also follows the same algorithm explained in Section 9.1. The result of the simulation is provided in Section 9.6.

Table 9.29. Replacement Rates of Collapse Model for Type I White Signs

Retroreflectivity Range (cd/lx/m^2)	Over 87.0	87.0 to 73.8	73.8 to 69.3	69.3 to 66.0	66.0 to 63.7	63.7 to 59.7	59.7 to 55.3	55.3 to 50.3	50.3 to 45.0	45.0 to 39.7	39.7 to 31.7	Under 31.7
Number of signs	24	22	22	26	20	22	23	28	27	25	29	33
Number of signs rejected by sign crews	0	0	0	0	0	0	0	1	1	1	2	8
Replacement rate (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	3.7	4.0	6.9	24.2

9.3.2.2. Best Curve Model

The data used to develop the "collapse" model were all from the NCSU field data. In contrast, the best curve model used sign deterioration curves from four studies: Oregon [Kirk, et. al. 2001], Purdue [Bischoff, et. al. 2002], FHWA [Black, et. al. 1991], and the NCSU field study. Sign retroreflectivity data from each study was examined to find the best deterioration curves for the signs of interest.

To find the best deterioration curves, R^2 values for each sign curve and the sign lifetime (when the sign went to 0 cd/lx/m^2) were examined together. The R^2 value indicates the proportion of the variation in the data that is explained by the curve. Generally speaking, the higher R^2 value, the more reliable the curve.

Figure 9.10 shows Type I red sign data from the NCSU field study to explain how the best deterioration curve was selected for the best curve model. For each color of sign, the team created five different deterioration curves, extended the curves as necessary to hit zero retroreflectivity, and computed the R^2 values using a spreadsheet program. Examples of three curves – linear, log, and polynomial – from NCSU field data for Type I red signs are expressed in Figure 9.10. The other two types of curves were power and exponential curves.

In Figure 9.10, polynomial and linear curve show better R^2 value than the log, with R^2 values of 0.43 and 0.41, respectively. The lifetime of signs is expected to be 17 years by a polynomial curve, and 20 years by a linear curve. In this case, the team eventually selected the linear deterioration curve with a 20-year sign lifetime for the simulation to have consistency between Type I and III signs, even though the R^2 value of the linear was less than the polynomial.

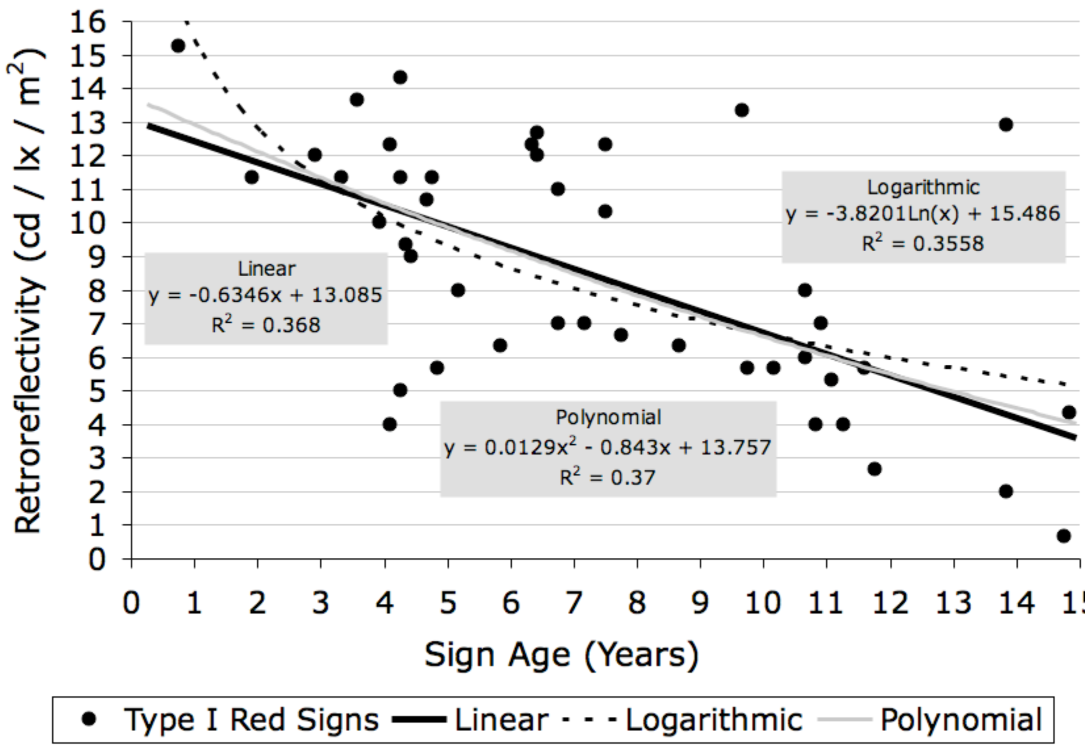


Figure 9.10. Various Deterioration Curves for Type I Red Signs from the NCSU Field Data

The results of the analysis of the deterioration curves that the team examined for each sign color are expressed in Table 9.30. The best deterioration curves for white, yellow, and green signs were selected from the FHWA study, and the red sign curve was selected from the NCSU study. For each sign color, the sign retroreflectivity deterioration equation by age is also shown.

Table 9.30. Deterioration Curves Selected for Type I Signs

Sign Color	Study	Deterioration Curves		R^2 value	Sign Lifetime (Years)
		Type	Equation		
White	FHWA	Linear	Ra = -4.845 × Age + 115.087	0.52	25
Yellow	FHWA	Linear	Ra = -3.392 × Age + 89.186	0.39	25
Red	NCSU	Linear	Ra = -0.645 × Age + 12.666	0.41	20
Green	FHWA	Linear	Ra = -0.561 × Age + 16.283	0.31	30

Once the team chose deterioration curves as in Table 9.30, the equation was used in the best curve simulation model to estimate the retroreflectivity at any point in the sign lifetime. Table 9.31 shows how Type I red signs deteriorate following the equation from Table 9.30.

Table 9.31. Deterioration for Type I Red Signs by Age

Sign Age (Year)	Retroreflectivity Range ($cd/lx/m^2$)
Under 1	Over 11.94
1 to 2	11.94 to 11.30
2 to 3	11.30 to 10.67
3 to 4	10.67 to 10.03
4 to 5	10.03 to 9.40
5 to 6	9.40 to 8.76
6 to 7	8.76 to 8.13
7 to 8	8.13 to 7.49
8 to 9	7.49 to 6.86
9 to 10	6.86 to 6.23
10 to 11	6.23 to 5.59
11 to 12	5.59 to 4.96
12 to 13	4.96 to 4.32
13 to 14	4.32 to 3.69
14 to 15	3.69 to 3.05
15 to 16	3.05 to 2.42
16 to 17	2.42 to 1.78
17 to 18	1.78 to 1.15
18 to 19	1.15 to 0.51
19 to 20	Under 0.51

Using the retroreflectivity range and the sign lifetime for each color, a replacement rate was assumed from NCSU field data. For example, Type I red signs from the NCSU field study were grouped in accordance with the retroreflectivity range in Table 9.31 and replacement rates are shown in Table 9.32.

Table 9.32. Replacement Rate Based on Best Curve Model for Type I Red Signs

Retroreflectivity Range ($cd/lx/m^2$)	Number of signs	Number of signs rejected by sign crews	Replacement rate (%)
Over 11.94	9	0	0.0
11.94 to 11.30	5	0	0.0
11.30 to 10.67	1	0	0.0
10.67 to 10.03	1	0	0.0
10.03 to 9.40	2	0	0.0
9.40 to 8.76	2	0	0.0
8.76 to 8.13	-	0	0.0
8.13 to 7.49	2	0	0.0
7.49 to 6.86	4	2	50.0
6.86 to 6.23	3	0	0.0
6.23 to 5.59	1	1	100.0
5.59 to 4.96	5	1	20.0
4.96 to 4.32	1	1	100.0
4.32 to 3.69	4	2	50.0
3.69 to 3.05	-	0	0.0
3.05 to 2.42	2	1	50.0
2.42 to 1.78	2	2	100.0
1.78 to 1.15	-	0	0.0
1.15 to 0.51	1	1	100.0
Under 0.51	-	0	0.0

Modified and high-level replacement rates were obtained separately as explained in Section 9.2.1. The damage rate in Section 9.2.2 was also used in the simulation. Note that the best curve simulation model follows the algorithm explained in Section 9.1. The result of simulation is provided in Section 9.6.

9.3.3 Retroreflectivity Based Simulation for Type III Signs

According to the NCSU field study, the team found the ratio between Type I and III signs as 0.72 to 0.28. In other words, our best estimate is that 28 percent of total signs were Type III in 2005 statewide. Considering the sign installation policy for Type III signs, the importance of Type 3 signs in the field will become larger and larger and that is why the team also created simulation for Type 3 signs and tried to validate it.

However, the team encountered difficulty in analyzing Type III signs through simulation. Figure 9.11 shows Type III sign data for white, yellow, red, and green color with their age and retroreflectivity value.

In Figure 9.11, around 93 percent of Type III signs were less than 10 years old and almost all signs had the retroreflectivity value above the proposed FHWA minimum standard. This means that NCDOT has installed Type III signs relatively recently and, consequently, the current Type III signs in the field are comparatively young signs. Hence there are not enough field data for older Type III signs to be helpful in creating a simulation program.

To overcome these limitations, the team created a simulation of Type III signs with some assumptions. The most important of these assumptions for Type III signs was to use some information from Type I sign data and from the best-fit sign deterioration curves from four studies: Oregon [Kirk, et. al. 2001], Purdue [Bischoff, et. al. 2002], FHWA [Black, et. al. 1991], and NCSU field study.

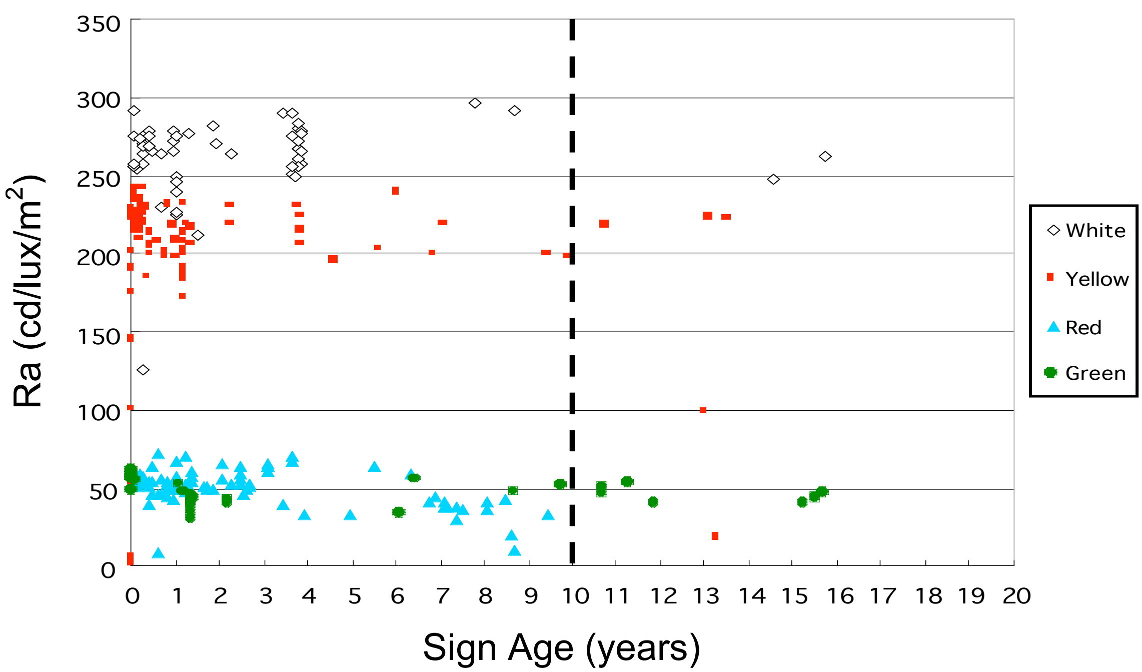


Figure 9.11. Type III Sign Field Data

The team created a general retroreflectivity deterioration curve for Type III signs by combining information from best-fit curves from other studies, NC Type I sign data, and general knowledge of the sign industry. The shape of our assumed curve is shown in Figure 9.12.

In Figure 9.12, the team assumed that Type III signs have lifetime of 20 years regardless of color. We assumed that their retroreflectivity value deteriorates following the best-fit curve until 14 years of age and then at an accelerated rate, reaching the proposed FHWA minimum standard value when the signs are 18 years of age. The proposed FHWA minimum value is 50cd/lx/m^2 for white and yellow signs and 7cd/lx/m^2 for red and green signs. When signs become 20 years, we assumed that they lose their retroreflectivity value down to the lowest retroreflectivity range from the Type I "Collapse Model." This value is around 35 cd/lx/m^2 for white and yellow signs, and 6 cd/lx/m^2 for red signs, and 2 cd/lx/m^2 for green signs. These values were borrowed from the NCSU Type I field data in the absence of Type III field data.

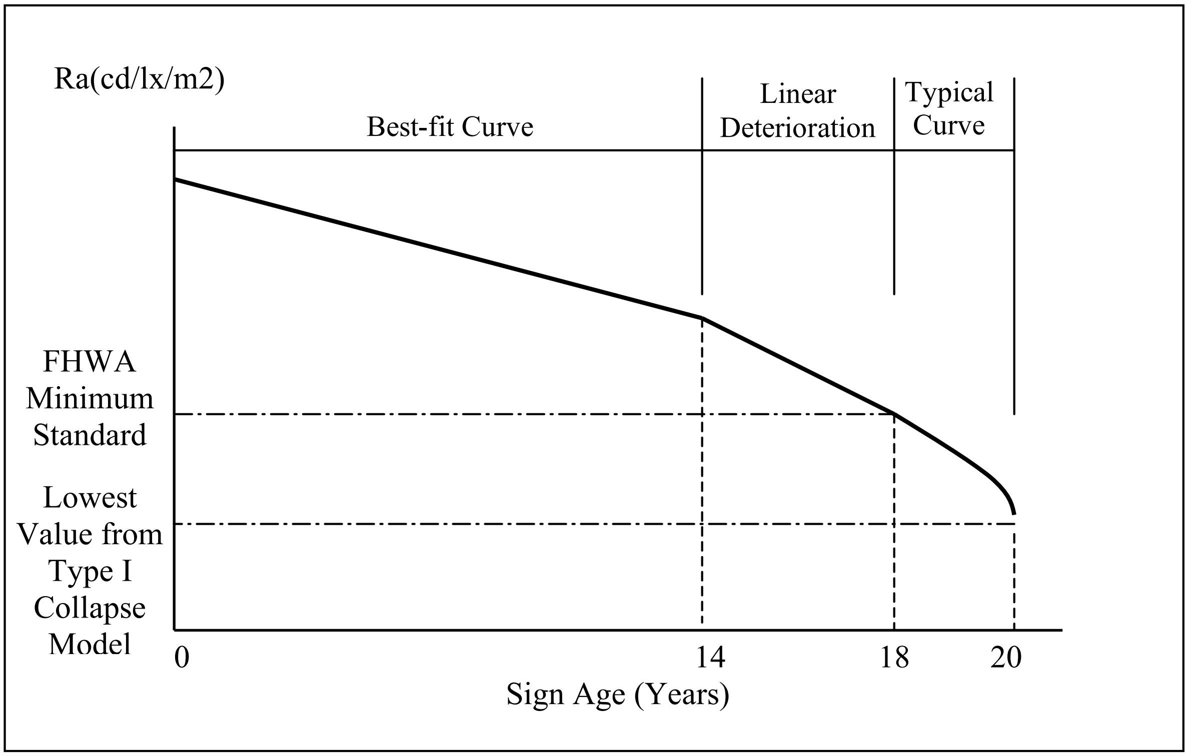


Figure 9.12. Typical Deterioration Curve for Type III Signs

To obtain the best-fit sign deterioration curves for Type III signs from 0 to 14 years in Figure 9.12, raw Type III sign field data from four studies-- Oregon [Kirk, et. al. 2001], Purdue [Bischoff, et. al. 2002], FHWA [Black, et. al. 1991], and our NCSU study--were examined. Table 9.3.3.1 shows the equations for deterioration by sign age for Type III signs used in the best-fit curve pattern of the simulation.

For the best-fit curves, the team determined the sign lifetime (until Ra = 0 cd/lx/m^2) for Type III as 30 years for white and green, 25 years for yellow, and 20 years for red. Table 9.34 shows the Type III red sign deterioration steps using the equation in Table 9.33.

Table 9.33. Equation of Sign Deterioration Curves for Type III Signs

Sign Color	Sign Study	R^2	Sign Retroreflectivity Equation by Age
White	FHWA	0.19	Ra = -4.61 × Age + 311.01
Yellow	Purdue	0.26	Ra = -0.55 × Age × Age + 193.01
Red	NCSU	0.44	Ra = -2.66 × Age + 52.55
Green	FHWA	0.48	Ra = -1.82 × Age + 55.15

In Table 9.34, each retroreflectivity value means low limit for each sign age. For example, the two-year sign age group has a retroreflectivity range from 49.9 to 47.3 cd/lx/m^2. Note that the retroreflectivity ranges with the sign age from 1 to 14-year were only used for Type III simulation as shown in Figure 9.12.

Table 9.34. Type III Red Sign Retroreflectivity Deterioration

Sign Age (Years)	Modified Retroreflectivity (cd/lx/m2)
1	49.9
2	47.3
3	44.6
4	42.0
5	39.4
6	36.8
7	34.1
8	31.5
9	28.9
10	26.3
11	23.6
12	21.0
13	18.4
14	15.8
15	13.1
16	10.5
17	7.9
18	5.3
19	2.6
20	0.0

To simulate sign ages from 18 to 20 years in Figure 9.12, the information from the Type I sign final simulation model was used. Table 9.35 shows the Type I red sign high-level replacement rate used in the collapse model. In Table 9.35, the last three retroreflectivity ranges that stand for sign ages from 6 to 8 years were used for Type III simulation from years 18 to 20. Replacement rates from Type I were also used for the simulation.

Table 9.35. Replacement Rate for Type I Red Signs

Sign Age (Years)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
R_A Range (cd/lx/m^2)	>13.3	12.3	11.3	11.0	9.0	7.0	5.7	<5.7
Replacement Rate (%)	0	20	20	20	20	20	29	58

Using the information in Tables 9.33, 9.34, and 9.35, the team created the Type III red sign replacement rates shown in Table 9.36. In Table 9.36, 20 retroreflectivity groups were made for Type III red signs. For the retroreflectivity groups which correspond to sign age from 1 to 14 years, the best-fit curve information was used in Table 9.34. For the retroreflectivity groups which correspond to sign age from 18 to 20 years, the information from the Type I simulation collapse model in Table 9.35 was used. For the sign groups from the age 15 to 17, a linear deterioration was employed from 15.8 cd/lx/m^2 for 14 year old signs to 7.0 cd/lx/m^2 for 18 year old signs. Zero percent replacement rates were assumed from the sign age 1 to 18 because the retroreflectivity value for those groups were higher than the proposed FHWA minimum standard. The replacement rates for signs of ages 18 to 20 years were borrowed from the Type I sign data in Table 9.35.

Table 9.36. Type III Red Sign Replacement Rates

Sign Age (Years)	**Retroreflectivity (cd/lx/m2)**	**Replacement Rate (%)**
1	49.9	0
2	47.3	0
3	44.6	0
4	42.0	0
5	39.4	0
6	36.8	0
7	34.1	0
8	31.5	0
9	28.9	0
10	26.3	0
11	23.6	0
12	21.0	0
13	18.4	0
14	15.8	0
15	13.6	0
16	11.4	0
17	9.2	0
18	7.0	20
19	5.7	29
20	< 5.7	58

The team simulated Type III signs using the replacement rates shown in Table 9.36 and the damage rates explained in Section 9.2.2 and the results of the simulation are provided in Section 9.6.

9.4 Selection of Simulation Model for Type I Signs

We explored two types of sign management system simulation: age-based and retroreflectivity-based. The team determined to use retroreflectivity-based simulation instead of age-based because it was more realistic for sign crews to judge signs according to retroreflectivity during nighttime inspection.

In the retroreflectivity-based simulation, two sets of models were created for Type I signs: collapse and best-curve models. In each model, two types of replacement rate-modified and high-level and various sign lifetimes were also examined to find the best simulation model. This section explains how the team chose model for each sign type.

The selection of Type I sign simulation was made based on the NCSU field study. The results of simulation were compared with the NCSU field data. Through the comparison, the team chose one of the following alternatives for Type I sign simulation:

1. Model: collapse or best-curve
2. Replacement rate: modified or high-level
3. Sign lifetime: from 8 to 30 years

As an example of our approach, consider the hypothetical simulation results in Table 9.4.1. If the minimum FHWA standard of retroreflectivity for signs in Table 9.37 was 50 cd/lx/m^2, 13 signs (5+4+4) from the first to third cells were regarded as 'above the minimum standard' signs and 11 signs (3+2+2+4) from the fourth to seventh cells were regarded as 'below the minimum standard' signs. Note also that new signs were counted as 'above the minimum standard'.

Table 9.37. Example of Type I Sign Simulation Results

Retroreflectivity (cd/lx/m^2)	Over 70	70 to 60	60 to 50	50 to 40	40 to 30	30 to 20	Below 20
Number of Signs	5	4	4	3	2	2	4

In Table 9.38, hypothetical field data are provided to show how the team compared results of simulation with the field data. In Table 9.38, the number of new signs for the next year was counted as 5 (numbers 5, 6, 7, 8, 9, and 10) because those signs would be replaced as new signs after inspection. If the proposed FHWA nighttime retroreflectivity minimum standard for the signs in Table 9.38 was 50 cd/lx/m^2 , 4 signs (numbers 1, 2, 3, and 4) would be regarded as 'above the standard' because their retroreflectivity was above 50 cd/lx/m^2. At the same time, signs 5, 6, 7, 8, 9, and 10 were counted as 'below the standard'. Note that the new signs in this case were also counted as below the standard signs because they have been 'in place' signs for some time before the inspection in the field.

Table 9.38. Simplified Example of Type I Sign Field Data

Number	Retroreflectivity ($cd/lx/m^2$)	Sign Crew Judgment
1	89	OK
2	75	OK
3	65	OK
4	55	OK
5	42	To be replaced due to damage
6	40	To be replaced due to low retroreflectivity
7	36	OK
8	22	To be replaced due to low retroreflectivity
9	16	To be replaced due to damage
10	9	To be replaced due to low retroreflectivity

- 5 new signs
(Numbers 5, 6, 8, 9, 10)

- 4 above standard signs
(Numbers 1, 2, 3, 4)

- 6 below standard signs
(Numbers 5, 6, 7, 8, 9, 10)

Using the results of the simulation and the field data, the team compared numbers of new signs, above the proposed FHWA minimum standard signs, and below the standard signs. For easier comparison, signs in the results of simulation were expressed as percent of the field data collected by the team in 2005.

Generally speaking, the closer the simulation results are to 100 percent the more reliable the simulation model. The team regarded results from 85 to 120 percent as acceptably reliable in the comparison and they are highlighted in the next tables. Tables 9.39 to 9.42 show the comparison between the NCSU field data and the results of simulation for each sign color.

In Table 9.39, only the 18-year collapse model with high-level replacement shows reliable results in the comparison with the field data. None of best-curve models is satisfactory in the comparison.

Table 9.39. Comparison for Type I White Signs

Category	Field Data (Percent)	Simulation Model				
		Replacement Rate	Collapse		Best Curve	
			Lifetime (Years)	Signs (Percent)	Lifetime (Years)	Signs (Percent)
New	122 (100%)	Modified	12	143 (117%)	20	128 (105%)
			15	129 (105%)	25	155 (127%)
			18	127 (103%)		
		High-level	12	161 (131%)	20	149 (122%)
			15	152 (124%)	25	158 (129%)
			18	147 (120%)		
Above the Minimum	693 (100%)	Modified	12	468 (68%)	20	588 (85%)
			15	511 (74%)	25	712 (103%)
			18	590 (85%)		
		High-level	12	519 (75%)	20	683 (999%)
			15	594 (86%)	25	724 (104%)
			18	674 (97%)		
Below the Minimum	307 (100%)	Modified	12	532 (173%)	20	412 (134%)
			15	489 (159%)	25	288 (94%)
			18	410 (133%)		
		High-level	12	481 (157%)	20	317 (103%)
			15	406 (132%)	25	276 (90%)
			18	326 (106%)		

Table 9.40. Comparison for Type I Yellow Signs

Category	Field Data (Percent)	Simulation Model				
		Replacement Rate	Collapse		Best Curve	
			Lifetime (Years)	Signs (Percent)	Lifetime (Years)	Signs (Percent)
New	313 (100%)	Modified	8	311 (99%)	15	223 (71%)
			10	346 (110%)	20	242 (77%)
			12	269 (86%)	25	240 (76%)
		High-level	8	349 (111%)	15	283 (90%)
			10	346 (110%)	20	284 (91%)
			12	345 (110%)	25	285 (91%)
Above the Minimum	427 (100%)	Modified	8	436 (102%)	15	676 (158%)
			10	569 (133%)	20	747 (175%)
			12	532 (125%)	25	734 (172%)
		High-level	8	482 (113%)	15	860 (202%)
			10	569 (133%)	20	864 (203%)
			12	652 (153%)	25	867 (203%)
Below the Minimum	573 (100%)	Modified	8	564 (98%)	15	324 (56%)
			10	431 (75%)	20	253 (44%)
			12	468 (82%)	25	266 (46%)
		High-level	8	518 (90%)	15	140 (24%)
			10	431 (75%)	20	136 (24%)
			12	348 (61%)	25	133 (23%)

In Table 9.40, only the 8-year collapse model with high-level replacement rate shows acceptable results in comparison with the field data. None of best-curve models is satisfactory in the comparison.

Table 9.41. Comparison for Type I Red Signs

Category	Field Data (Percent)	Simulation Model				
		Replacement Rate	Collapse		Best Curve	
			Lifetime (Years)	Signs (Percent)	Lifetime (Years)	Signs (Percent)
New	320 (100%)	Modified	8	305 (95%)	10	239 (75%)
			9	297 (93%)	12	265 (83%)
			10	270 (84%)	15	244 (76%)
			12	234 (73%)	20	248 (77%)
		High-level	8	371 (116%)	10	282 (88%)
			9	369 (115%)	12	326 (102%)
			10	339 (106%)	15	304 (95%)
			12	329 (103%)	20	304 (95%)
Above the Minimum	600 (100%)	Modified	8	594 (99%)	10	665 (111%)
			9	639 (107%)	12	736 (123%)
			10	604 (101%)	15	678 (113%)
			12	650 (108%)	20	677 (113%)
		High-level	8	648 (108%)	10	717 (119%)
			9	700 (117%)	12	826 (138%)
			10	676 (113%)	15	771 (129%)
			12	775 (129%)	20	771 (129%)
Below the Minimum	400 (100%)	Modified	8	406 (101%)	10	335 (84%)
			9	361 (90%)	12	264 (66%)
			10	396 (99%)	15	322 (81%)
			12	350 (88%)	20	323 (81%)
		High-level	8	352 (88%)	10	283 (71%)
			9	300 (75%)	12	174 (44%)
			10	324 (81%)	15	229 (57%)
			12	225 (56%)	20	229 (57%)

In Table 9.41, 8-year and 9-year collapse models with modified replacement and 8-year collapse model with high-level replacement show reliable results in the comparison. Again, none of best-curve models provides acceptable results in the comparison.

Table 9.42. Comparison for Type I Green Signs

Category	Field Data (Percent)	Simulation Model				
		Replacement Rate	Collapse		Best Curve	
			Lifetime (Years)	Signs (Percent)	Lifetime (Years)	Signs (Percent)
New	174 (100%)	Modified	10	166 (95%)	20	87 (50%)
			12	200 (115%)	25	97 (56%)
			15	126 (72%)	30	96 (55%)
			18	137 (79%)		
		High-level	10	239 (138%)	20	118 (68%)
			12	229 (131%)	25	124 (71%)
			15	190 (109%)	30	126 (73%)
			18	174 (100%)		
Above the Minimum	761 (100%)	Modified	10	417 (55%)	20	485 (64%)
			12	600 (79%)	25	537 (71%)
			15	485 (64%)	30	535 (70%)
			18	593 (78%)		
		High-level	10	591 (78%)	20	657 (86%)
			12	683 (90%)	25	688 (90%)
			15	713 (94%)	30	701 (92%)
			18	736 (97%)		
Below the Minimum	239 (100%)	Modified	10	583 (244%)	20	515 (215%)
			12	400 (167%)	25	463 (194%)
			15	515 (215%)	30	465 (194%)
			18	407 (170%)		
		High-level	10	409 (171%)	20	343 (143%)
			12	317 (133%)	25	312 (130%)
			15	287 (120%)	30	299 (125%)
			18	263 (110%)		

In Table 9.42, only the 18-year collapse model with high-level replacement shows reliable results in the comparison with field data.

In the end, the team wanted to select one model for all sign colors. The collapse model was selected instead of the best-curve model because only collapse model had acceptable results. Second, a high-level replacement rate was chosen because only red signs had acceptable results with the modified replacement rate. The collapse model with a high-level replacement rate provided at least one reliable result in the comparison for each sign color. Hence, the Type I sign simulation model for each sign color was determined as shown in Table 9.43.

Table 9.43. Selection of Retroreflectivity Based Simulation Model

Sign Type	Sign Color	Simulation Model	Replacement Rate	Sign Lifetime (Years)
I	White	Collapse	High-level	18
	Yellow			8
	Red			8
	Green			18

The simulation models in Table 9.43 showed the most reliable results for each Type I sign color in the comparison with the NCSU field data. The team was then ready to apply them to various situations to enhance sign management system for the NCDOT.

9.5 Validation

The team placed emphasis on the validation of the simulation because one of the major purposes of the project was to provide a practical simulation optimized with North Carolina sign inventory conditions for the NCDOT. The team tried to validate simulation in two ways.

First, the NCSU field data collected in five divisions was used to validate the Type I sign simulation. Because Type I signs have been in place for a long time, the results of simulation for a stabilized sign condition could be matched with current field data.

Second, the team used NCDOT financial code data from 2005 to validate Type I and III sign simulation results. The team compared new sign costs statewide to simulation results to see whether the simulation was valid or not.

9.5.1 Comparison of Simulation Results with NCSU Field Data

The team compared the results of the simulation to NCSU field data for Type I signs. Three different numbers from both simulation results and field data were compared. They were the numbers of 'new', 'above the standard', and 'below the standard' signs. New signs are those replaced due to low retroreflectivity, damage, etc. Above the standard signs are those that have retroreflectivity values above the proposed FHWA minimum standard. Below the standard signs are those that have reflectivity values lower than the minimum standard value.

Note that all the numbers discussed below were from the best of the simulation models chosen earlier, the "collapse" model with the "high-level" replacement rate. The percentages in Table 9.44 were calculated for the number of signs inspected in the field as a percentage of the number of signs estimated by the simulation assuming a population of 1,000 signs of each color. The number of new signs in Table 9.44 was from the simulation results multiplied by inspection frequency for each color, expressed per 1,000 inspected signs.

In an ideal situation, the ratio would be 100 percent for new, above the standard, and below the standard signs. However, there are some reasons why it is not possible to have the ratio of exactly 100 percent in the comparison. First of all, even if we tried to collect field data statewide and calculated average number of signs in some category from the data, there should be some variance in the data. Second, although number of new signs from the field data was close to the average number of signs replaced in every case, there should be also some variance year to year. As a result, the team concluded the range of 88 to 120 percent was small enough to say that the simulation was close to the real sign situation in NC.

Table 9.44. Comparison of Simulation Results with NCSU Field Data for Type I Signs

Sign Color	Number of New Signs		Number of Signs Above the Standard		Number of Signs Below the Standard	
	Field Data	Simulation	Field Data	Simulation	Field Data	Simulation
White	122	147 *(120%)*	693	674 *(97%)*	307	326 *(106%)*
Yellow	313	349 *(111%)*	427	482 *(113%)*	573	518 *(90%)*
Red	320	371 *(116%)*	600	648 *(108%)*	400	352 *(88%)*
Green	174	174 *(100%)*	761	736 *(97%)*	239	263 *(110%)*

9.5.2 Comparison of Simulation Results with NCDOT Financial Data

The team also tried to validate the simulation using NCDOT financial code data. Expenditure information provided to the team by the NCDOT showed that \$3.1 million was spent under budget codes 4301 and 4302 statewide in 2005. These budget codes represent low retroreflectivity and natural damage in 4302 and vandalism in 4301.

The team compared the amount of money spent for the new sign material from the NCDOT financial code data to total sign cost calculated by simulation results. Table 9.45 shows how the team calculated the total sign cost for new signs.

In Table 9.45, the 'estimated number of new signs from simulation' column was from the results of simulation in which 1,000 signs of each color were used; in case of white sign, following the same ratio of the NCSU field study as the 86 percent of Type I new signs and 14 percent of Type III new signs, 50 signs were calculated. For example, the estimated number of new white signs 50, calculated as 86 percent of 58 new signs from the Type I simulation result and 14 percent of 4 new signs from the type III simulation result ($0.86 \times 58 + 0.14 \times 4 = 50$). The estimated number of signs for "other" color was calculated using the average from the other four colors of signs.

Table 9.45. Annual Sign Material Cost Estimated from Simulation

Sign Type	Sign Color	Estimated Number of New Signs from Simulation of 1,000	Total Sign Estimate from NCSU Study	Total Number of New Signs Statewide	Average Cost, $ Per Sign	Total Cost for New Signs($)
All	White	50	384,000	19,300	41.53	1,018,000
	Yellow	105	374,000	39,300	65.01	2,074,000
	Red	58	52,700	3,100	48.66	163,000
	Green	34	67,200	2,300	103.77	119,000
	Other	26	93,500	2,400	52.92	128,000
Total			971,000	66,400	52.92	**3,500,000**

From the total sign estimate in the previous NCSU study [Kirtley, et. al. 2001, Palmquist, et. al. 2002], the team calculated the number of new signs needed statewide from the simulation results. For example, the estimated number of new white signs per year (19,300) was from the total sign estimate from NCSU study and the percentage of new signs from the simulation result (50 / 1,000 = 19,300 / 384,000).

Once the number of total new signs for all colors was determined, the team multiplied it by weighted average sign cost to get the total cost for new signs for each color of signs. The total new sign cost in 2005 statewide from simulation was calculated as $3.5 million as compared with the total cost from NCDOT financial code data of $3.1 million. The team concluded that the result of the calculation using the simulation and NCSU sign count study was close enough to say that the simulation was valid for the NCDOT.

9.6 Simulation Results

The research team created a sign management simulation for each sign type and color. The final selections of simulation parameters are shown in Table 9.46.

Table 9.46. Selected Simulation Model for Each Type and Color

Sign Type	Sign Color	Simulation			
		Model	Sign Lifetime (Years)	Replacement Rate Type	Damage Rate (%)
I	White	Collapse	18	High-level	3.5%
	Yellow	Collapse	8	High-level	8.2%
	Red	Collapse	8	High-level	2.5%
	Green	Collapse	18	High-level	2.7%
III	White	-	20	Using Type I Rate	0.6%
	Yellow	-	20	Using Type I Rate	1.7%
	Red	-	20	Using Type I Rate	2.8%
	Green	-	20	Using Type I Rate	0.0%

As next step, the Type I and III simulations were consolidated by sign color into one simulation for each color. A single simulation was used to mimic actual sign conditions in the field because Type I and III signs are related to each other on the roads (as Type III signs replace Type I signs the population of each changes).

9.6.1 Combination of Type I and III Simulation

At first, a total of eight different simulation programs for two types (Type I and III) and four colors (white, yellow, red, and green) were created to analyze the sign management system for NCDOT. However, considering current field condition of signs, Type I and III signs should be examined together because most of Type I signs rejected and damaged are replaced by Type III signs according to NCDOT sign management policy.

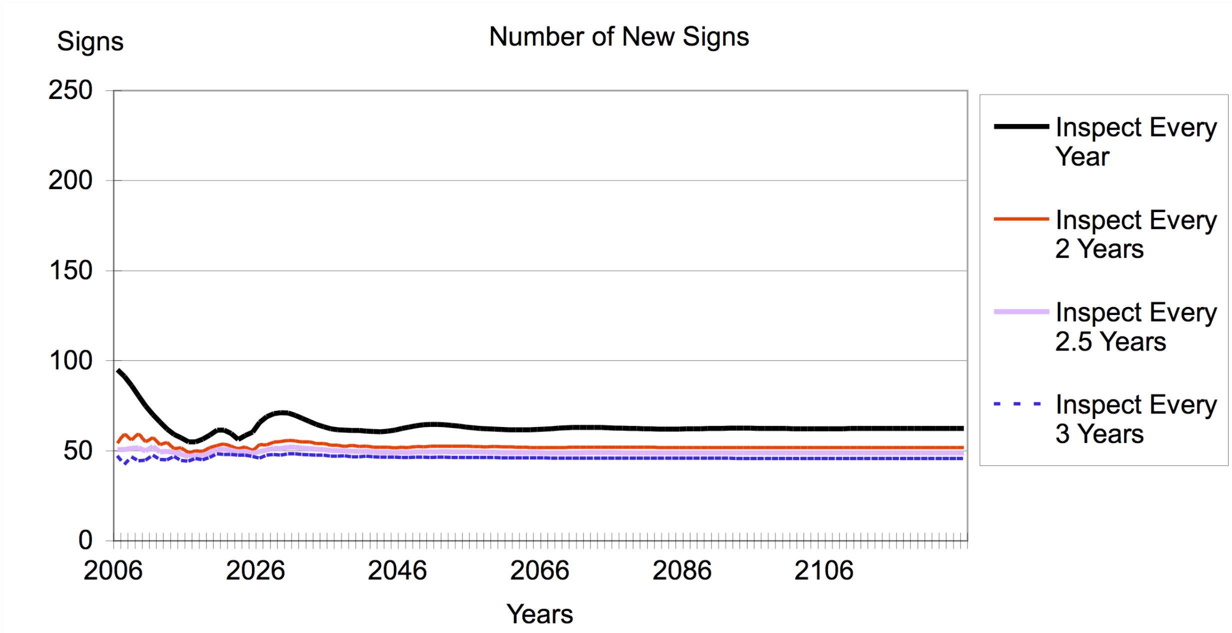
The team confirmed from NCSU sign field data collected from five divisions in 2005 and 2006 that around 89 percent of Type I signs rejected and damaged in 2005 were replaced with Type III signs in 2006. Because of this unique sign type transfer situation, the team combined Type I and III simulations together for each sign color to represent overall sign conditions in NC.

The other thing that was considered in the combination of simulation was the damage rate used for each sign type because Type I and III signs had quite different damage rates in our field study. From the NCSU sign field study, it was very clear that the damage rate of Type I signs was higher than Type III signs. This is most likely because Type I signs tended to be on lower-volume and secondary roads. So, the team expected that if all Type I signs were replaced by Type III, the damage rate of Type III signs would increase linearly up to the current total damage rate. In the case of Type I signs, we assumed that damage rate would stay constant through the years.

9.6.2 Simulation Results for Each Color

The results of each simulation were expressed in two categories: number of new signs and below the standard signs. Note that the category of above the standard signs is not expressed because it is always just total number of signs minus below the standard signs. A total of 1,000 signs were assumed and basically four types of inspection frequencies were examined for each simulation: inspect every year, inspect every 2 years, inspect every 3 years, and use the current inspection frequency.

Using the current sign distribution from the NCSU field data in the first year, up to 120-year expectation for white and yellow signs and 200-year expectation for red and green signs were expressed as the results of simulation. Figures 9.13 to 9.16 show the results of simulation for each color separately.



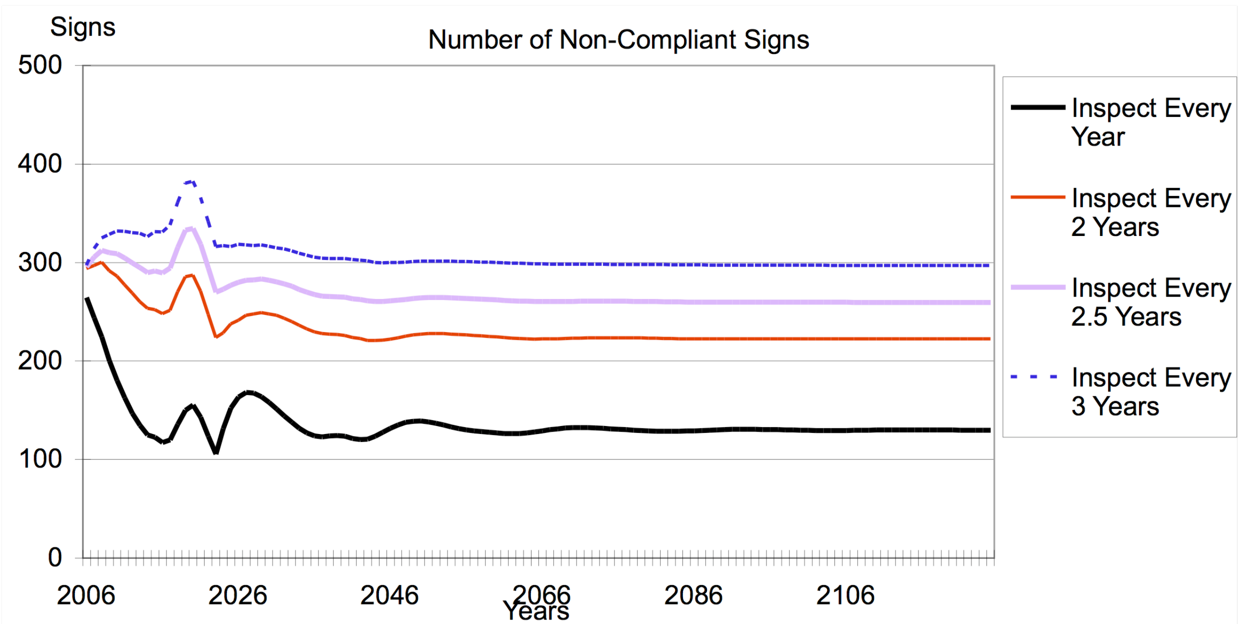
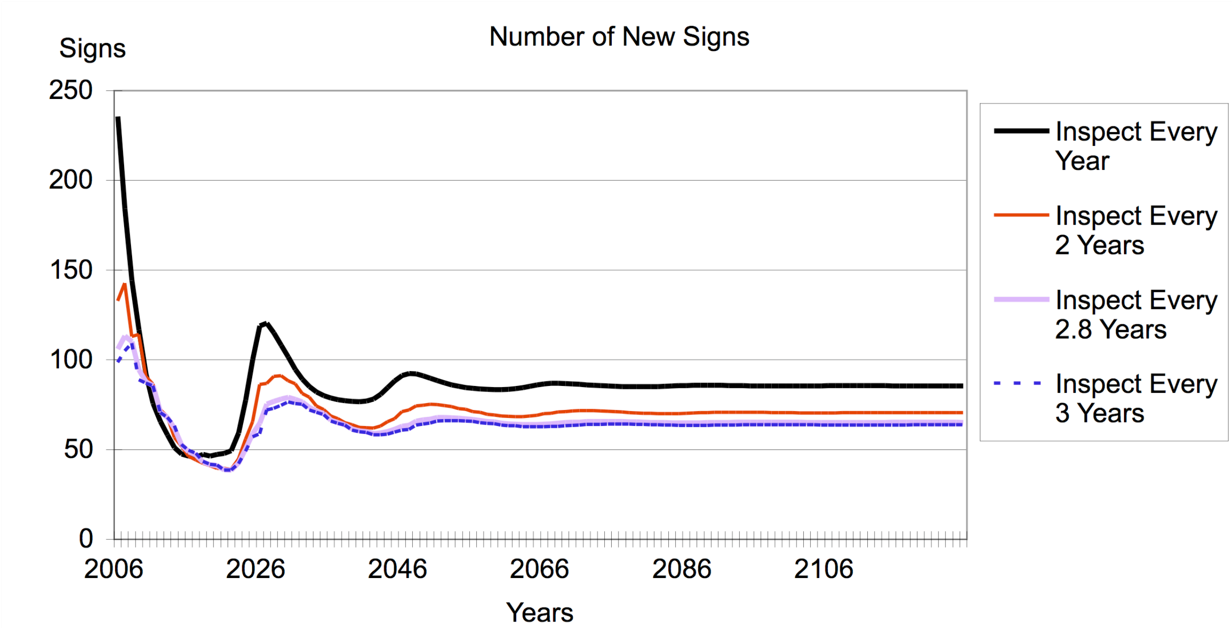


Figure 9.13. Simulation Results for White Signs



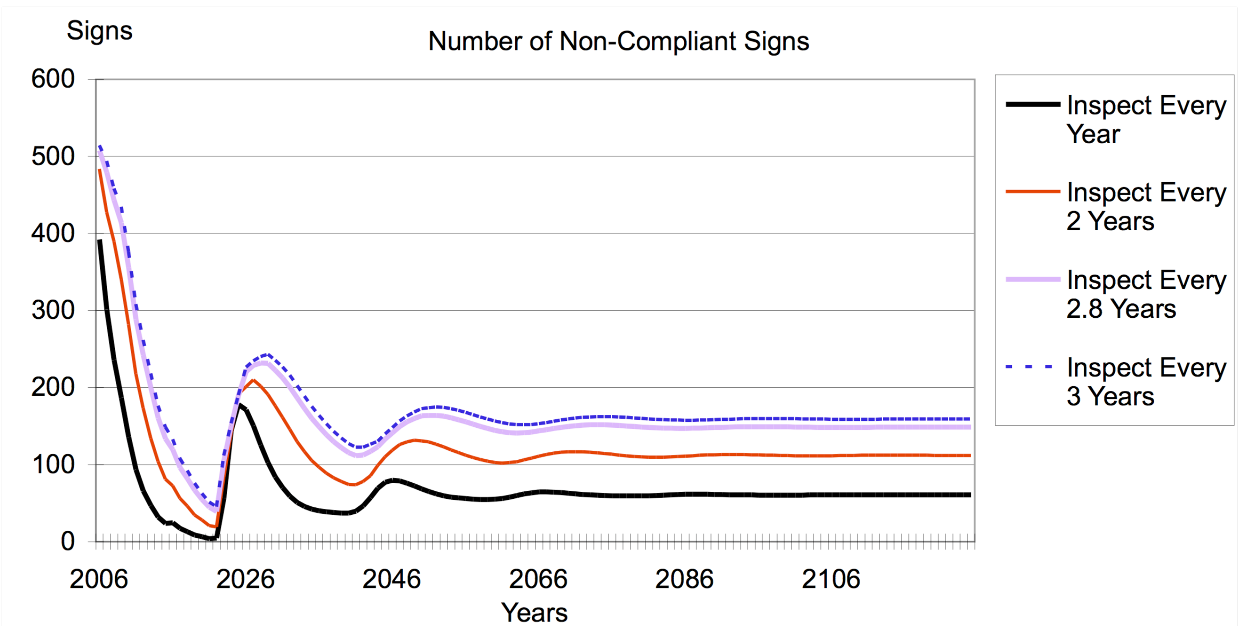
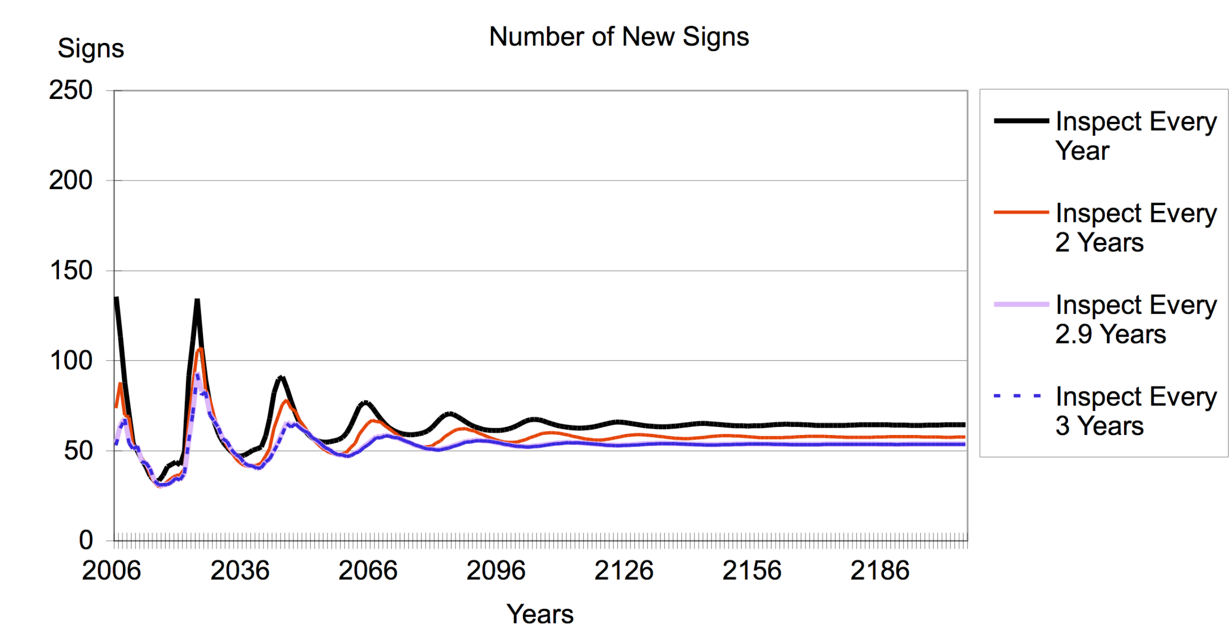


Figure 9.14. Simulation Results for Yellow Signs



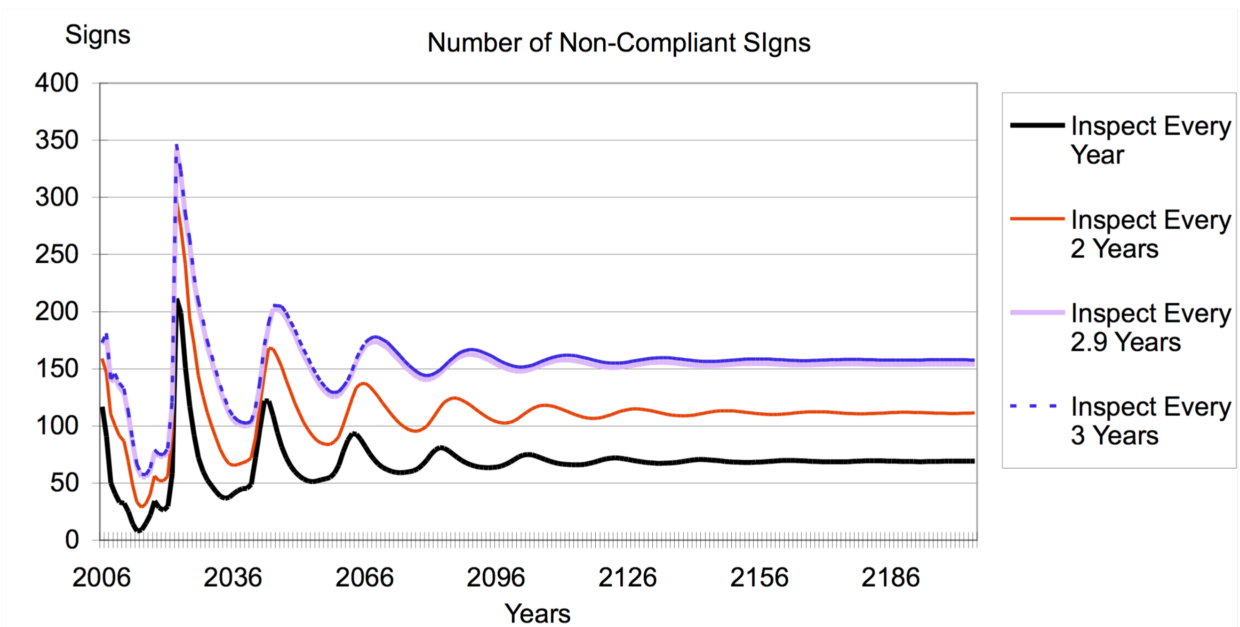
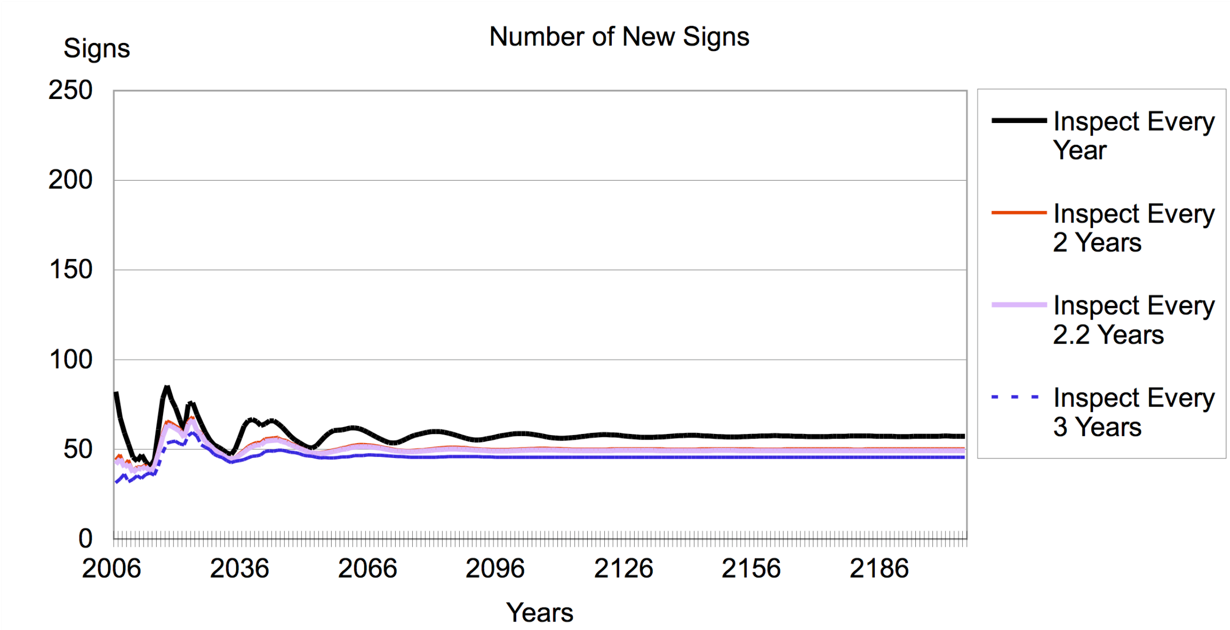


Figure 9.15. Simulation Results for Red Signs



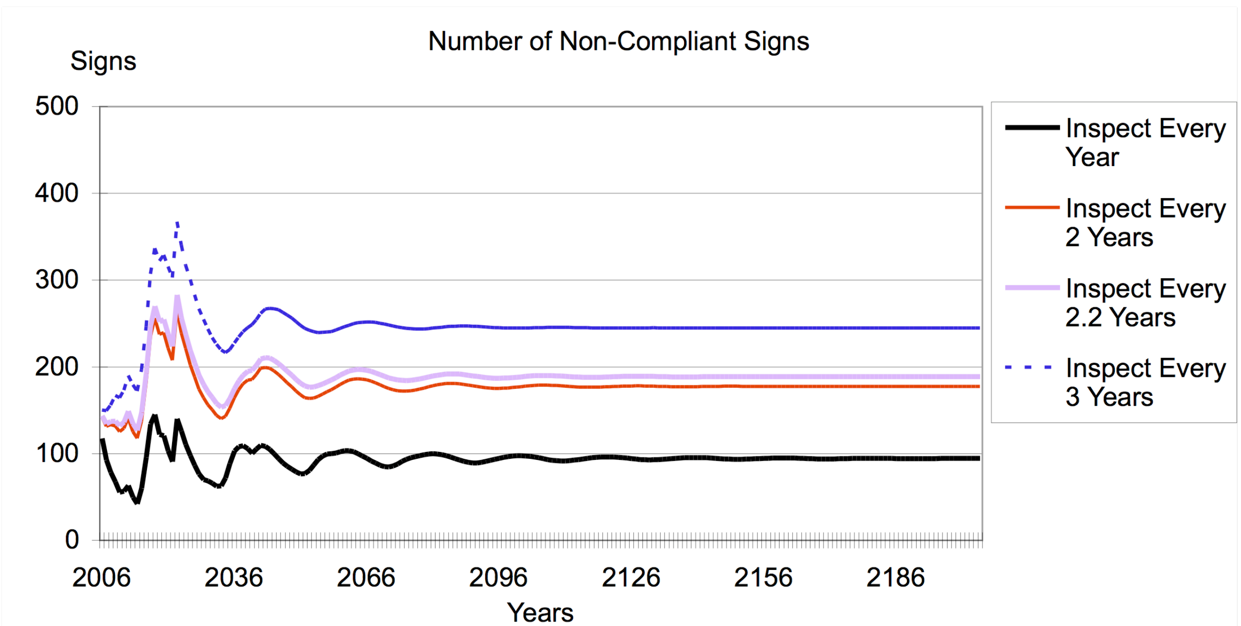


Figure 9.16. Simulation Results for Green Signs

The results of simulation for each color were shown in Figures 9.13 to 9.16. The team offers several comments to explain the results.

Type III simulations were based on the assumption that the lifetime of the signs was 20 years and Type III signs start to be replaced because of low retroreflectivity when they are 18 years old. That is why all sign colors show distinctive changes from 18 to 20 years.

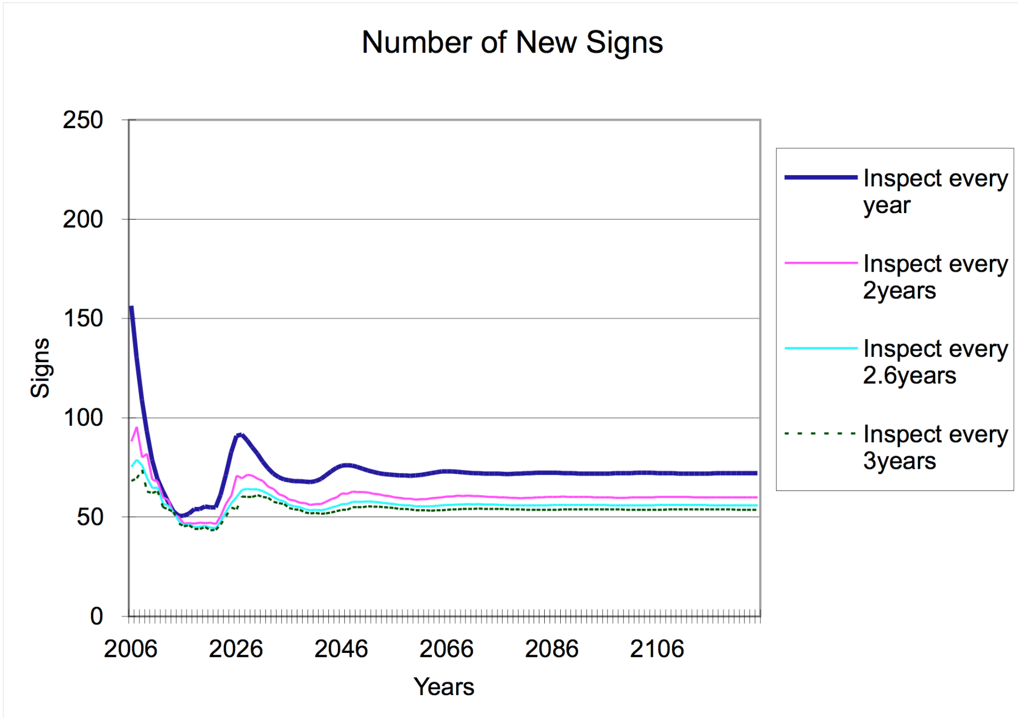
For all sign colors, the numbers of new signs increase as inspections happen more frequently. On the contrary, numbers of below the standard signs decrease with more frequent inspection. White signs show a very stable condition throughout the years. Costs of new signs and numbers of below the standard signs are expected to be consistent if no conditions mentioned above are changed.

Yellow signs are expected to change in cost and condition. New sign costs for yellow signs will decrease and sign condition will improve as below the standard signs go down around 15 percent after 15 years as shown in Figure 9.14. This improvement is mainly from the policy to install Type III signs. The reason why only yellow signs show distinctive improvement from the sign policy is that Type I yellow signs have short lifetimes and relatively lower retroreflectivity compared to other Type I sign colors.

Red signs show around 15 percent of them is below the standard through the years. The reason why red signs have a relatively good situation in the results is that they are usually very critical on the roads and they have been managed with a high priority during nighttime inspection by sign crews.

Green signs also show stable results with relatively good sign conditions. New sign costs are expected to increase a little bit through the years.

As a next step, the team combined the results of all sign color following the same ratio of NCSU field sign data obtained from five divisions in 2005. Figure 9.17 shows the combined results of all signs. Note that only four sign colors were combined to show the tendency of new sign cost and sign condition in the future as other sign colors probably will follow these results.



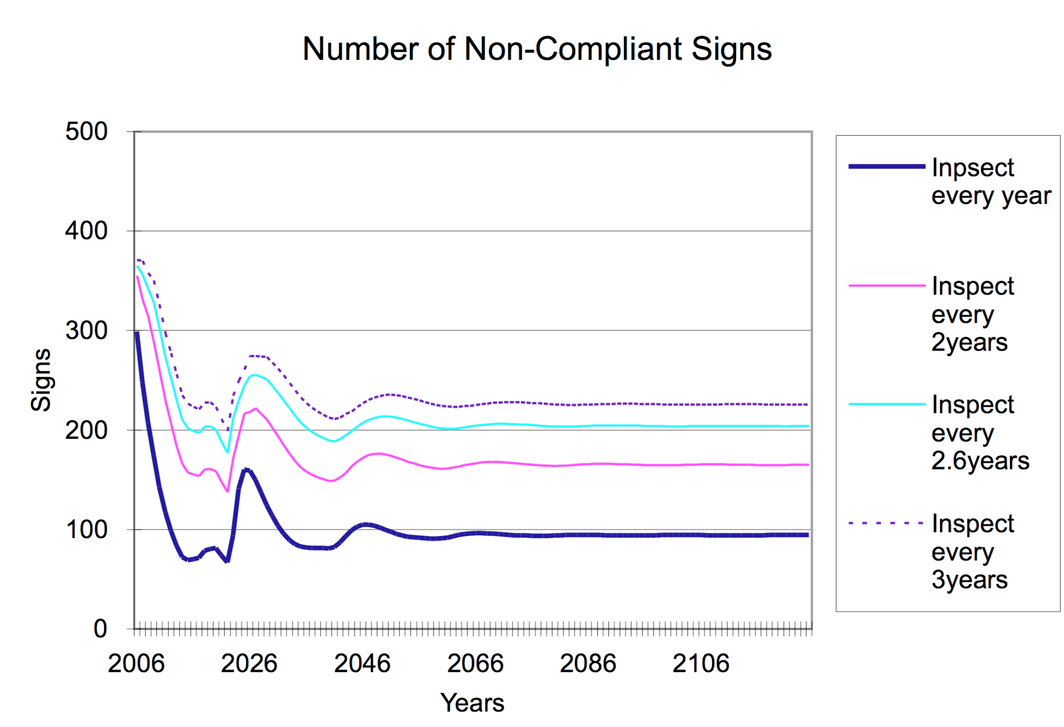


Figure 9.17. Combined Simulation Results for All Signs

Figure 9.17 shows that as Type I signs are replaced with Type III, the general state of signs is expected to improve with lower new sign costs and below the standard signs.

However, around 20 percent signs are predicted to be below the standard signs if there is no change from current sign related conditions. The team examined various situations with the change of sign factors like replacement rate, inspection frequency, sign type transfer ratio, etc. to try to identify the best sign reliability with reasonable cost in the next section.

9.7 Application for Sign Inventory Management

After the team created a sign management system simulation for both Type I and III signs successfully the next step was to apply those simulations to analyze sign management choices for the NCDOT.

In this Section, the problems of the current sign inventory system and some possible scenarios to enhance the condition will be discussed. Moreover, the impact of each scenario in terms of budget and reliability will be also examined through the simulation results.

9.7.1 Current Problem

The FHWA proposed minimum retroreflectivity levels in 2003 to have serviceable signs for nighttime driving as expressed in Table 9.47 [Carson, et. al. 2003].

Table 9.47. FHWA Proposed Minimum Retroreflectivity Levels

Sign Color	Criteria	Sign Type	
		I	III
Black on White	-	50	50
Black on Yellow	For text signs measuring 48 inches or more and all bold symbol signs	*	50
White on Red	Minimum contrast ratio ≥ 3:1 (white / red retroreflectivity)	35 // 7	35 // 7
White on Green	Shoulder	* // 7	120 // 15
* Sheeting type should not be used.			

In Table 9.47, the retroreflectivity for white signs should be more than 50 cd/lx/m^2 for both Type I and Type III signs. In case of yellow signs, Type I should not be used anymore and the retroreflectivity for Type III yellow signs should be more than 50 cd/lx/m^2. As for white signs, the team expected that the retroreflectivity for Type I yellow signs already in the field should be more than 50 cd/lx/m^2 to be reliable on the roads. The background retroreflectivity for Type I red and green signs should be more than 7 cd/lx/m^2 to satisfy the FHWA proposed minimum retroreflectivity levels.

The team examined a total of 1,047 Type I and III signs in five divisions to see how many signs were compliant (satisfied the proposed FHWA standard). As stated previously in Type III sign simulation, Type III signs in NC are relatively young and they currently have sufficient retroreflectivity to comply with the proposed standard according to the NCSU field study. However, in the case of Type I signs, the number of non-compliant signs were large enough to cause nighttime sign management reliability concerns. Table 9.48 shows the percent of non-compliant Type I signs by sheeting color from the NCSU field study.

Table 9.48. Percent of Non-Compliant Type I Signs, by Color

Sign Color	**Minimum Retroreflectivity ($cd/lx/m^2$)**	**Non-Compliant Signs (%)**
White	50	31
Yellow	50	60
Red	7	40
Green	7	24
Total	-	44

In Table 9.48, about 44 percent of Type I signs were non-compliant, indicating that some changes in sign management may be needed.

There could be many ways to improve the current situation. For example, sign crews can be trained to increase their standards for rejecting signs or sign inspection frequency can be increased.

The team proposed various scenarios of sign management and simulated each scenario to see the impact on budget and sign performance in the field. The results of simulation for each scenario were expressed as three categories: sign management cost, above the standard signs, and below the standard signs. Sign management cost was used to analyze impacts on the budget and above and below the standard signs were used to show reliability of signs on the roads.

9.7.2. Sign Inventory Management System Cost Analysis

The team examined sign management system costs, combining the material cost to replace signs and inspection cost. The materials costs are recent data supplied by the NCDOT and are expressed in Table 9.49.

The inspection cost was calculated as $0.55 per sign for visual inspection and $2.80 per sign for inspection using a retroreflectometer. Table 9.50 and 9.51 show how the team calculated sign inspection cost.

In Table 9.50, the total number of signs in NC was from the NCSU sign count study [Kirtley, et. al. 2001, Palmquist, et. al. 2002] and the inspection frequency was acquired from the 2005 NCSU sign field data. Salary and work time for sign crews were assumed. Data from rows 7 to 11 were also from the NCSU field data and 40 signs per hour--the key result--is the sign inspection speed for NCDOT crews.

Table 9.49. Sign Material Cost

Sign Color \ Sign Type	Type I	Type III
White	$25.49	$41.53
Yellow	$23.63	$48.66
Red	$40.16	$65.01
Green	$75.92	$103.77

Table 9.50. Visual Inspection Cost

Row Number	Item	Data	Source of Calculation Using Row Number
1	Total Number of Signs in NC	970,000	[Kirtley, et. al. 2001, Palmquist, et. al. 2002]
2	Inspection Frequency	Every 2.64 years	Section 9.2.3
3	Signs Inspected Every Year	367,000	= 1 / 2
4	Salary for Sign Crew	40,000 ($/year)	Assumed
5	Work Time for Sign Crew	1820 (hours/year)	Assumed
6	Salary for Sign Crew	21.98 ($/hour)	= 4 / 5
7	Nighttime Inspection	7 (nights)	Observed
8	Nighttime Work Time	3 (hours/night)	Observed
9	Sign Crew Members on Each Team	2	Observed
10	Total Nighttime Inspection Time	42 (hours)	= 7 × 8 × 9
11	Total Signs Inspected by Sign Crew	1681	Observed
12	Signs Inspected by Sign Crew	40 (signs/hour)	= 11 / 10
13	Total Inspection Time Required	9,700 (hours)	= 3 / 12
14	Total Inspection Cost	202,000 ($)	= 6 × 13
15	Visual Inspection Cost	0.55 ($/sign)	= 14 / 3

Total inspection cost, $202,000, was obtained by multiplying total inspection time required (Row 13) by salary for sign crew (Row 6) and then visual inspection cost, $0.55 per sign, was calculated dividing total inspection cost (Row 14) by signs inspected per year (Row 3).

Table 9.51. Inspection Cost Using a Retroreflectometer

Row #	Item	Data	Source of Calculation Using Row Number
1	Total Number of Signs in NC	970,000	[Kirtley, et. al. 2001, Palmquist, et. al. 2002]
2	Inspection Frequency	Every 2.64 years	Section 9.2.3
3	Signs Inspected Every Year	367,000	= 1 / 2
4	Salary for Sign Crew Member	40,000 ($/year)	Assumed
5	Work Time for Sign Crew	1820 (hours/year)	Assumed
6	Salary for Sign Crew	21.98 ($/hour)	= 4 / 6
7	Daytime Inspection	7 (days)	Observed
8	Daytime Work Time	8 (hours/day)	Observed
9	Members of the Team	3	Observed
10	Total Daytime Inspection Time	192 (hours)	= 7 × 8 × 9
11	Total Signs Inspected by the Team	1057	Observed
12	Sign Crew Skill Factor	1.5	Assumed
13	Signs Inspected by Sign Crew	8 (signs/person-	= (11 / 10) × 12
14	Total Inspection Time Required	44,500 (hours)	= 3 / 13
15	Cost per Retroreflectometer	10,000 ($)	Section 4.1
16	Number of Divisions	14	NCDOT
17	Teams in Each Division	4	Assumed
18	Total Equipment Cost	560,000 ($)	= 15 × 16 × 17
19	Lifetime of Equipment	10 (years)	Assumed
20	Equipment Cost per Year	56,000 ($/year)	= 18 / 19
21	Total Inspection Cost	1,034,000 ($)	= 6 × 14 + 20
22	Inspection Cost Using a	2.80 ($/sign)	= 21 / 3

In Table 9.51, data from Row 1 to Row 6 follow same sequence expressed in Table 9.50. Data from Row 7 to Row 11 were from the 2005 NCSU field study. The sign crew skill factor (Row 12) was assumed because sign crews were expected to work faster as experts in their job than the NCSU team did in our field study.

Row 13 shows that 8 signs per person-hour are expected if a sign crew inspects signs using a retroreflectometer. Equipment cost was also assumed in Row 15 to Row 20 and was added to the final inspection cost but proved to be relatively insignificant. The final cost to inspect signs using a retroreflectometer was estimated to be $2.80 per sign.

9.7.3 Possible Scenarios

Possible scenarios were created by changing key factors in the simulation, such as replacement rate or inspection frequency. The results for scenarios were expressed as costs for sign management, the number of above the standard signs, and the number of below the standard signs. Some scenarios were combined together to see all possible alternatives that satisfy both budget and reliability for the NCDOT.

9.7.3.1 Inspection Frequency Adjustment

Inspection frequency is one of the key simulation factors as explained previously. Generally speaking, the more frequent the nighttime sign inspection, the less deficient, below the standard signs. However, at the same time the budget for new signs and inspection would be increase with the more frequent sign inspection. Using different inspection frequencies, budget and sign reliability could be analyzed.

For each sign type and color, three types of inspection frequencies were examined: inspect every year, inspect every 2 years, and inspect every 3 years. Table 9.52 shows current inspection frequency found by the NCSU field study and three type of inspection frequencies used in simulation scenarios.

9.7.3.2 Elevation of Sign Crew's Retroreflectivity Limit

A sure way to follow the proposed FHWA minimum standard is to reject all signs below the standard during nighttime sign inspection. However, that case will cost more and might be beyond the financial resources devoted to sign maintenance by the NCDOT. The simulation program enables the DOT to examine the budget and reliability impacts of any change in the sign crews' retroreflectivity limit.

Before the team examined the rejection of all signs below a certain retroreflectivity, the team first analyzed current retroreflectivity practice of NCDOT sign crews based on the field data from five divisions. Figure 9.18 shows the current retroreflectivity practice of sign crews for Type I white signs.

Table 9.52. Current Sign Inspection Frequency and Scenarios

Sign Type	Sign Color	Current Inspection Frequency (Year)	Inspection Frequency of Scenario		
			Scenario 1	Scenario 2	Scenario 3
I	White	2.54	Every year	Every 2-year	Every 3-year
	Yellow	2.83	Every year	Every 2-year	Every 3-year
	Red	2.98	Every year	Every 2-year	Every 3-year
	Green	2.61	Every year	Every 2-year	Every 3-year
III	White	2.27	Every year	Every 2-year	Every 3-year
	Yellow	2.54	Every year	Every 2-year	Every 3-year
	Red	2.88	Every year	Every 2-year	Every 3-year
	Green	1.74	Every year	Every 2-year	Every 3-year

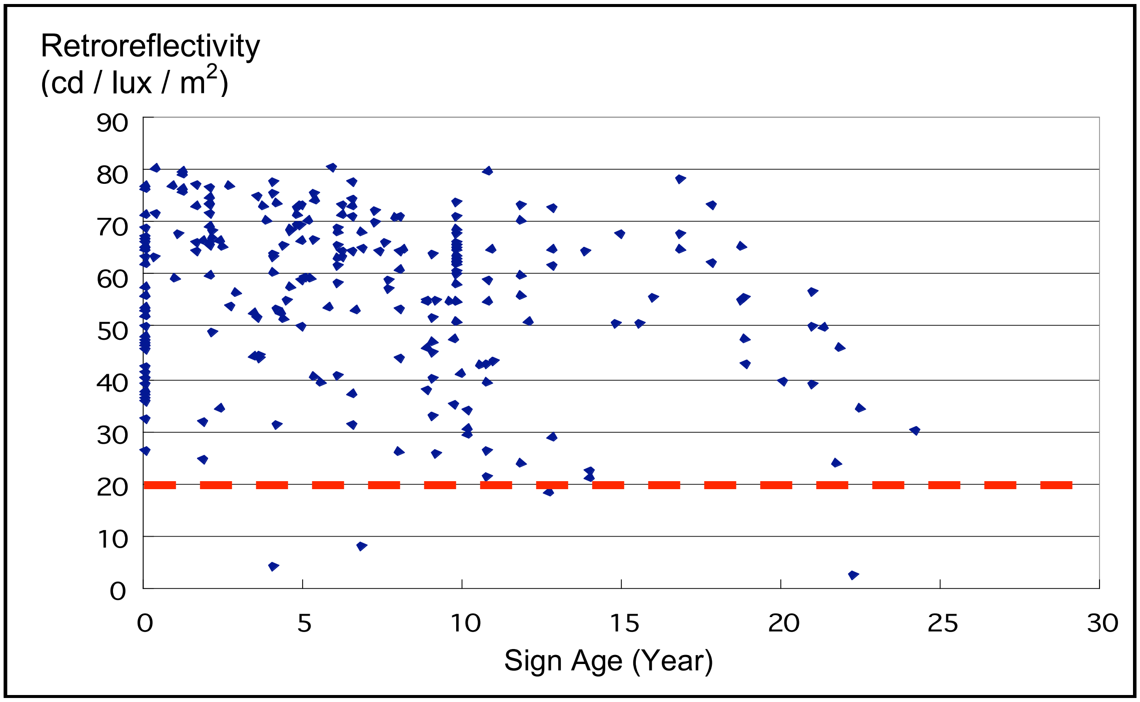


Figure 9.18. Type 1 White Sign Data

In Figure 9.18, Type I white signs not rejected by sign crews in 2005 nighttime sign inspection were expressed with their retroreflectivity. According to the signs in Figure 9.18, it is reasonable to say that current retroreflectivity practice for Type I white sign is 20 cd/lx/m^2 because there is almost no sign below that retroreflectivity value.

The team then created scenarios to elevate the practice to improve sign retroreflectivity. These scenarios are related to the one of key factors in the simulation, replacement rate, because signs below a certain retroreflectivity will be replaced so the replacement rate for those sign groups will be also modified.

Table 9.53 shows how replacement rates were changed for scenarios involving Type I white signs. In scenario 1 of Table 9.53, the assumption of a retroreflectivity limit of 30 cd/lx/m^2 was made so that all signs below 30 cd/lx/m^2 are rejected during nighttime sign inspection. The team changed the NCSU field data that all signs below 30 cd/lx/m^2 retroreflectivity value were rejected as original 7 signs became 24 signs rejected because of low retroreflectivity out of 37 undamaged signs. Hence, the replacement rate of the last group (36.0 ~) in scenario 1 of Table 9.53 changed from 18.9 percent (7 / 37 = 18.9) to 64.9 (24 / 37 = 64.9) percent from the result of calculation of modified data. Following the same idea, replacement rates for scenario 2 with a retroreflectivity limit of 40 cd/lx/m^2 and scenario 3 with a retroreflectivity limit of 50 cd/lx/m^2 were also expressed in Table 9.53.

Table 9.53. Replacement Rates of Scenarios for Type I White Signs

Retroreflectivity Range (cd/lx/m^2)	>88.7	80.0	73.4	69.0	66.0	63.7	59.8	55.3	51.0	44.3	36.0	<36.0
Original Replacement Rate (%)	0.0	0.0	0.0	0.0	0.0	4.2	4.2	4.2	8.0	8.0	8.0	18.9
Scenario 1 – Replacement Rate (%)	0.0	0.0	0.0	0.0	0.0	4.2	4.2	4.2	8.0	8.0	8.0	64.9
Scenario 2 – Replacement Rate (%)	0.0	0.0	0.0	0.0	0.0	4.2	4.2	4.2	8.0	8.0	48.1	100
Scenario 3 – Replacement Rate (%)	0.0	0.0	0.0	0.0	0.0	4.2	4.2	4.2	8.0	82.6	100	100

Table 9.54 shows current retroreflectivity practices by sign crews and different retroreflectivity limits for Type I other sign colors to be used in other scenarios.

The team also simulated two different inspection methods: visual inspection and inspection using a retroreflectometer. The results of the simulation were the same except sign management costs, which were $0.55 per sign for the visual inspection and $2.80 per sign for the inspection using a retroreflectometer. Because the team assumed that the visual inspection could be performed with exact retroreflectivity limit like using retroreflectometers, the results of sign condition are same for both the visual inspection and inspection using retroreflectometers. The results of each simulation are provided in Section 9.7.4.

Table 9.54. Retroreflectivity Limit of Scenarios for Type I Signs

Sign Color	Current Practice (cd/lx/m2)	Revised Retroreflectivity Limit (cd/lx/m2)		
		Scenario 1	Scenario 2	Scenario 3
White	20	30	40	50
Yellow	20	30	40	50
Red	4	5	6	7
Green	4	5	6	7

9.7.3.3 Ratio Change of Type I and III Signs

According to the current sign policy of the NCDOT, most Type I signs are replaced by Type III when they are rejected because of low retroreflectivity, damage, etc. Around 89 percent of Type I signs rejected in 2005 were substituted for Type III in 2006 field data. Following up on this policy, the team examined scenarios with the percent changes as expressed in Table 9.55.

Table 9.55. Type I to Type III Ratio Change Scenarios

Sign Color	Percent of Type I Signs replaced with Type III		
	Scenario 1 (Current)	Scenario 2	Scenario 3
White	66 %	100 %	0 %
Yellow	94 %	100 %	0 %
Red	92 %	100 %	0 %
Green	50 %	100 %	0 %

In Table 9.55, Scenario 1 represents current sign replacement conditions from the data collected in 2005 and 2006. Scenario 2 changes all Type I signs to Type III and Scenario 3 changes no Type I signs to Type III whenever they are replaced in the field. White and green signs are expected to show distinctive differences in the results because the current percent of Type I signs replaced by Type III is relatively low compared to yellow and red signs. The results of scenarios are provided in Section 9.7.4.

9.7.3.4 Total Replacement

The team also examined the scenario that signs are replaced without inspection. Instead, signs would be replaced when their age exceeds warranty periods or when their retroreflectivity value slipped under the proposed FHWA minimum standard according to our simulation model. Table 9.56 shows the age of signs replaced in the total replacement scenario.

Table 9.56. Age of Signs Replaced in Total Replacement Scenario

Type and Condition / Sign Color	Scenario 1 Replacement by Retroreflectivity		Scenario 2 Replacement by Warranty Period	
	Type I	Type III	Type I	Type III
White	13	18	8	13
Yellow	4	18	8	13
Red	6	18	8	13
Green	12	18	8	13

In Table 9.56, Scenario 1 shows a condition that signs are replaced when they have retroreflectivity value below the minimum standard. For the example of a Type I white sign, the retroreflectivity value is typically greater than 50 cd/lx/m^2, which is the proposed FHWA minimum standard, until the signs are 12 years old, so Scenario 1 was made to replace all Type I white signs at the age of 13 years.

Scenario 2 follows the warranty period of 7 years for Type I signs and 12 years for Type III signs. Therefore, all Type I signs that are 8 years old and all Type III signs that are 13 years old will be replaced regardless of their retroreflectivity value. We should expect high costs and almost perfect sign performance relative to the FHWA proposed minimum values with the total replacement scenario; the results are provided in Section 9.7.4.

9.7.4 Results of Scenarios

In the beginning of the project the team created retroreflectivity-based and age-based simulations separately, focusing on either retroreflectivity or sign age as a key factor to judge whether signs were deficient. The team also simulated each sign type and color individually. After comparing the results from simulations and the field data that the NCSU team collected in 2005, the team selected retroreflectivity-based simulation as the most promising way to generate realistic and useful results for the NCDOT.

The simulation validation was completed by comparing the simulation results with field data and financial information. After the successful validation, the team combined the Type I and III simulations together for each sign color to simulate more closely NC conditions.

As a result, the team created simulation for each sign color: white, yellow, red, and green. Using the simulations, the team examined various scenarios changing factors in the simulation such as replacement rate, inspection frequency, and percentage of new Type III signs.

The results of each simulation scenario were expressed in three categories: sign management cost, the number of above the proposed FHWA minimum standard signs, and the number of below the proposed FHWA minimum standard signs. The sign management cost consists of material cost for new signs and inspection cost. All simulation scenarios began with a population of 1,000 total signs that replicated the conditions of signs in the field in NC in 2005. Simulations for white and yellow signs lasted for 120 years and red and green signs lasted for 200 years, which is long enough for the population to stabilize (the results do not change much year-to-year beyond those years) so we can see a reasonable "average" emerge.

Examining the results of each scenario, it is possible to estimate the impact of each modification in terms of budget and sign condition for the NCDOT. The results of scenarios are shown from Figure 9.19 to 9.38. Note that in creating these results we only changed one factor at a time. For instance, for Figures 9.19 to 9.22 we only changed the inspection frequency while leaving all else as in current NCDOT policies.

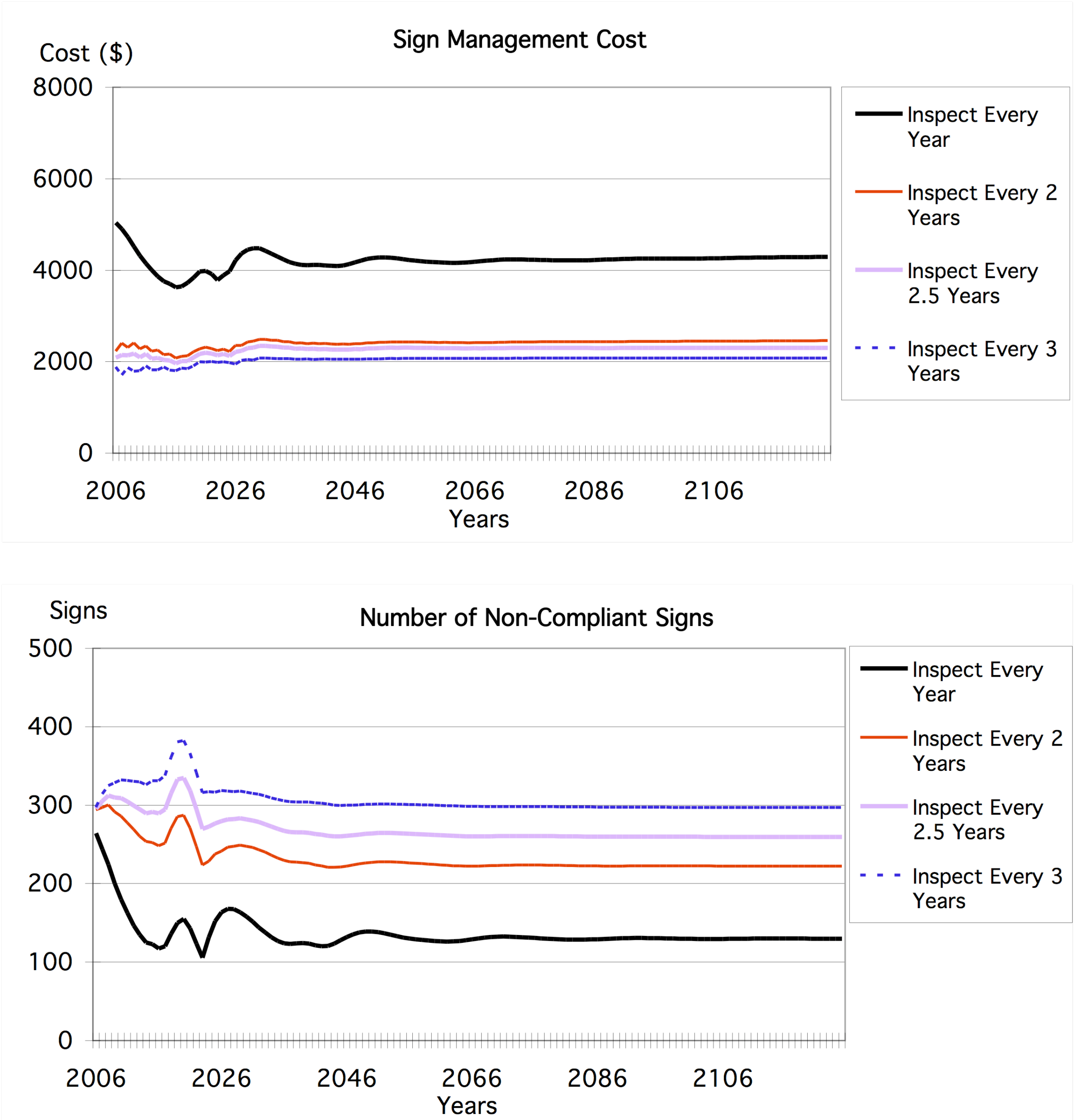


Figure 9.19. Inspection Frequency Adjustment - White Signs

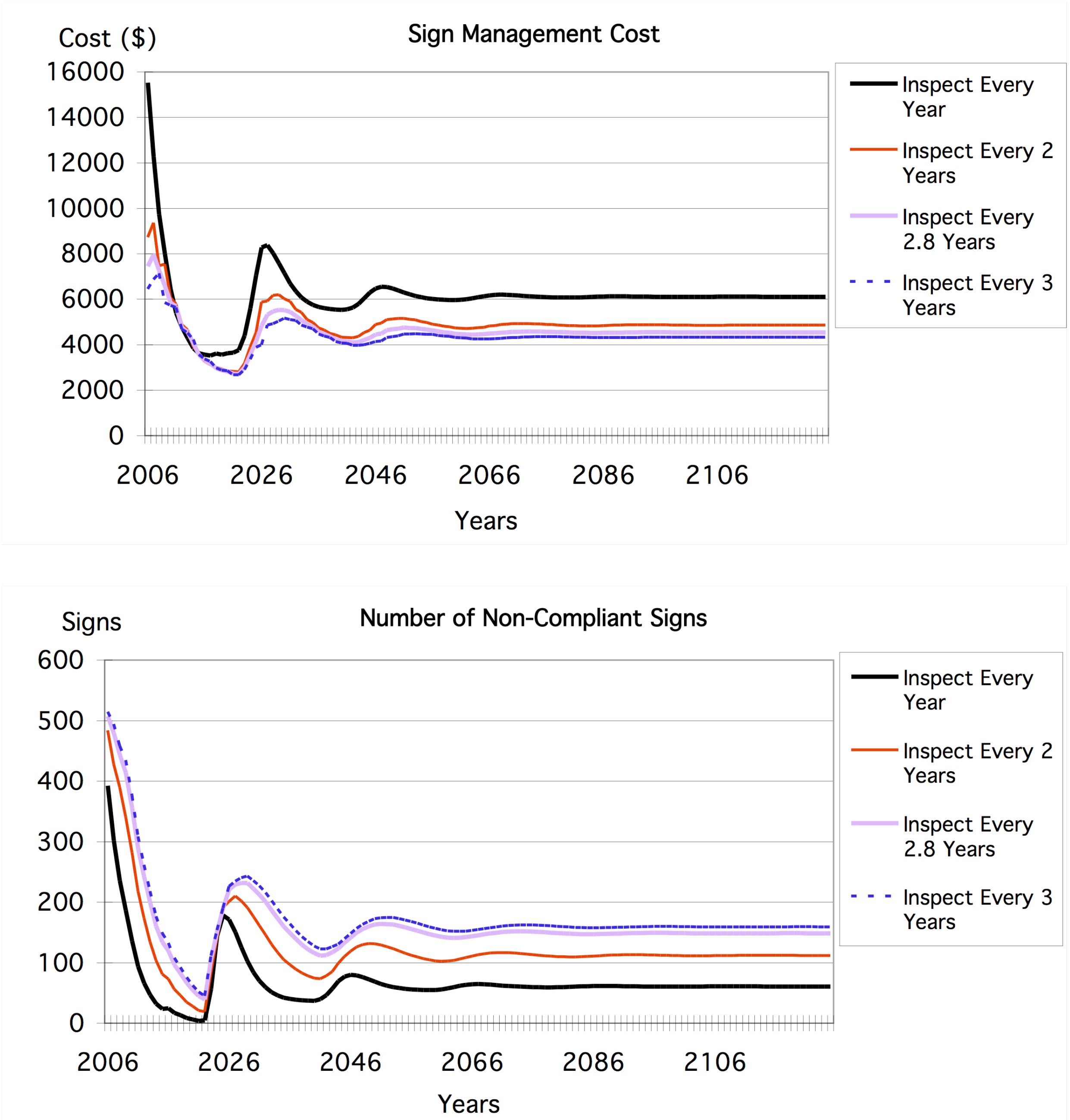
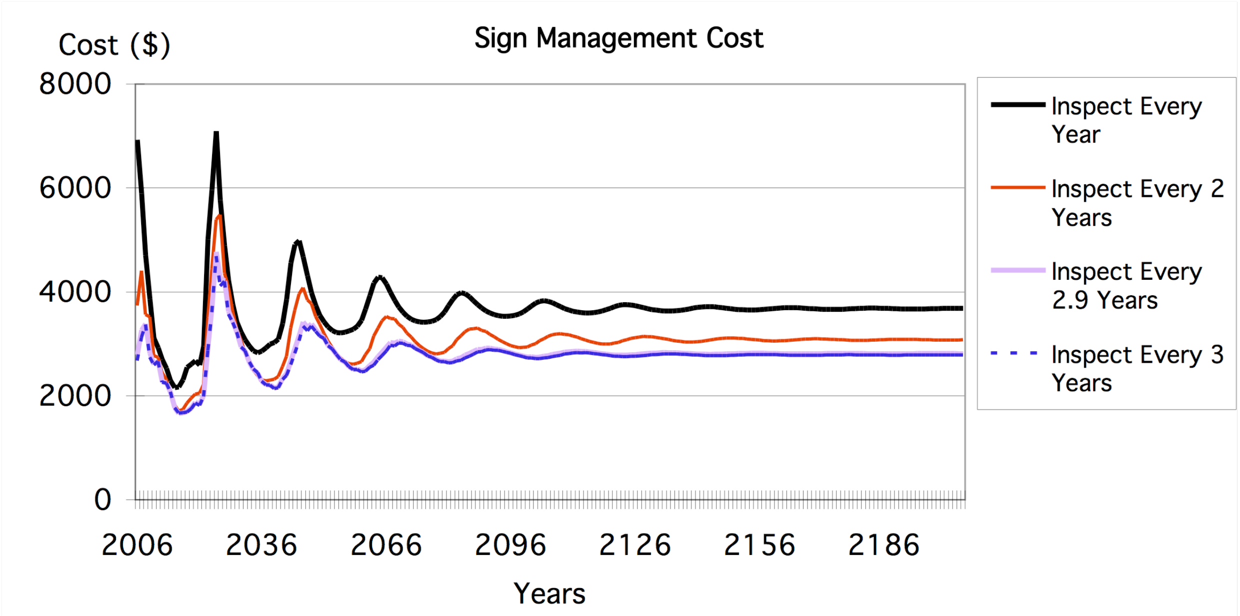


Figure 9.20. Inspection Frequency Adjustment - Yellow Signs



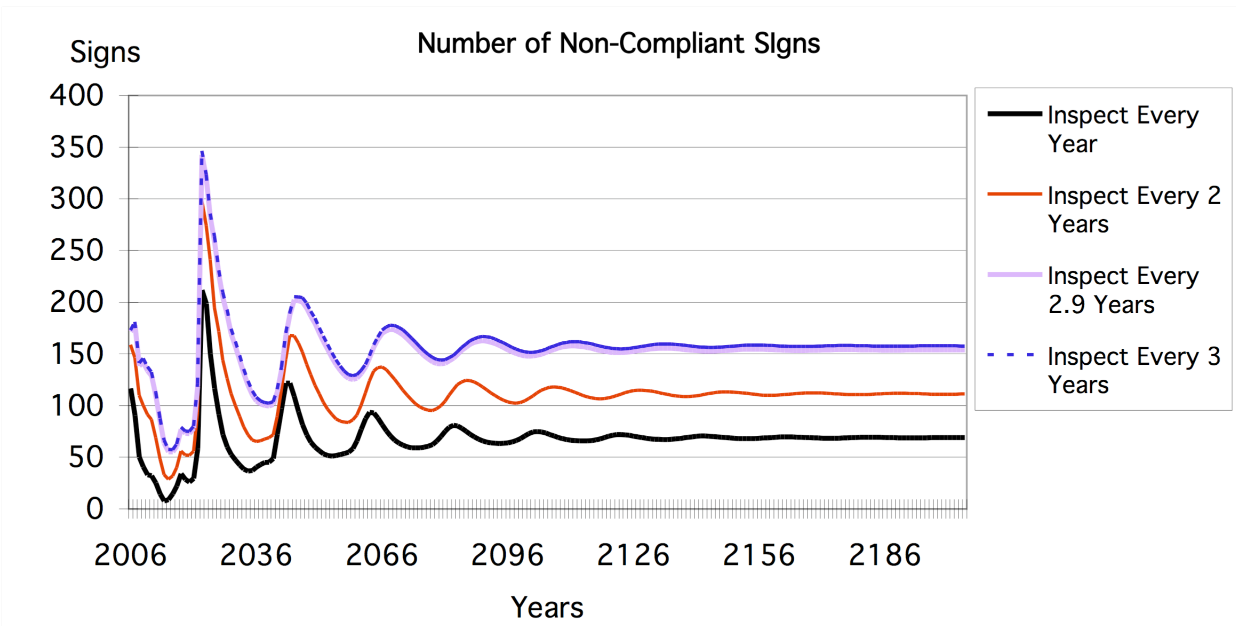
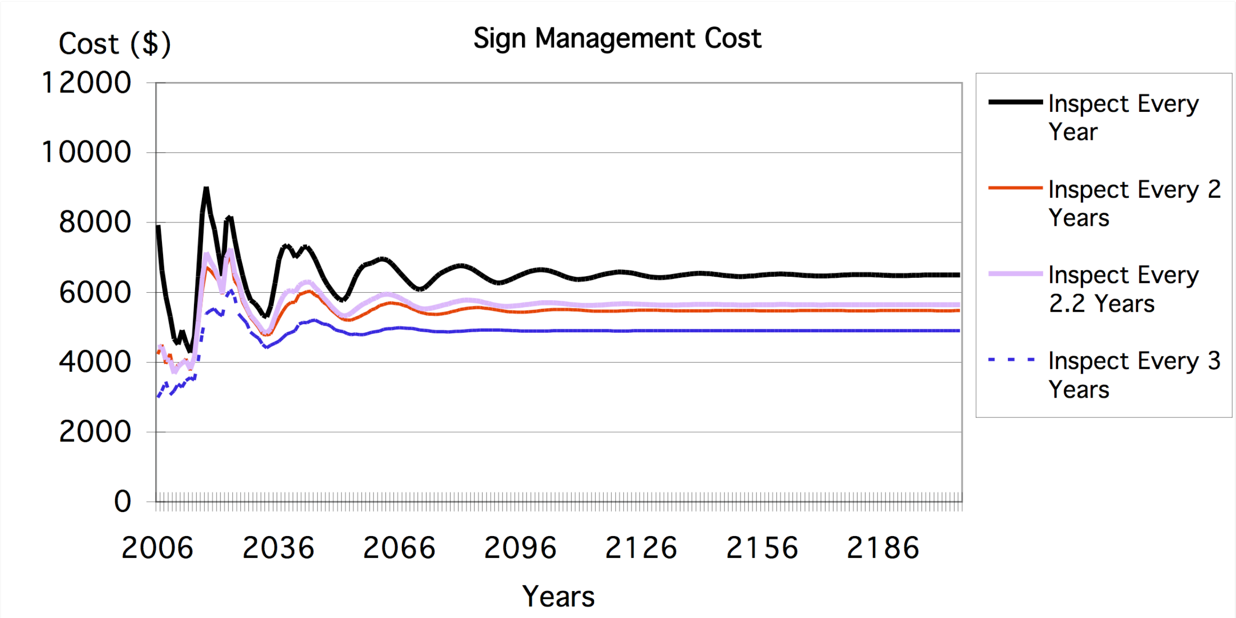


Figure 9.21. Inspection Frequency Adjustment - Red Signs



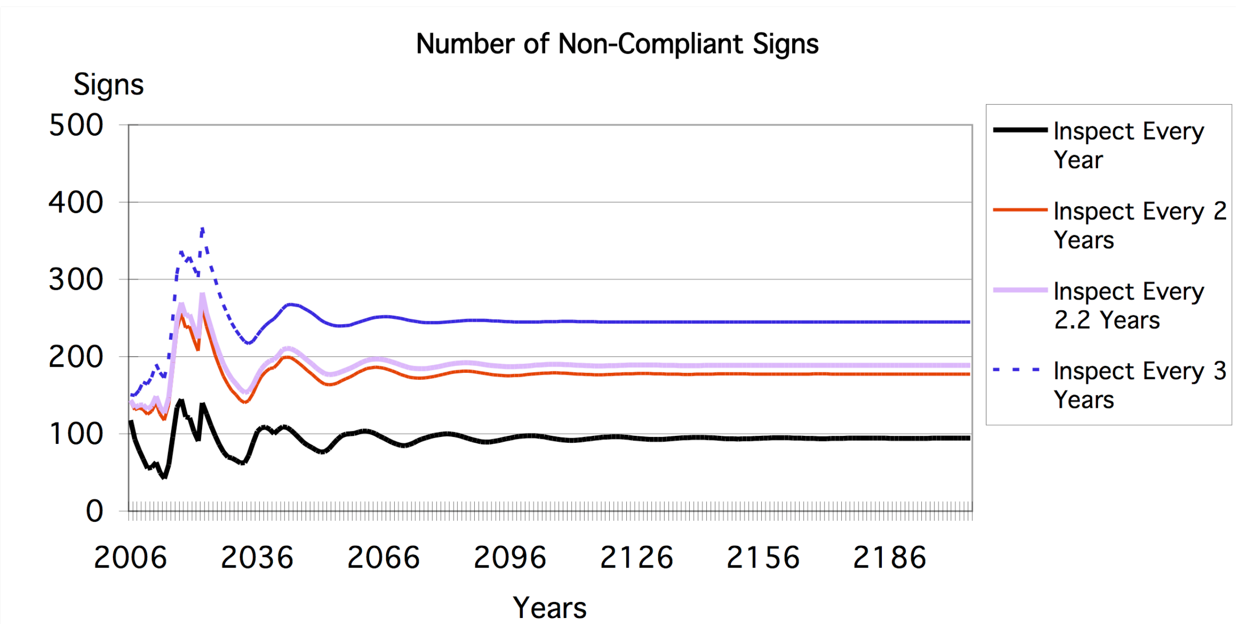
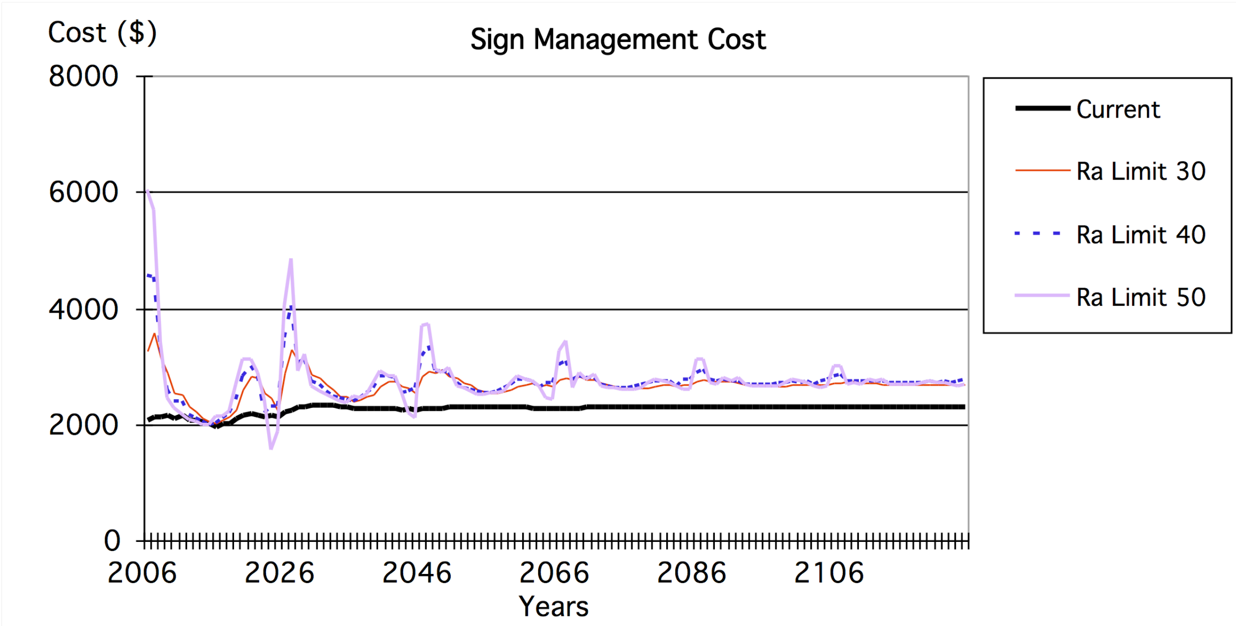


Figure 9.22. Inspection Frequency Adjustment - Green Signs



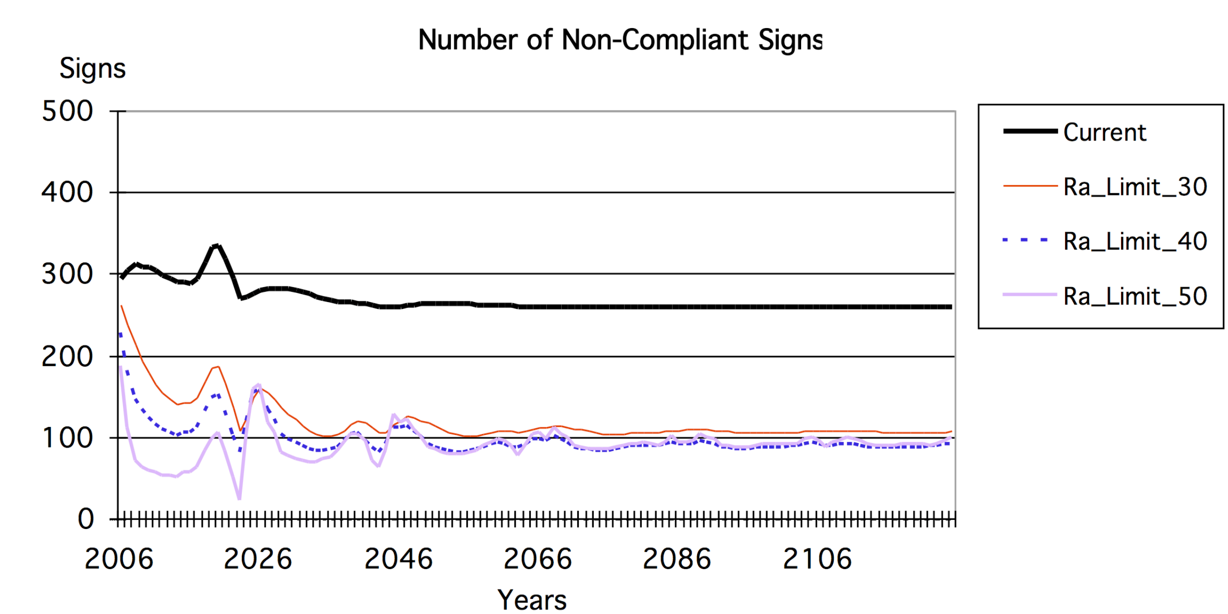
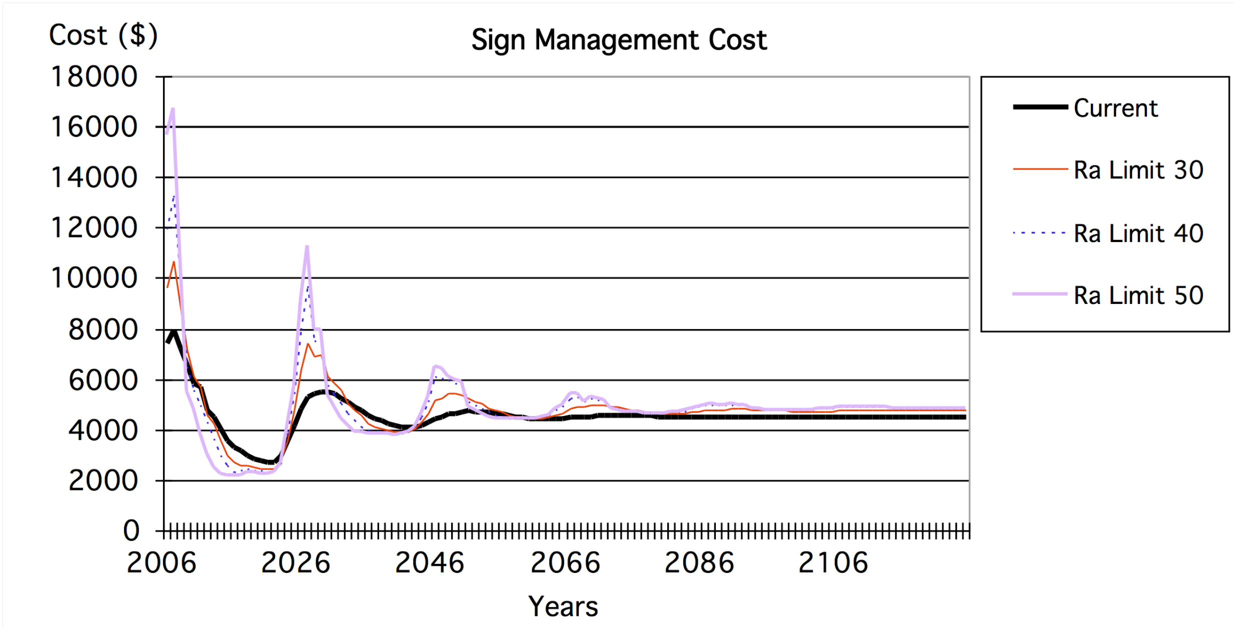


Figure 9.23. Changing Visual Inspection Rejection Threshold - White Signs



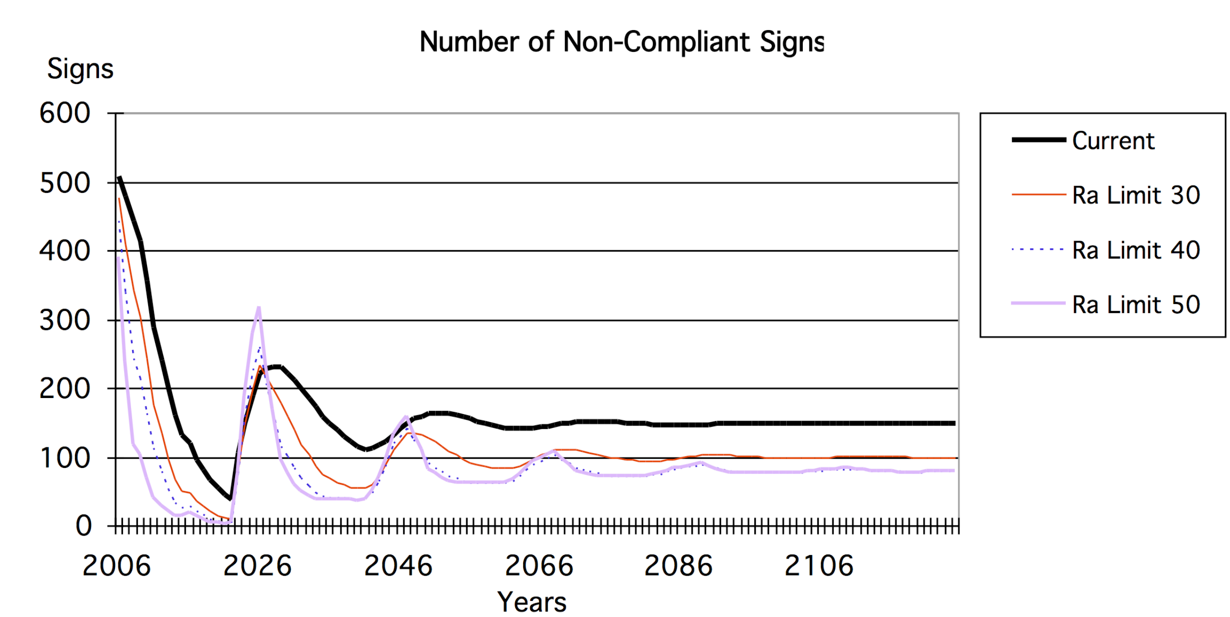


Figure 9.24. Changing Visual Inspection Rejection Threshold - Yellow Signs

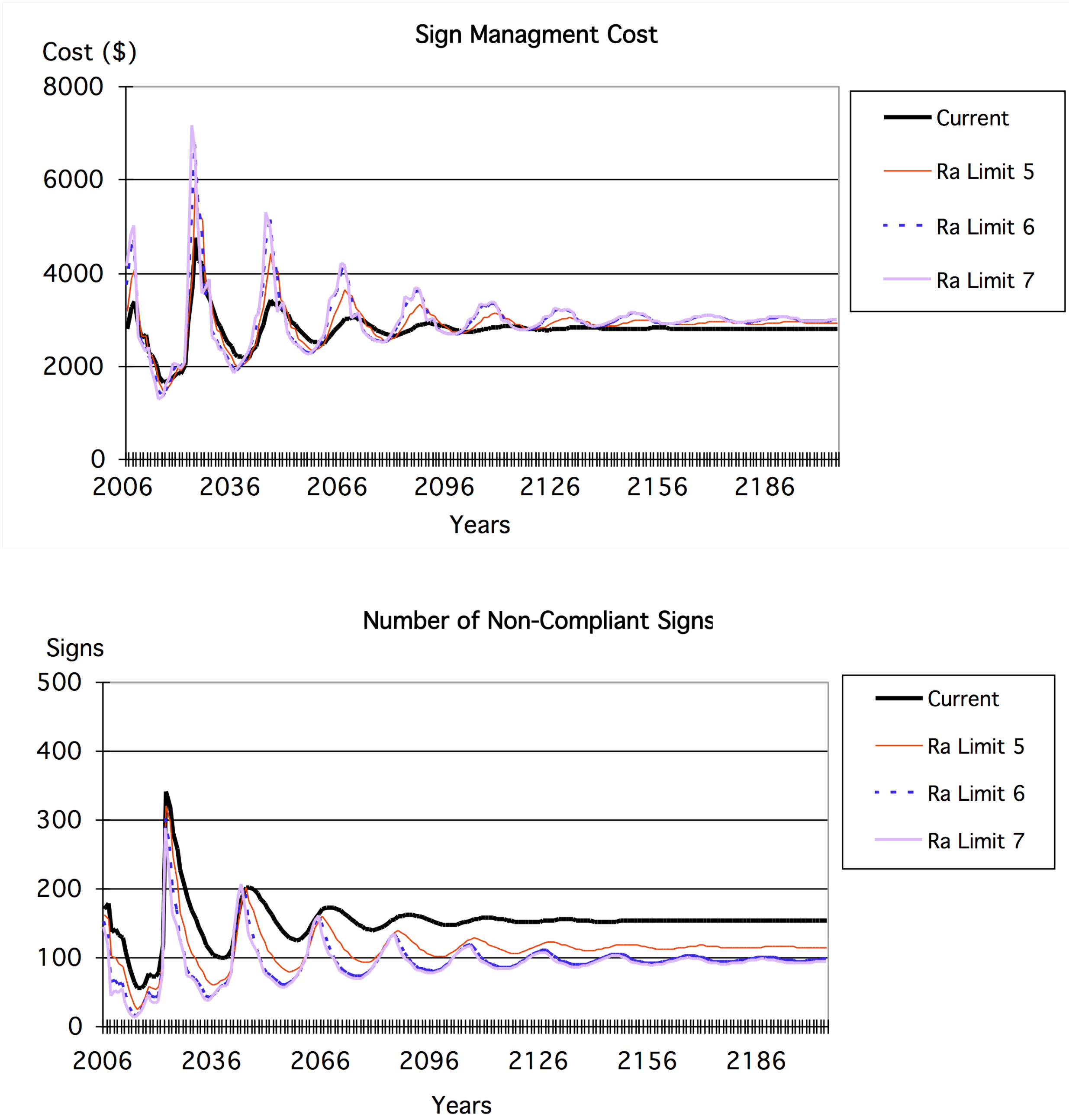


Figure 9.25. Changing Visual Inspection Rejection Threshold - Red Signs

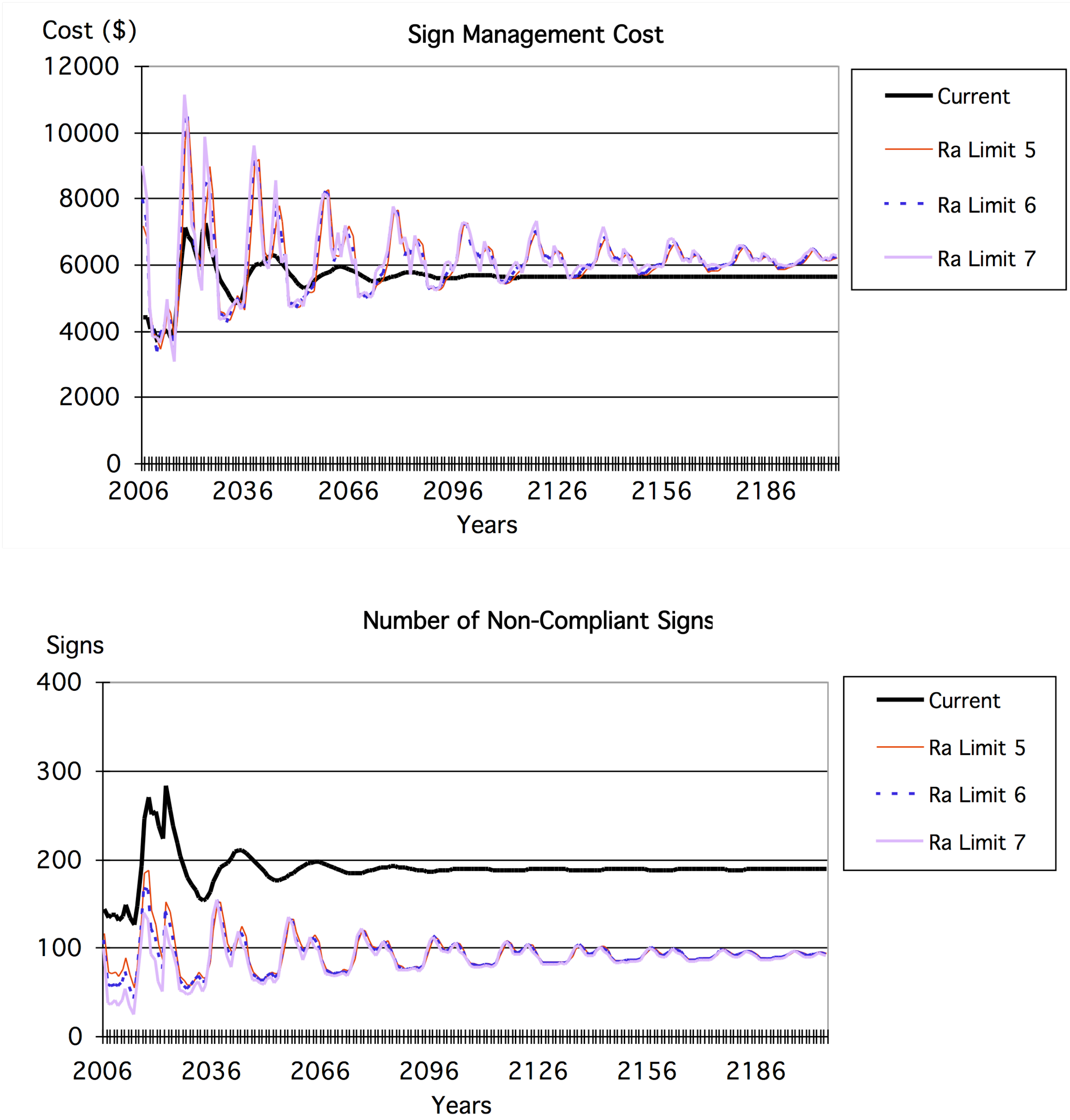
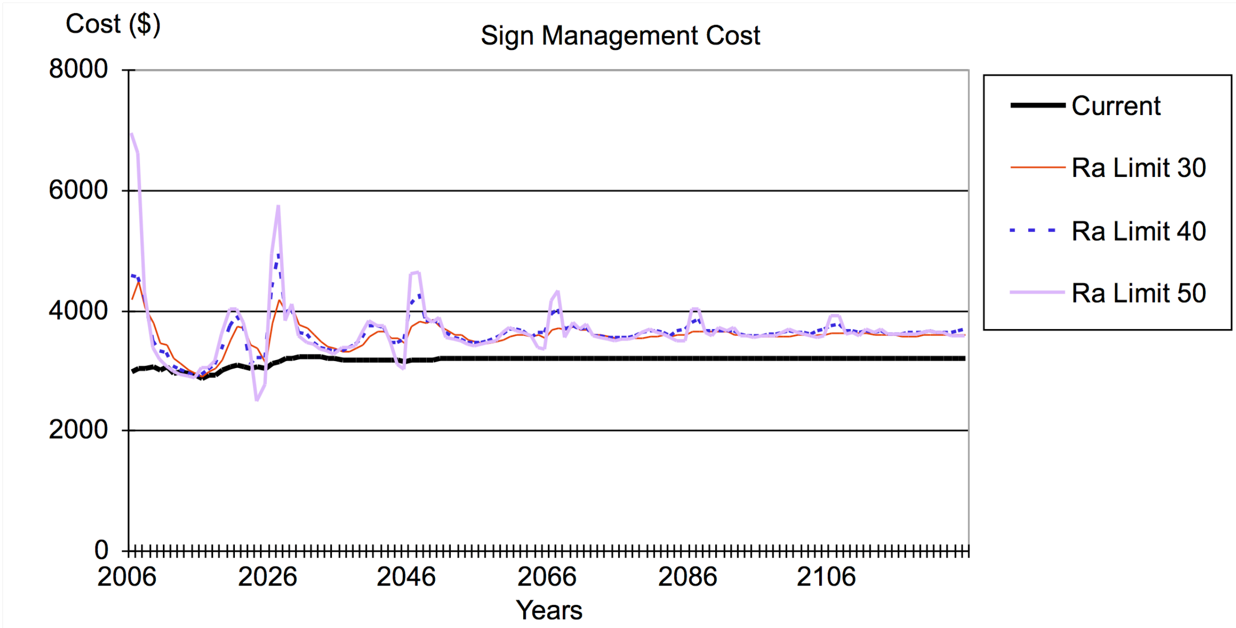


Figure 9.26. Changing Visual Inspection Rejection Threshold - Green Signs



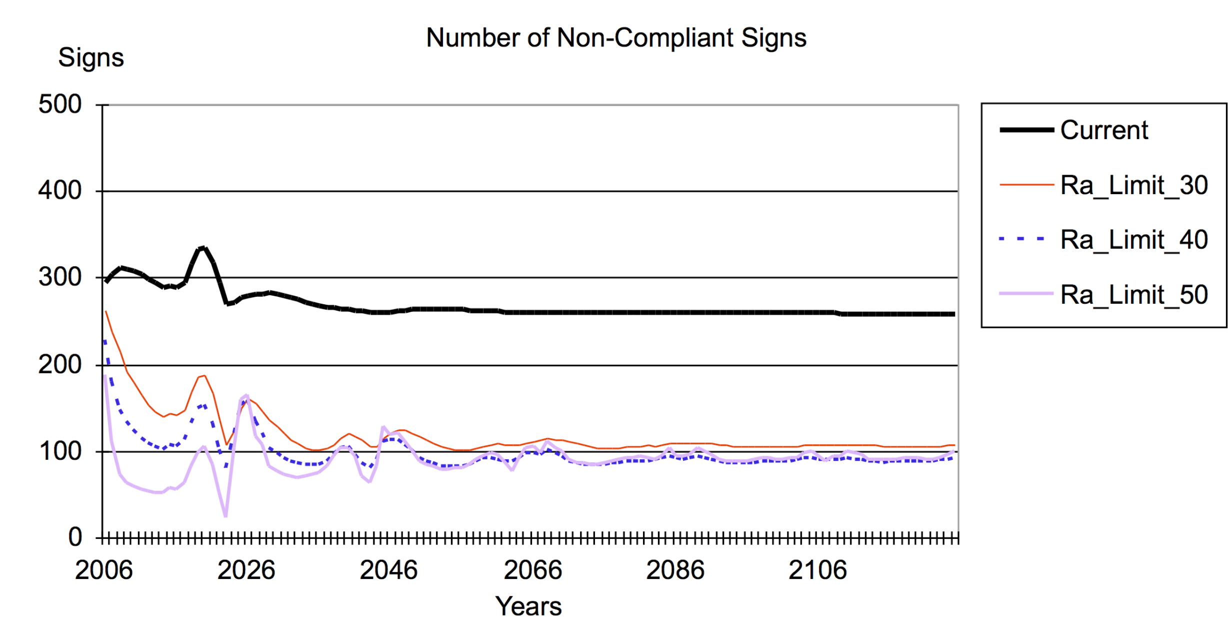
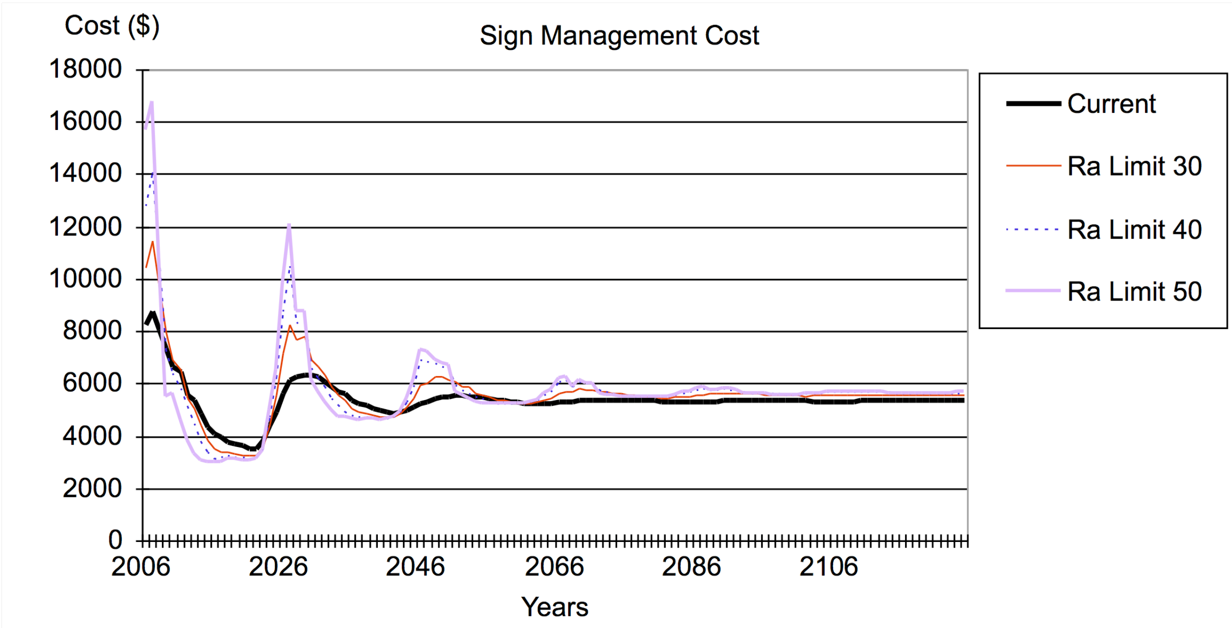


Figure 9.27. Changing Inspection Rejection Threshold while Using a Retroreflectometer - White Signs



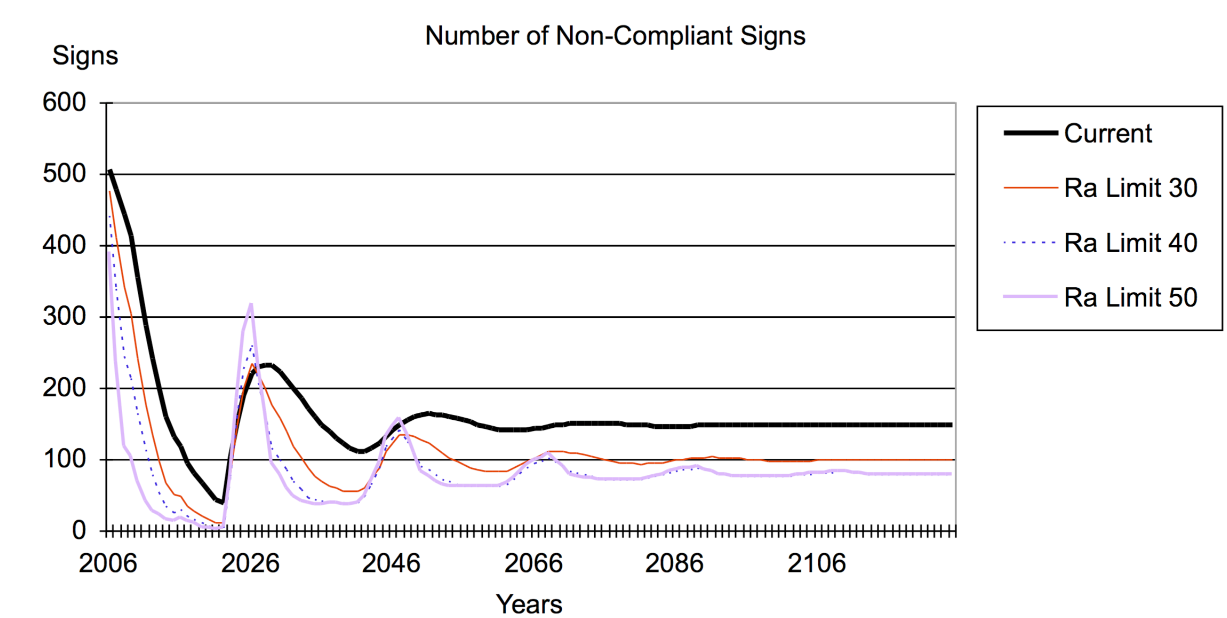


Figure 9.28. Changing Inspection Rejection Threshold while Using a Retroreflectometer - Yellow Signs

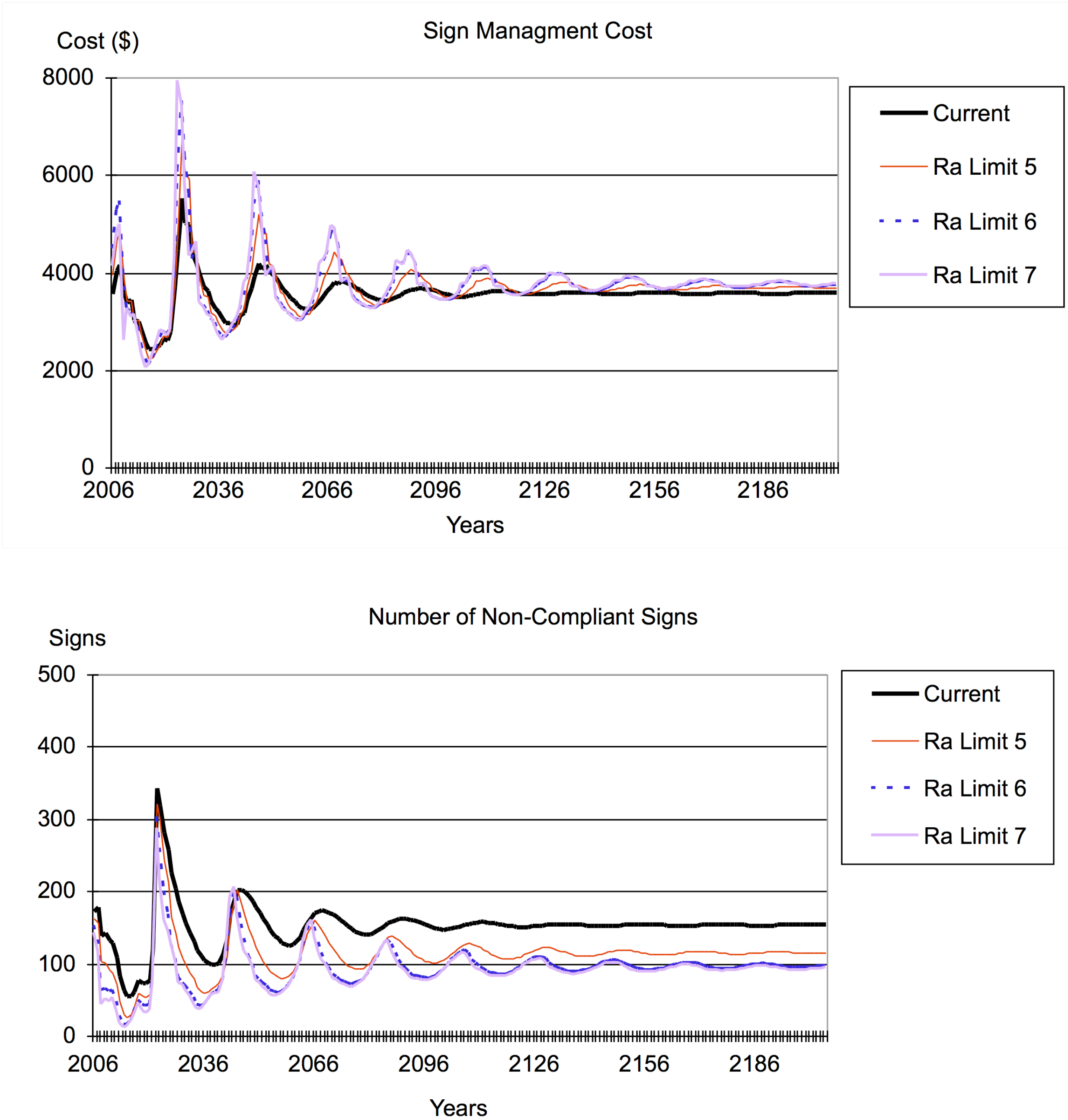
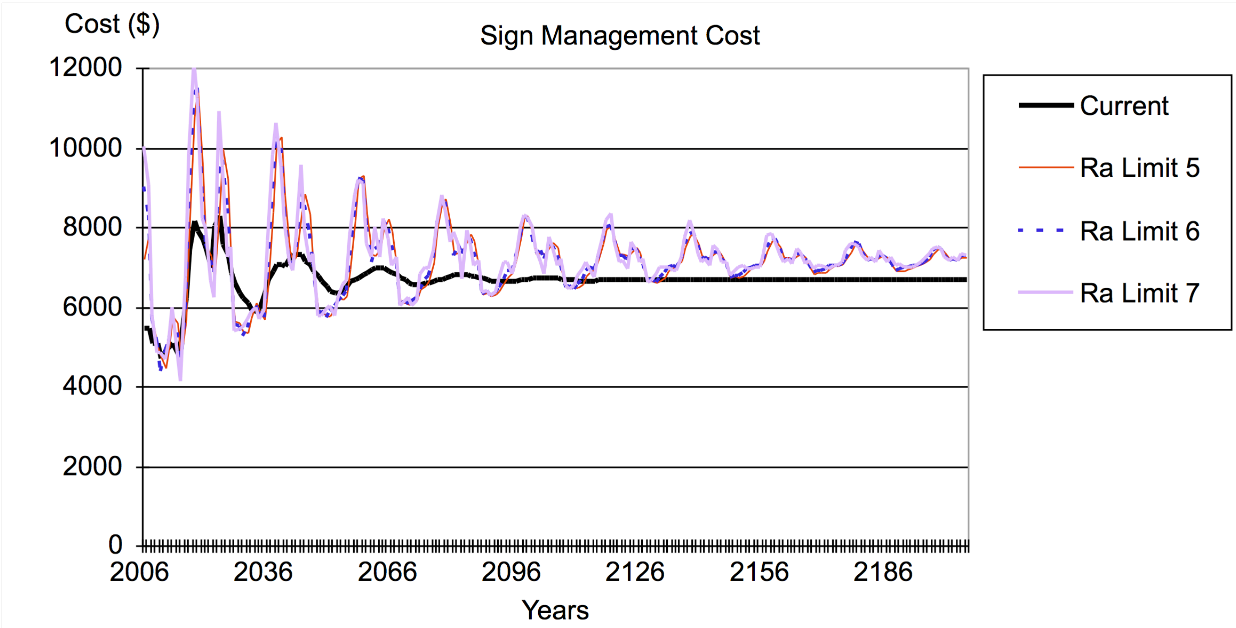


Figure 9.29. Changing Inspection Rejection Threshold while Using a Retroreflectometer - Red Signs



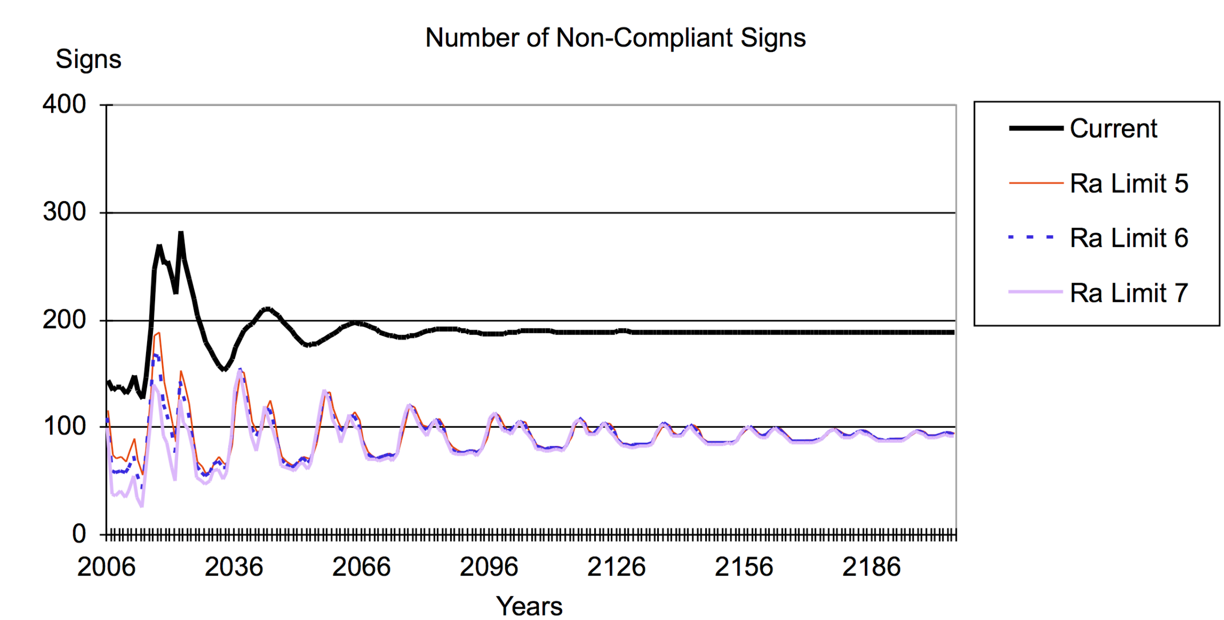
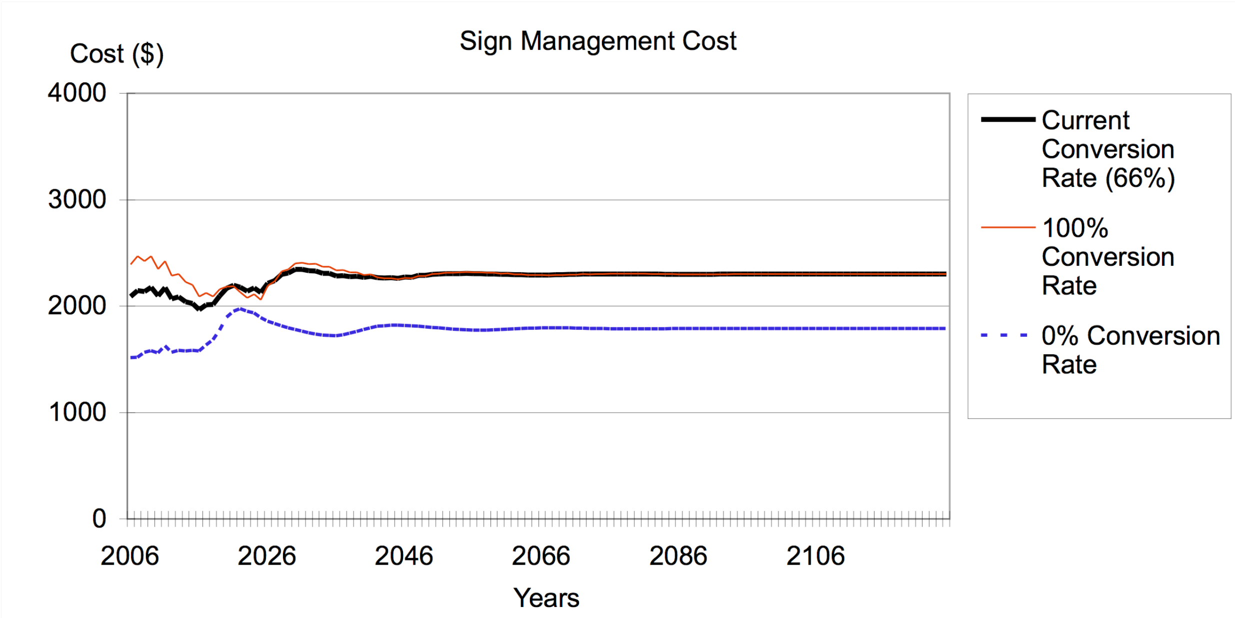


Figure 9.30. Changing Inspection Rejection Threshold while Using a Retroreflectometer - Green Signs



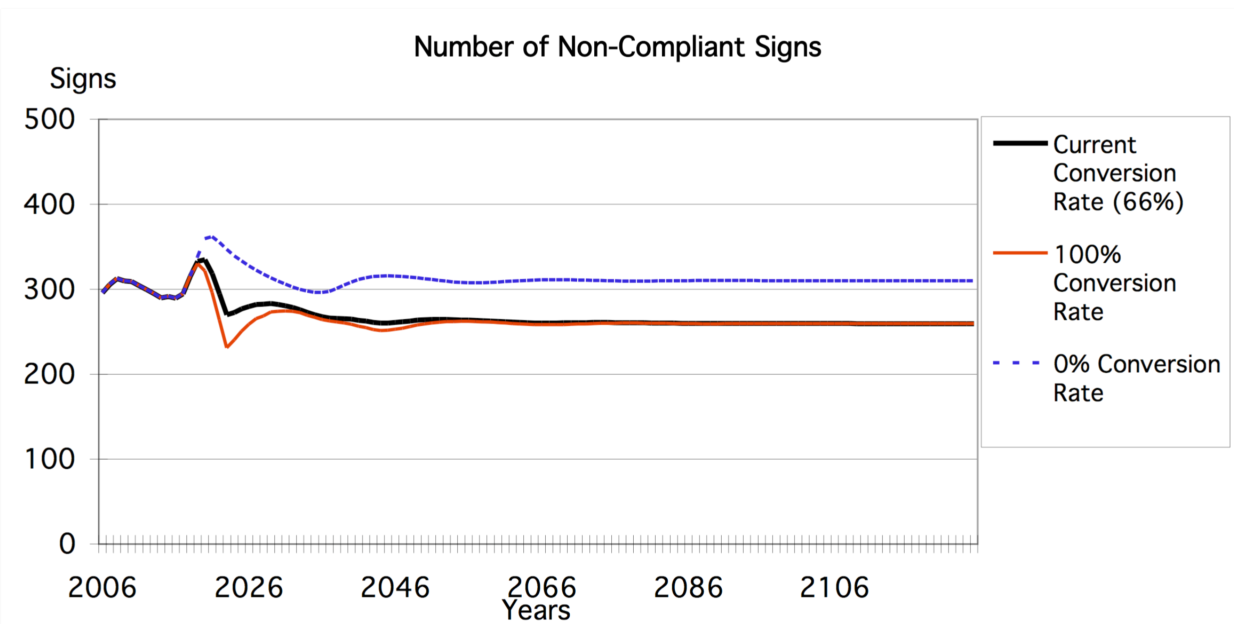


Figure 9.31. Varying Rate at which Type I Signs are Converted to Type III Signs - White Signs

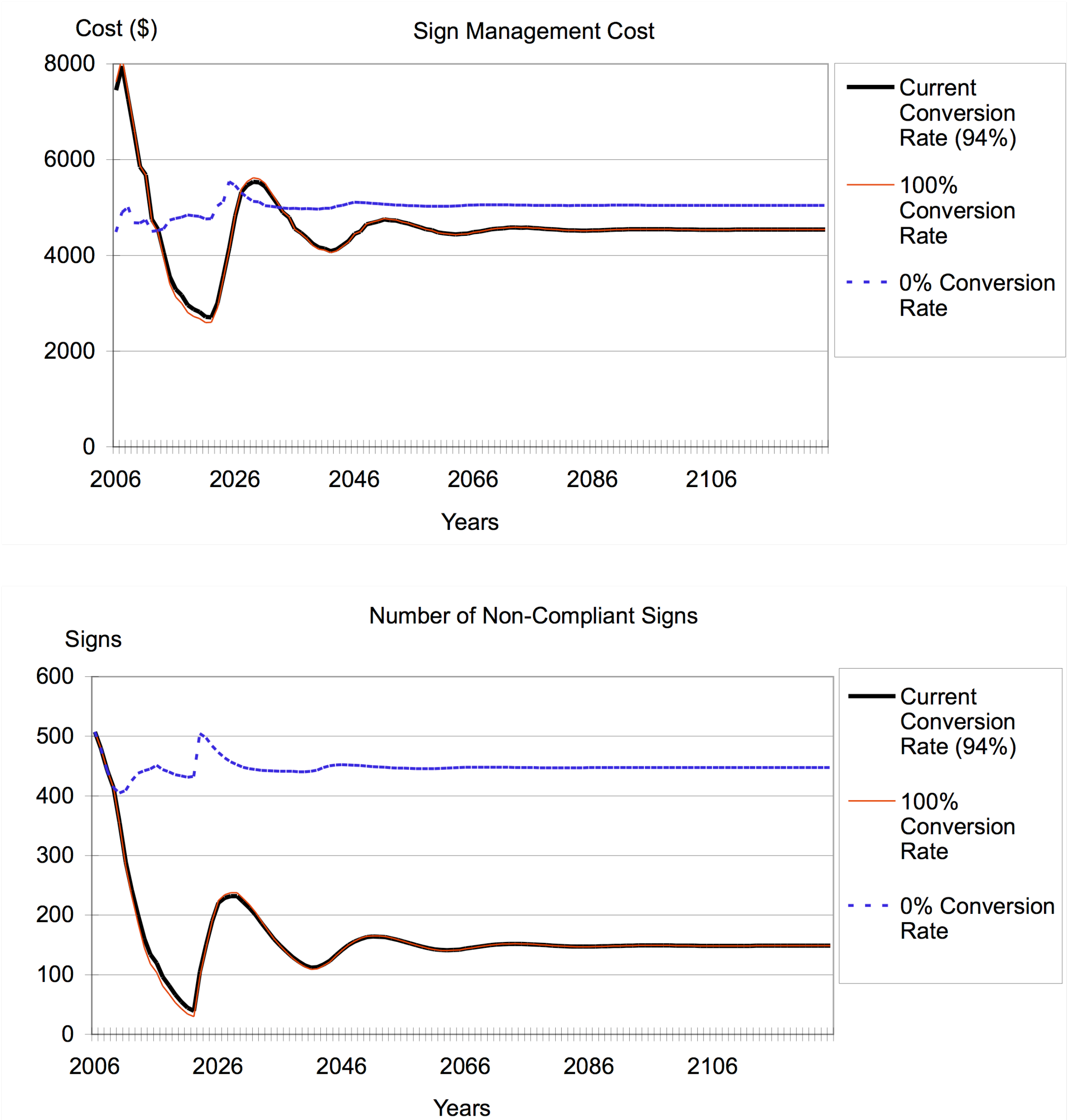
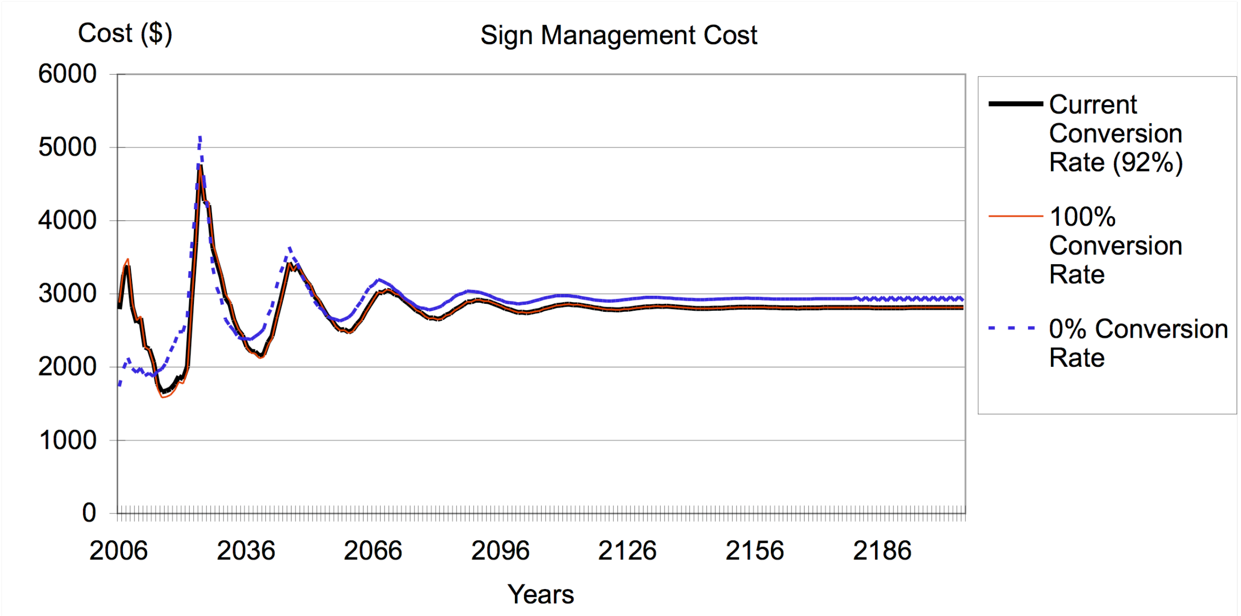


Figure 9.32. Varying Rate at which Type I Signs are Converted to Type III Signs - Yellow Signs



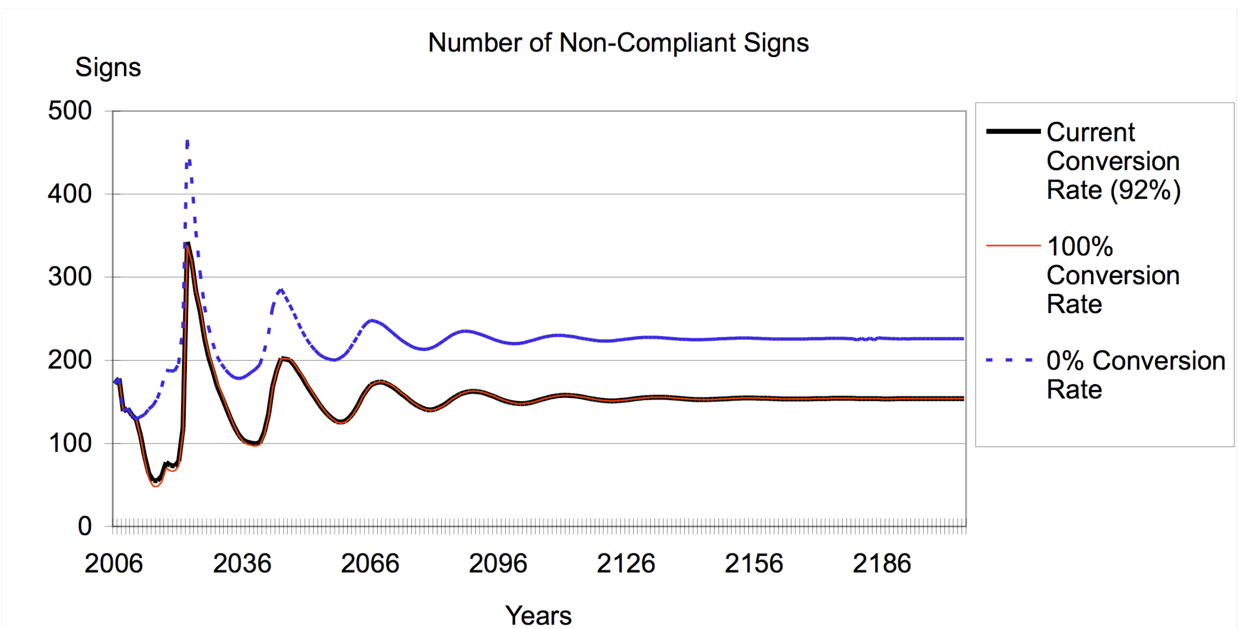
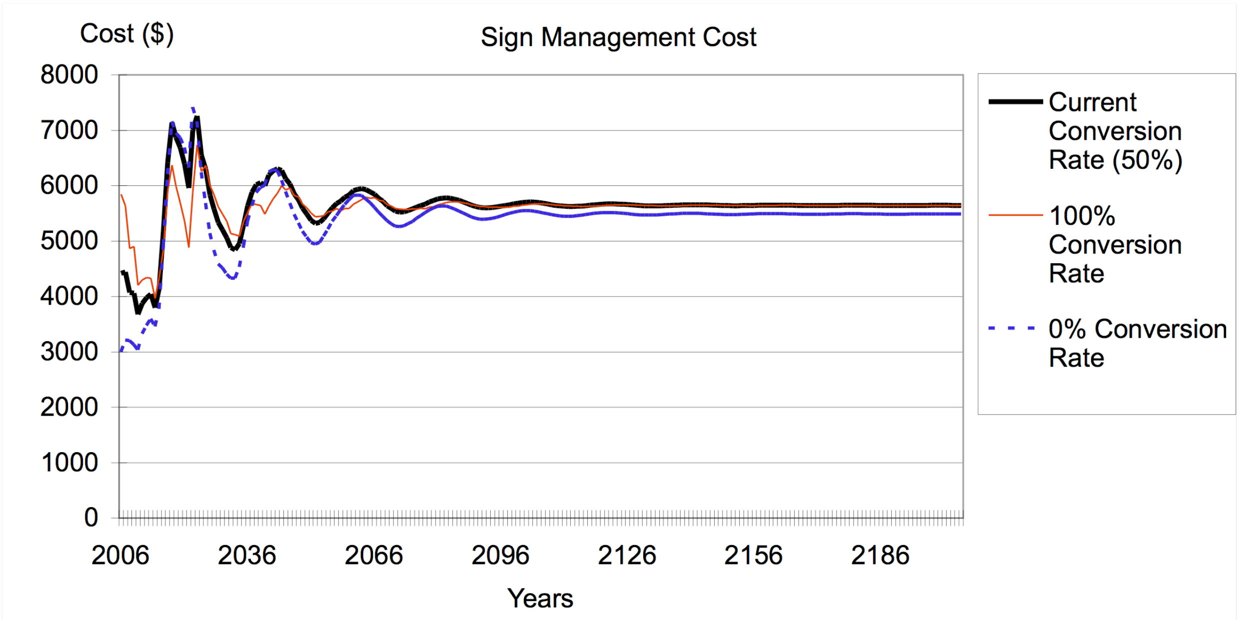


Figure 9.33. Varying Rate at which Type I Signs are Converted to Type III Signs - Red Signs



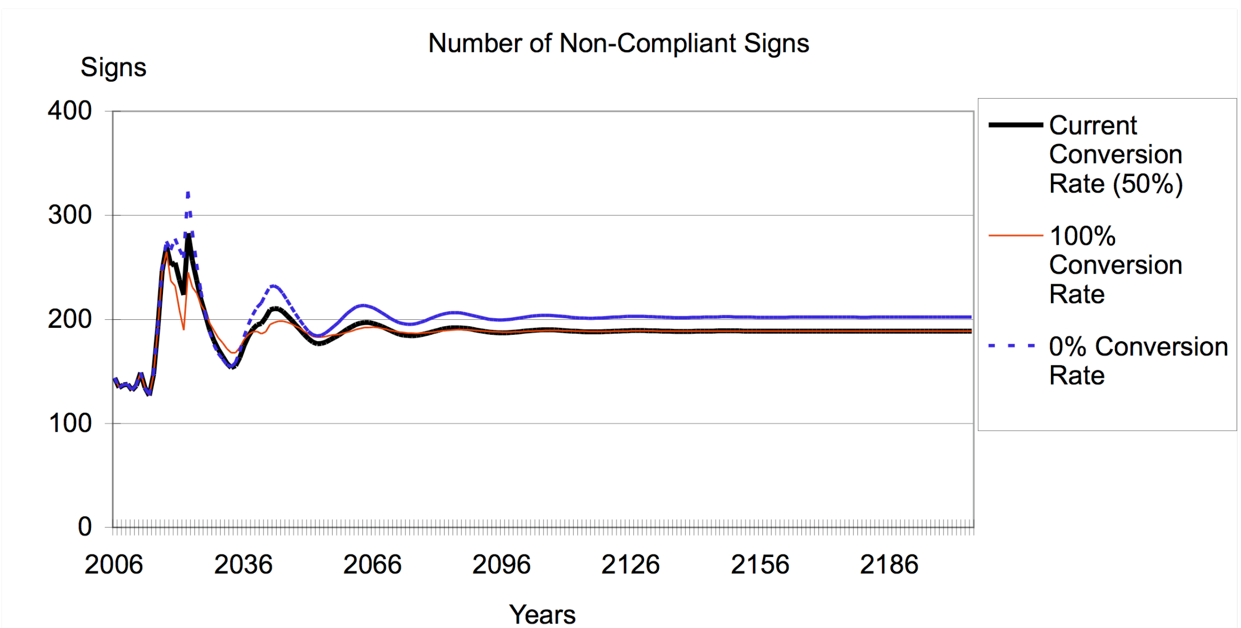


Figure 9.34. Varying Rate at which Type I Signs are Converted to Type III Signs - Green Signs

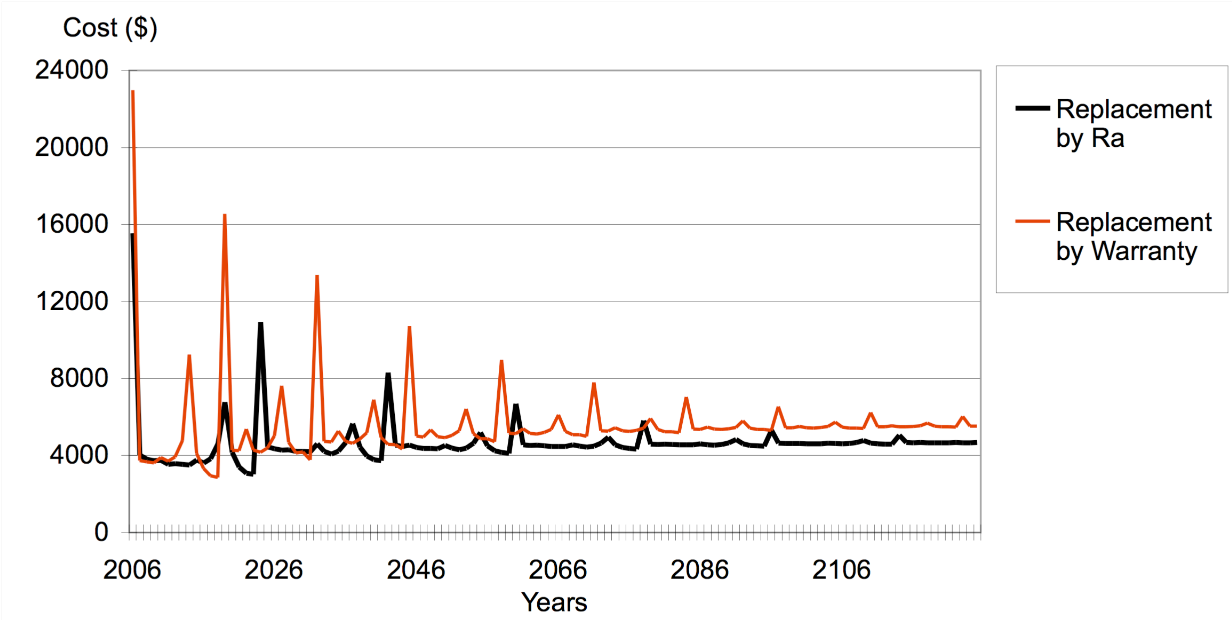


Figure 9.35. Total Replacement - White Signs

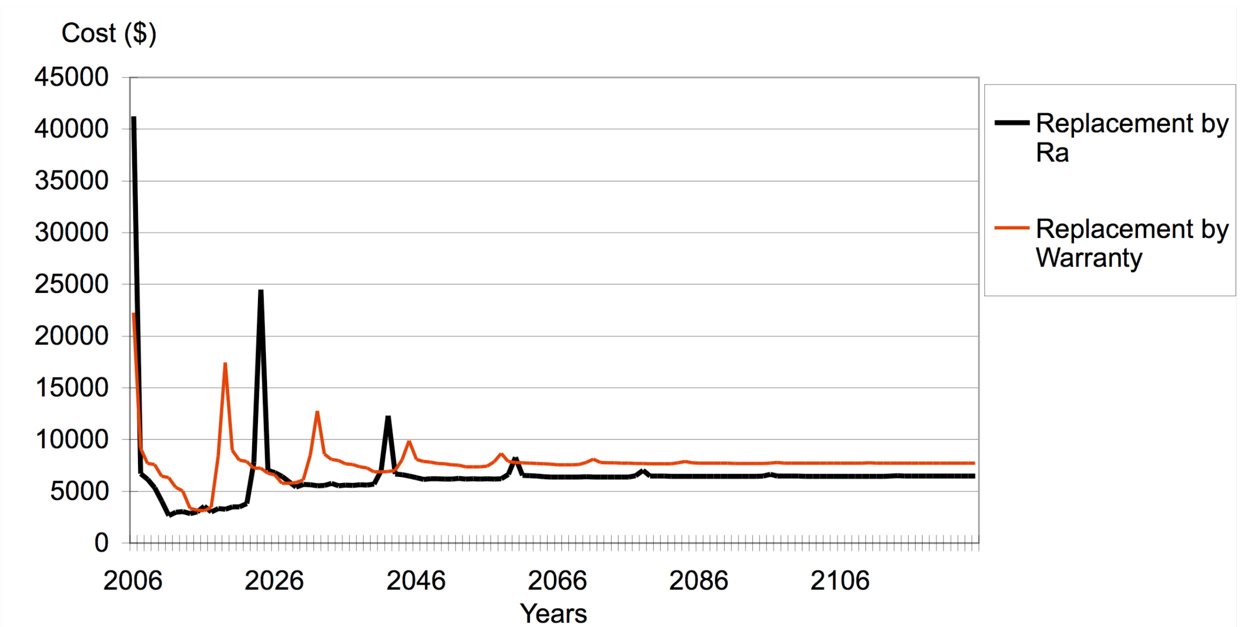


Figure 9.36. Total Replacement - Yellow Signs

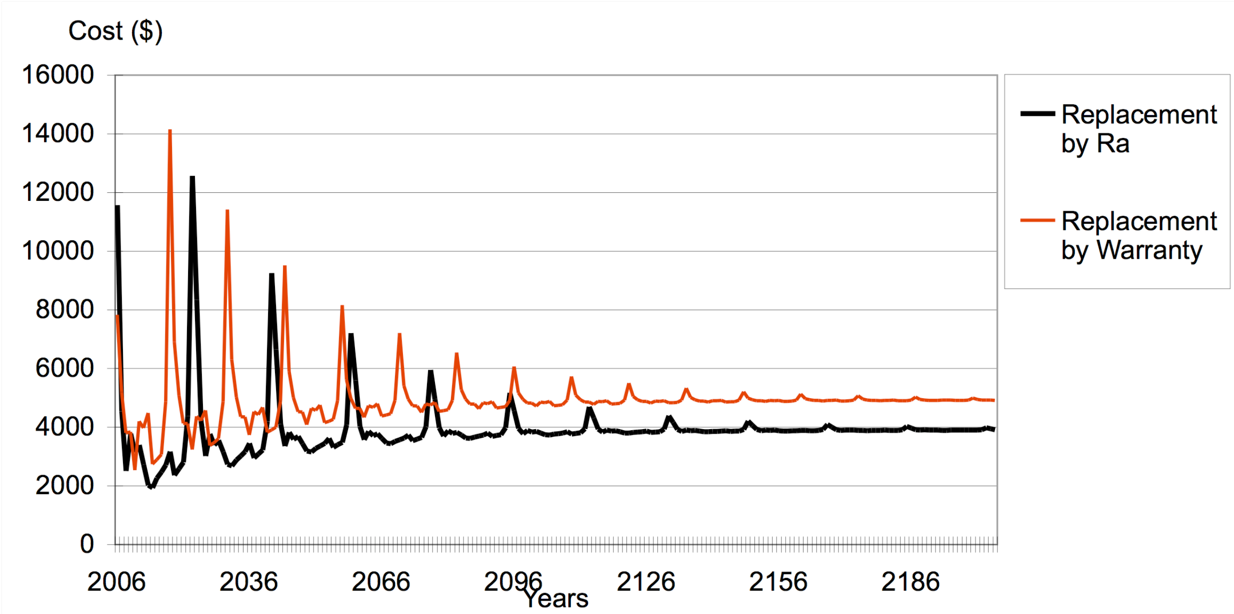


Figure 9.37. Total Replacement - Red Signs

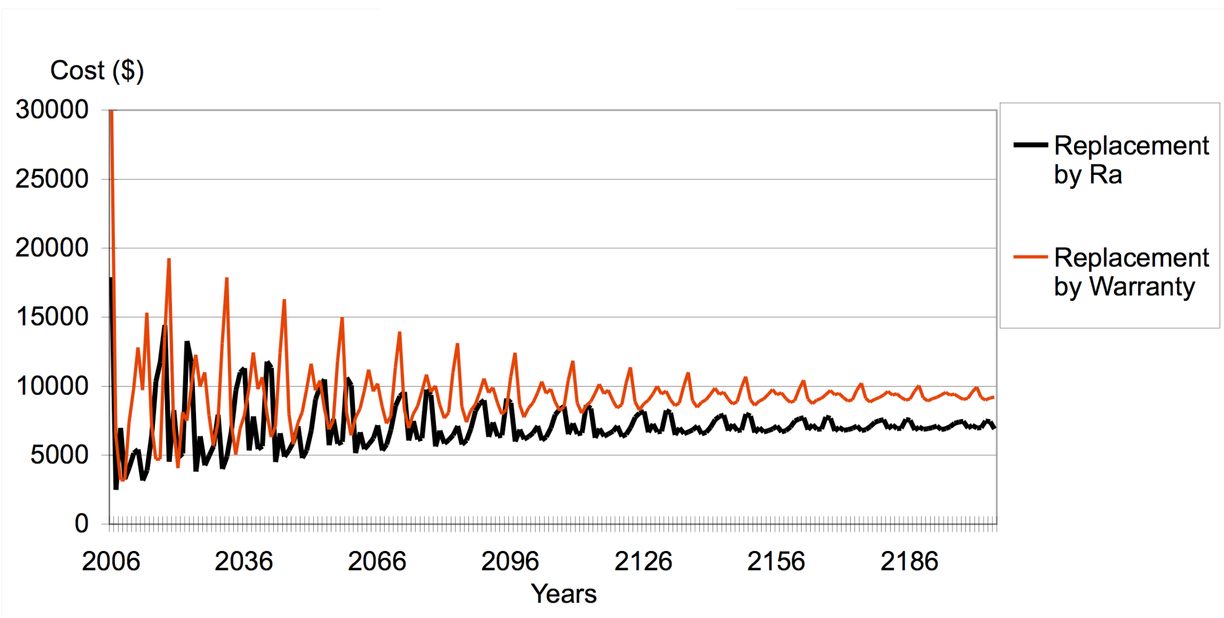


Figure 9.38. Total Replacement - Green Signs

In the Figures 9.19 to 9.38, only the numbers of signs below the proposed FHWA minimum standard are expressed because the combination of the number of signs above and below the standard always add to 1,000, the total population of signs used in the simulations.

Figures 9.19 to 9.22 investigate an inspection frequency change for each sign color. Inspection frequencies of ‘inspect every year’, ‘inspect every 2 years’, and ‘inspect every 3 years’ were examined through simulation in contrast to the current inspection frequency obtained from the field data collected in 2005. As expected, more frequent inspection requires higher budgets and provides better sign conditions with lower portions of 'below the standard' signs.

Figures 9.23 to 9.26 change the threshold or retroreflectivity limit at which sign crews performing visual inspection generally reject signs. In this scenario, the team assumed that this threshold can be changed by training if desired. Again, we see a clear pattern of rising costs providing better sign quality.

On the other hand, Figures 9.27 to 9.30 provide the results of scenarios changing the retroreflectivity limit while performing inspection using retroreflectometers. The results for sign condition are the same as the previous scenarios (from Figures 9.23 to 9.26), but the sign management costs are higher because it is much more expensive to inspect signs using a retroreflectometer.

Figures 9.31 to 9.34 test the sign installation policy that new installs Type III signs instead of Type I signs when Type I signs should be replaced. Two new scenarios and the current conversion rate found from the NCSU field study were expressed in the figures. The conversion rate of 100 percent changes all Type I signs to Type III when they are replaced and 0 percent means keeping the current Type I and Type III sign ratio by installing the same type of signs when they are replaced. This made a much large difference for yellow signs than other colors because Type I yellows signs have short lifetimes with lower retroreflectivity values compared to other sign colors.

Figures 9.35 to 9.38 represent a total sign replacement scenario with no sign inspection. In this scenario, signs are replaced either when their retroreflectivity value sinks to the proposed FHWA minimum standard in the simulation or when they exceed current market warranty period. These are costly policies but result in virtually perfect sign systems relative to the retroreflectivity standard. Note that the graph of the number of signs below the proposed FHWA minimum standard is not provided because almost no signs are found in that category.

Tables 9.57 to 9.60 show the results of each scenario in the 120th year for white and yellow signs and 200th year for red and green signs. In the Tables, the team crossed the other variables with the inspection frequency variable. For example, the case of 100 percent conversion rate from Type I to Type III signs was divided into a total of four scenarios: current inspection frequency, inspect every year, inspect every 2 years, and inspect every 3 years. Note that signs below the standard are expressed as percent ages. Costs range from \$1.77 to \$9.36 per sign while the percentages of below the standard signs range from 0 to over 47 percent.

Table 9.57. 120th Year Simulation Results for a Population of 1,000 White Signs

Strategy Number	Scenarios			Simulation Results	
	Title	Condition	Inspection Frequency	Sign Management Cost ($)	Percent of Signs Below the Standard
1	Current	Current	Current	2270	26.9
2			Every Year	4210	13.6
3			Every 2 Years	2400	23.2
4			Every 3 Years	2040	30.6
5	Changing Visual Inspection Rejection Threshold	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	2670	12.0
6			Every Year	4410	7.4
7			Every 2 Years	2780	10.2
8			Every 3 Years	2520	13.8
9		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	2730	9.8
10			Every Year	4460	5.8
11			Every 2 Years	2830	8.3
12			Every 3 Years	2580	11.4
13		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	2750	9.0
14			Every Year	4520	3.8
15			Every 2 Years	2850	7.5
16			Every 3 Years	2600	10.5
17	Changing Inspection Rejection Threshold While Using a Retroreflectometer	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	3570	12.0
18			Every Year	6700	7.4
19			Every 2 Years	3940	10.2
20			Every 3 Years	3270	13.8
21		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	3620	9.8
22			Every Year	6750	5.8
23			Every 2 Years	3990	8.3
24			Every 3 Years	3340	11.4
25		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	3650	9.0
26			Every Year	6810	3.8
27			Every 2 Years	4010	7.5
28			Every 3 Years	3360	10.5
29	Varying Rate at Which Type I Signs are Converted to Type III Signs	100% Conversion Rate	Current	2290	26.6
30			Every Year	4230	13.5
31			Every 2 Years	2430	22.9
32			Every 3 Years	2070	30.2
33		0% Conversion Rate	Current	1770	31.1
34			Every Year	3690	15.7
35			Every 2 Years	1940	27.3
36			Every 3 Years	1630	34.9
37	Total Replacement	By Ra	-	4640	0.0
38		By Warranty	-	5560	0.0

Table 9.58. 120th Year Simulation Results for a Population of 1,000 Yellow Signs

Strategy Number	Scenarios			Simulation Results	
	Title	Condition	Inspection Frequency	Sign Management Cost ($)	Percent of Signs Below the Standard
1	Current	Current	Current	4570	16.2
2			Every Year	6120	6.9
3			Every 2 Years	4880	12.4
4			Every 3 Years	4350	17.3
5	Changing Visual Inspection Rejection Threshold	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	4810	11.0
6			Every Year	6210	5.3
7			Every 2 Years	5100	8.4
8			Every 3 Years	4620	11.8
9		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	4920	8.7
10			Every Year	6260	4.4
11			Every 2 Years	5190	6.6
12			Every 3 Years	4740	9.3
13		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	4940	8.2
14			Every Year	6280	4.0
15			Every 2 Years	5210	6.1
16			Every 3 Years	4770	8.8
17	Changing Inspection Rejection Threshold While Using a Retroreflectometer	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	5620	11.0
18			Every Year	8470	5.3
19			Every 2 Years	6210	8.4
20			Every 3 Years	5370	11.8
21		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	5730	8.7
22			Every Year	8510	4.4
23			Every 2 Years	6310	6.6
24			Every 3 Years	5500	9.3
25		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	5720	8.2
26			Every Year	8530	4.0
27			Every 2 Years	6330	6.1
28			Every 3 Years	5490	8.8
29	Varying Rate at Which Type I Signs are Converted to Type III Signs	100% Conversion Rate	Current	4560	16.1
30			Every Year	6110	6.8
31			Every 2 Years	4880	12.3
32			Every 3 Years	4340	17.2
33		0% Conversion Rate	Current	5010	44.7
34			Every Year	7760	27.3
35			Every 2 Years	5840	38.4
36			Every 3 Years	4810	46.5
37	Total Replacement	By Ra	-	6520	0.0
38		By Warranty	-	7690	1.1

Table 9.59. 200th Year Simulation Results for a Population of 1,000 Red Signs

Strategy Number	Scenarios			Simulation Results	
	Title	Condition	Inspection Frequency	Sign Management Cost ($)	Percent of Signs Below the Standard
1	Current	Current	Current	2790	15.1
2			Every Year	3670	6.7
3			Every 2 Years	3060	11.0
4			Every 3 Years	2760	15.5
5	Changing Visual Inspection Rejection Threshold	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	2910	11.4
6			Every Year	3710	5.8
7			Every 2 Years	3150	8.3
8			Every 3 Years	2890	11.7
9		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	2970	9.5
10			Every Year	3750	4.4
11			Every 2 Years	3200	6.8
12			Every 3 Years	2950	9.7
13		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	2990	9.1
14			Every Year	3800	3.2
15			Every 2 Years	3210	6.4
16			Every 3 Years	2960	9.3
17	Changing Inspection Rejection Threshold While Using a Retroreflectometer	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	3680	11.4
18			Every Year	5960	5.8
19			Every 2 Years	4280	8.3
20			Every 3 Years	3640	11.7
21		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	3740	9.5
22			Every Year	6010	4.4
23			Every 2 Years	4330	6.8
24			Every 3 Years	3700	9.7
25		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	3740	9.1
26			Every Year	6050	3.2
27			Every 2 Years	4340	6.4
28			Every 3 Years	3710	9.3
29	Varying Rate at Which Type I Signs are Converted to Type III Signs	100% Conversion Rate	Current	2790	15.2
30			Every Year	3670	6.8
31			Every 2 Years	3060	11.0
32			Every 3 Years	2760	15.6
33		0% Conversion Rate	Current	2880	22.3
34			Every Year	4330	9.0
35			Every 2 Years	3390	16.0
36			Every 3 Years	2860	22.8
37	Total Replacement	By Ra	-	3910	0.0
38		By Warranty	-	4910	0.2

Table 9.60. 200th Year Simulation Results for a Population of 1,000 Green Signs

Strategy Number	Scenarios			Simulation Results	
	Title	Condition	Inspection Frequency	Sign Management Cost ($)	Percent of Signs Below the Standard
1	Current	Current	Current	5570	18.9
2			Every Year	6490	9.3
3			Every 2 Years	5450	17.7
4			Every 3 Years	4840	24.6
5	Changing Visual Inspection Rejection Threshold	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	6120	9.4
6			Every Year	6700	6.3
7			Every 2 Years	6040	8.7
8			Every 3 Years	5620	12.5
9		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	6140	9.1
10			Every Year	6760	5.5
11			Every 2 Years	6050	8.5
12			Every 3 Years	5650	12.0
13		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	6180	8.7
14			Every Year	6840	4.2
15			Every 2 Years	6080	8.1
16			Every 3 Years	5740	11.7
17	Changing Inspection Rejection Threshold While Using a Retroreflectometer	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	7150	9.4
18			Every Year	8960	6.3
19			Every 2 Years	7170	8.7
20			Every 3 Years	6370	12.5
21		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	7180	9.1
22			Every Year	9010	5.5
23			Every 2 Years	7180	8.5
24			Every 3 Years	6400	12.0
25		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	7220	8.7
26			Every Year	9090	4.2
27			Every 2 Years	7210	8.1
28			Every 3 Years	6420	11.7
29	Varying Rate at Which Type I Signs are Converted to Type III Signs	100% Conversion Rate	Current	5600	18.8
30			Every Year	6460	9.4
31			Every 2 Years	5420	17.7
32			Every 3 Years	4840	24.3
33		0% Conversion Rate	Current	5410	20.1
34			Every Year	6940	8.9
35			Every 2 Years	5650	18.6
36			Every 3 Years	4800	27.3
37	Total Replacement	By Ra	-	7120	0.0
38		By Warranty	-	9360	0.0

After the team created scenarios for each color expressed in Tables 9.57 to 9.60, a combination of all four sign colors was generated to represent real sign conditions in the field. The sign distribution found in the previous NCSU study [Kirtley, et. al. 2001, Palmquist, et. al. 2002] was used as shown in Table 9.61. Note that results for the "other" color were estimated from the average of the standard four sign colors.

Table 9.61. Sign Color Distribution in NC

Sign Color	White	Yellow	Red	Green	Other	Total
Distribution	39.5%	38.6%	5.4%	6.9%	9.5%	100.0%

Using the percentage in Table 9.61, 120-year (or 200-year) simulation results for each color were combined and provided in Table 9.62 and Figure 9.39. In Figure 9.39, all strategies are positioned with the sign management costs and the percent of non-compliant (below the proposed FHWA minimum standard) signs. A polynomial trend line with the equation and R^2 value is also provided to show a general relation between sign management costs and sign condition. Examining the combined results, we should be able to find an optimum sign management strategy for the NCDOT.

The "ideal" sign asset management scenario for the NCDOT, or any other DOT, would minimize both maintenance costs and the percentage of signs in a non-compliant condition. The definition of "ideal" is dependent on the maximum percentage of non-compliant signs a DOT will accept, on the limitations of the DOT budget, and on the abilities of the sign inspectors (in the case of visual nighttime inspection).

Each of the 38 sign asset management scenarios were simulated using the simulation program described in this chapter. Scenario 1, visual nighttime inspection with the current NCDOT sign inspection parameters, resulted in an annual cost per sign of $3.56 and in 19.0% of all signs being non-compliant. The percentage of non-compliant signs in Scenario 1 can serve as a benchmark for evaluating the other scenarios, since it would be absurd for the NCDOT to select an alternative scenario that results in worse sign conditions than currently exist. For this reason, scenarios 4, 32, 33, 35, and 36 should be eliminated as alternatives that could be considered for implementation. In a similar manner, Scenarios 3, 31, and 34 could also be eliminated as offering little improvement on the current method. These eight eliminated scenarios are all visual nighttime inspection method scenarios. Scenarios 17 to 24 can also be eliminated because it is absurd to measure signs with a retroreflectometer and not reject them at the FHWA minimum standard retroreflectivity levels.

The change in sign inspection and replacement practices that would probably be the easiest for NCDOT to implement is 100% Type I to Type III conversion, which is represented by Scenario 29. The increase in conversion rate from 89% to 100% improves sign condition by 0.2% and increases annual sign maintenance costs by one cent per sign (though short-term costs are higher (*5*)). Since the improvement in sign condition is slight, other changes should be considered, and Scenario 29 should be eliminated from consideration.

Table 9.62. 120-year (or 200-year) Simulation Results for a Population of 1,000 Signs of All Colors

Strategy Number	Scenarios			Simulation Results	
	Title	Condition	Inspection Frequency	Sign Management Cost ($)	Percent of Signs Below the Standard
1	Current	Current	Current	3560	19.0
2			Every Year	5160	9.0
3			Every 2 Years	3750	15.8
4			Every 3 Years	3300	21.3
5	Changing Visual Inspection Rejection Threshold	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	3890	10.3
6			Every Year	5310	5.7
7			Every 2 Years	4060	8.3
8			Every 3 Years	3700	11.5
9		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	3960	8.4
10			Every Year	5350	4.6
11			Every 2 Years	4120	6.8
12			Every 3 Years	3780	9.4
13		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	3980	7.8
14			Every Year	5400	3.5
15			Every 2 Years	4140	6.2
16			Every 3 Years	3810	8.9
17	Changing Inspection Rejection Threshold While Using a Retroreflectometer	Ra Limit 30 – W, Y Ra Limit 5 – R, G	Current	4760	10.3
18			Every Year	7570	5.7
19			Every 2 Years	5200	8.3
20			Every 3 Years	4450	11.5
21		Ra Limit 40 – W, Y Ra Limit 6 – R, G	Current	4820	8.4
22			Every Year	7620	4.6
23			Every 2 Years	5270	6.8
24			Every 3 Years	4530	9.4
25		Ra Limit 50 – W, Y Ra Limit 7 – R, G	Current	4840	7.8
26			Every Year	7670	3.5
27			Every 2 Years	5290	6.2
28			Every 3 Years	4540	8.9
29	Varying Rate at Which Type I Signs are Converted to Type III Signs	100% Conversion Rate	Current	3570	18.8
30			Every Year	5160	9.0
31			Every 2 Years	3760	15.6
32			Every 3 Years	3310	21.1
33		0% Conversion Rate	Current	3520	32.2
34			Every Year	5710	17.8
35			Every 2 Years	4000	27.8
36			Every 3 Years	3320	34.9
37	Total Replacement	By Ra	-	5590	0.0
38		By Warranty	-	6740	0.4

One way to approach interpreting the scenario results is to pick an acceptable percentage of non-compliant signs and to find the increase in sign maintenance costs and changes in sign asset management strategies associated with the improvement in sign compliance. To achieve approximately 10% or fewer non-compliant signs, the least expensive scenarios are 5, 9, 12, 13, and 16. All of these scenarios use the visual nighttime inspection method. Table 9.62 shows that it is possible to cut the number of non-compliant signs in half with only a 10% increase in cost for these 5 scenarios. Another consideration is the rejection threshold for each scenario, since it is more difficult for the NCDOT to train sign inspectors to have a visual retroreflectivity rejection threshold closer to the proposed standard. Considering training, the scenarios that may be the most acceptable to the NCDOT are Scenarios 5 and 12 which theoretically require less of an improvement in training while reducing the percentage of non-compliant signs to approximately 10% or less and increasing maintenance costs per sign by less than 10%.

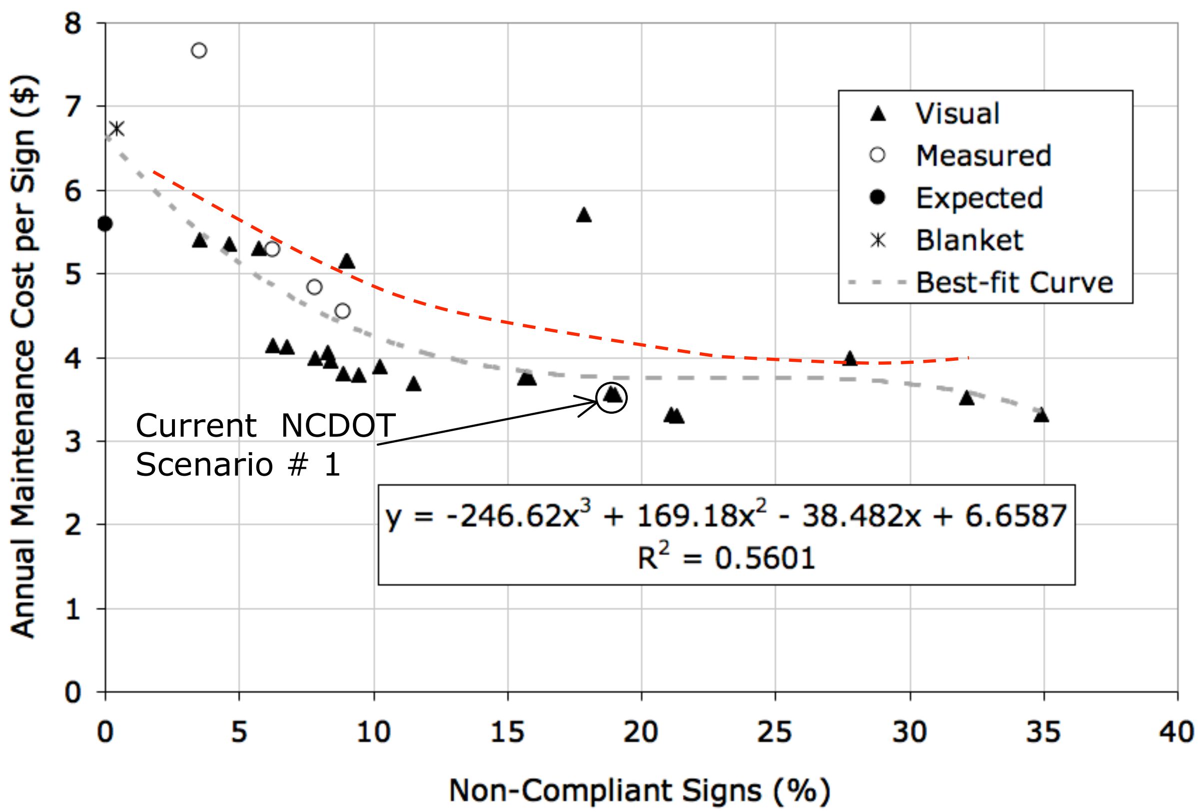


Figure 9.39. Annual Maintenance Cost per Sign vs. Percent of Non-Compliant Signs

Figure 9.39 can also assist in visualization of the simulation scenario results at various sign condition thresholds. Figure 9.39 plots the annual maintenance cost per sign versus the percentage of non-compliant signs for the 38 scenarios and shows the best-fit polynomial curve through the data points. In the figure the retroreflectivity maintenance strategy of each scenario is identified by an assigned symbol. Scenarios 1-16 and 29-36 use visual inspection, 17-28 use retroreflectometer measurement, 37 uses expected sign life and 38 uses blanket replacement. Scenarios 37 and 38, the expected sign lifetime and blanket replacement methods, respectively, result in a negligible percentage of non-compliant signs in Figure 9.39 but are also among the most expensive in sign maintenance cost ($5.59 and $6.74). Also in Figure 9.39 the measured retroreflectivity method scenarios inhabit the upper left portion of the chart, which corresponds to fewer non-compliant signs but higher maintenance costs.

The remaining points in Figure 9.39 represent the visual nighttime inspection method scenarios, most of which have a low annual maintenance cost between $3 and $4 per sign and a large spread in non-compliant sign percentage. The middle of the dashed best-fit curve (created from all 38 scenarios) shows how the annual maintenance cost remains nearly constant as the percentage of non-compliant signs increases from 15% to 30%. This means that it should not cost much more than Scenario 1 to reduce the percent of non-compliant signs to 15%, and slightly more to reduce the percent of non-compliant signs to 10%, as demonstrated in Table 9.62.

10.0 CONCLUSIONS

The conclusions section of the report is divided into subsections based on the results. The conclusions are presented in three different sections. These are Deterioration, Damage, and Inspector Performance.

Based on the nighttime rides and daytime inspection it is clear that both damage and retroreflectivity field inspections can be conducted simultaneously at night. This is important for damage inspections because it is difficult to clearly see some types of damage during the day.

10.1 Deterioration

In order to determine the final deterioration curves the NCSU research team conducted a comprehensive study of all literature that was studied and summarized all the previous research papers and reports related to sign retroreflectivity deterioration. The NCSU research team reanalyzed previous studies to try to discover the optimal function form (for each sign color and type) to predict sign deterioration rates. From this investigation some of the important conclusions made are as follows.

Most existing signs are 15 years old or younger. This means that signs older than 15 years are nearly always replaced due to either low retroreflectivity or damage. Based on the NCSU study it was found that a linear curve typically best describes expected sign deterioration. The best-fit linear deterioration curve intercepted the X-axis (retroreflectivity of zero) between 20 and 30 years. The research found that R^2 values were usually not good for the trend lines between age and retroreflectivity. Almost all of the R^2 values from the data or from the literature were less than 0.5. This means that the data from all studies is highly scattered. This also means that there may be some other factors influencing the rate at which signs deteriorate other than age. Although the effect of each factor may be low individually, the factors collectively cause the scatter. In this paper the discussion is confined to the most important factor causing deterioration (age). The other factors, if considered, would be helpful in designing a microscopic simulation.

10.2 Damage

In order to determine sign damage rates the field study noted all signs that were identified by the sign inspectors as being damaged. There was a significant difference between replacement rates of damaged signs by division. The reason for this may be due to the differences in the standards used by inspectors.

One of the initial study goals was to obtain better estimates of the vandalism and natural damage rates for NC signs. The field study data that were collected led to one quantifiable estimate. In general, the field study damage rate was found to be about 2.37% of inspected signs per year. Of this total damage, 1.3% of signs are damaged irreparably by humans each year, 0.9% by natural causes each year, and about 0.17% of signs each year are damaged due to both natural and human causes. The most common types of damage were paint balls, guns, eggs, and tree sap. More vandalism was found on secondary roads and the color yellow was more prone to vandalism. Finally, there was a significant difference between the replacement rates of damaged signs by division.

A second investigation, based on cost data, enabled the study team to determine an overall sign replacement rate. This value was found to be 6.9 percent of all signs per year. The researchers estimated that 4.7 percent of all signs are replaced due to damage each year, and this percentage includes 2.4 percent of signs each year that are replaced outside the inspection process due to vandalism. These rates will all be valuable in the simulation program.

10.3 Inspector Performance

In order to determine an inspector performance level the field study measured the retroreflectivity of all the signs that were observed by the inspectors. The NCSU team checked the data with the FHWA proposed minimum standards in order to assess the inspector performance.

Another goal of the study was to model the performance of NC sign inspectors. The data showed that the inspectors were generally responding to better retroreflectivity by rejecting fewer signs. Thus, they had a very low false negative rate. However, the inspectors did not reject quite a few signs that had poor retroreflectivity. What this shows is that they were using a different retroreflectivity standard than the FHWA proposed minimums. Still, rejection rates did increase as retroreflectivity decreased. In fact, there were very few signs left standing in the field with a retroreflectivity value below 20.

The study found that presently 54% of the Type I signs are below the proposed FHWA minimum standards. However, almost all of the Type III signs were well above the proposed minimums. The inspector accuracy based on the proposed FHWA minimums for Type I signs was 67% for white, 51% for yellow, 74% for red, and about 63% for green signs. The inspector accuracy for the different divisions varied from 54% to 83%.

10.4 Follow-up Field Study

The follow up field study conducted in 2006 resulted in several findings regarding sign data collection procedures, sign retroreflectivity, and sign replacement. First, using an inventory number to mark each sign facilitates any future retroreflectivity measurement of signs by making signs easier to identify during data collection. Second, during the follow-up field study the team discovered that there was a retroreflectivity measurement discrepancy in 2005 and the discrepancy was corrected using 2006 retroreflectivity values. Third, in 2005, 72% of signs measured were Type I and 28% were Type III. In 2006, approximately 60% of signs were Type I and 40% were Type III.

Examining the signs from the 2005 field study one year later led to some interesting findings about sign replacement. Approximately 20% of the signs measured in 2005 had been replaced or removed by division sign crews between the original and follow-up field studies, with 2% of the signs removed and 18% replaced. Across all five Divisions, 89% of signs are replaced with Type III sheeting, just over 10% short of the NCDOT goal of 100% Type III replacement. Yellow and red signs were replaced 90% of the time with Type III sheeting, while white and green signs are replaced at least 62% with Type III. The higher Type III replacement percentage for yellow and red signs may be due to these signs having a higher replacement priority. Overall, 80% of Action Code 1, 62% of Code 2 and 38% of Code 3 signs were replaced within one year. A total of 57% of rejected signs in 2005 were replaced by 2006. Unexpectedly, 11%

of signs not rejected in 2005 were replaced by 2006, which can likely be attributed to additional sign damage occurring after the 2005 field study, Type III blanket upgrades along a road corridor, and the upgrading of all signs on a support.

10.5 Division Sign Replacement Priorities

During the visit of the research team to the divisions, the team discussed sign replacement and maintenance issues with each sign crew. Regardless of division, sign crews took pride in keeping the state roadways that their families use safe. The research team found that each division had its own particular "culture" or attitudes towards sign maintenance and this results in unique sign replacement priorities that differ somewhat by division. There are several factors that influence when a sign is replaced after it has been damaged or deteriorates.

10.5.1 Inspection Frequency

The frequency of nighttime inspection determines when deficient signs are detected and recorded by the sign crews as needing replacement. The research team found the inspection frequencies in each division to vary. The general standard is to inspect signs every year for primary and interstate roads and every two to three years for secondary roads. However, this can vary up to every five years for secondary roads. The frequency of nighttime inspection is influenced by the number of sign crews assigned to each county in a division as well as the available budget that year for nighttime inspection. The available funds for nighttime inspection labor costs along a particular route type (interstate, primary, secondary) can be reduced by unexpected labor-intensive sign projects during the normal course of the fiscal year.

10.5.2 Budget Allocation

Budget pressures can also affect sign inspectors' decisions about whether to reject a marginal sign. In some divisions, if a sign shows any indication of damage it is marked for replacement. In other divisions, the damage has to affect the sign's ability to communicate its safety message to drivers in order for it to be marked for replacement. This second practice is common in divisions where one or several of the route type replacement budgets are depleted. Each division's sign budget is divided into allocations for interstate, primary, and secondary route roads.

In some cases, if the budget for a particular route type has already been expended, deficient signs are allowed to stay out in the field until funds are available for their replacement. The research team qualitatively found that budget pressures mostly affected deficient large green project signs, but they also somewhat affected yellow warning signs and white regulatory signs. These signs are typically assigned action codes of two and three by inspectors, which means that these signs have a lower priority for replacement. Signs with an action code of one, such as *stop* and *do not enter* signs, are considered to be the most critical to motorist safety, and every division visited by the research team replaced these signs as soon as possible, regardless of budget concerns.

10.5.3 Upgrading Signs

In some divisions, the research team observed an impetus to aggressively replace type I sheeting signs with type III signs. In these divisions, signs with type I sheeting that were one to three years away from being deficient in retroreflectivity were marked for replacement so that they could be replaced sooner with type III signs. Type I signs that also had low levels of damage that would typically not result in replacement also had their replacement accelerated in some divisions. Sign crews in divisions that were aggressive in replacing type I signs did not express to the research team any budget pressures regarding their replacement decisions.

10.5.4 Other Influences

The research team also observed a division where the sign crews said that their traffic services supervisor emphasized year-round, daytime sign inspection while the crews were performing their daily maintenance tasks. The research team found that this division had a lower rate of vandalized signs in the field than other divisions.

Because this research project was not structured to consider the effect of inspector age on sign replacement, the research team cannot make any determinations on the subject. However, it was observed qualitatively that in some divisions, an older, and more experienced sign inspector conducts the nighttime inspection with a less experienced, and typically younger sign crew member. This arrangement facilitates on-the-job training, knowledge transfer, and mentoring within the sign crew.

10.6 Sign Inventory Management Simulation

The team reached interesting conclusions based on the results of the scenarios provided in Section 9.7.4. Note that for simplicity and uniformity results for each scenario were expressed for a total of 1,000 signs and only the number of signs below the proposed FHWA minimum standard is provided to represent sign condition.

The current NCDOT sign management practices found by the NCSU sign field study in 2005 and 2006 include to inspect signs every 2.64 years, a Type I to Type III sign conversion rate of 89 percent, and a relatively low retroreflectivity limit. The team had several observations after examining current scenarios shown Figures 9.19 to 9.22 for each sign color.

- White signs will have very stable sign management costs and also relatively constant sign conditions in the exception of one bulge around 2020. Even though there will be stable budget and sign conditions, the portion of below the standard signs will be more than a quarter.
- Management costs for yellow signs are expected to decrease drastically from $8,000 to $3,000 per 1,000 signs during the next 20 years. In that period, a majority of Type I signs will be replaced by Type III, which will improve overall sign condition considerably. The current percentage of below the standard signs at around 50 percent will decrease to about 15 percent once the sign condition is stabilized.
- Red signs show very spiky results in the simulation before they stabilize. A sudden increase in the number of below the standard signs is anticipated in 20 years, due to the end of the lifetime for many Type III signs being installed now. Overall sign condition is expected to be good with around 15 percent of signs below the standard.
- For green signs, sign management costs and conditions will be stable for around 10 years, but after that a sudden increase in sign management costs and the number of below the standard signs is expected. Once the sign condition is stabilized, less than 20 percent of signs in the field will be below the standard.

The team also examined the results of scenarios according to different inspection frequency: inspect every year, inspect every 2 years, and inspect every 3 years. The results of each case with different inspection frequency are also provided in Figures 9.19 to 9.22. As expected, more frequent inspection has higher costs and provides the best sign condition. If the NCDOT can inspect signs every year, the overall sign condition would improve, with the number of below standard signs sometimes being halved. However, sign management costs for the initial years, up to five years, would increase greatly, and probably not remain within the acceptable budget. Generally, the differences in sign management costs between inspecting every 2 years and every 3 years is not that big, but the impact on sign condition is significant.

Next, the team examined changing visual inspection rejection threshold. Results are provided in Figures 9.23 to 9.26 for each sign color. This is a very practical scenario because compared to the small increase of sign management costs, sign condition will be improved significantly. The major concern for NCDOT is the initial increase in sign management costs. When inspectors have adapted the FHWA standard as their retroreflectivity limit, the number of signs below the standard will stabilize at around 10 percent, which is about half of the current practice.

The team also examined changing inspection rejection threshold while using a retroreflectometer. With this scenario, the results for sign condition are essentially the same as with previous scenarios. The sign management costs increase, though, because of higher inspection costs using retroreflectometers by about $1 per sign per year.

The results while examining the sign type conversion rate scenarios (provided in Figures 9.31 to 9.34) provided a very interesting outcome, especially for yellow and red signs. For both sign colors, sign conditions are much better when the current Type III sign installation policy continues than to install Type I signs, but average sign management costs for the current conversion rates are less than the zero percent conversion rate in the long run. NCDOT will eventually have better sign conditions and a smaller budget if the current conversion rate is continued.

The results for total replacement scenarios are provided in Figures 9.35 to 9.38. Even if the sign condition is almost perfect with zero signs below the standard, sign management costs for total replacement by retroreflectivity and by warranty period are likely unacceptable to the NCDOT. According to the results, the sign management budget would have to increase by more than 10 times the current sign management budget in the early years.

After the team examined the results of scenarios for each sign color separately, sign management costs and the numbers of signs below the proposed FHWA minimum standard were computed for all signs together (all colors) based on the previous NCSU sign count study [Kirtley, et. al. 2001, Palmquist, et. al. 2002]. Table 9.62 and Figure 9.39 showed these results. It is logical to see that high costs for sign management generally result in a lower number of signs below the standard. However, in the long run for some cases, a lower number of signs below the standard is expected even with a low sign management cost. For example, in the long run strategies 5, 9, 13, and 16 all cost only about $0.30 to $0.40 per sign more than the current policy (about 10 percent higher costs) while reducing the percent of signs below the standard from 19 to 10 or less.

11.0 RECOMMENDATIONS

The recommendations of the report have been divided into subsections based on the results. The different recommendations are in three different sections which are Deterioration, Damage, and Inspector Performance.

11.1 Deterioration

Based on the results of the NCSU research study the following recommendations are made regarding sign deterioration.

First, future researchers should collect more Type III sign data as the data that was used in this study was primarily for Type I signs. Future researchers should also collect more data on old signs (i.e., signs older than 15 years) in order to derive a more accurate deterioration curve over an extended period of years.

Second, AASHTO study should consider conducting research for more than 3 years in its NTPEP program to benefit future researchers in coming up with a more accurate curve. The research done at AASHTO currently is only for three years, after which signs are taken down and replaced with new signs. If instead the signs were left in place it would benefit future researchers in determining a deterioration rate that will benefit the Departments of Transportation across the country. Also, other states should establish sign farms. This will help the individual states in having data for their respective geographic locations and climatic conditions.

Third, future studies should be conducted under natural field conditions i.e. without cleaning signs. Cleaning will give a higher retroreflectivity but it is not what drivers see at night. Drivers see signs in their natural state and hence cleaning a sign will not give the desired solution.

Finally, future research must consider not only age, but also other factors that could possible affect sign deterioration. This will help feed a microscopic simulation and aid in determining deterioration rates that are more accurate by considering the influence of other new factors.

11.2 Damage

The recommendations for sign damage are as follows.

First, damage rates can now be used by other researchers in their studies. The NCSU research team will continue to investigate these questions and studies in other states would also be highly appropriate.

Second, the divisions with higher damage rates must make an effort to replace their signs quickly. Also, divisions must check the signs after the mowing season and replace all the mower damaged signs. Likewise, the signs should be inspected after hunting season an all damaged signs should be replaced.

Finally, signs on the secondary roads must be checked more frequently to identify and replace damaged signs as the damage rate is higher on secondary roads.

11.3 Inspector Performance

The recommendations for inspector performance are as follows.

First, inspector rejection rates can now be used by other researchers in their studies. The NCSU research team will continue to investigate these questions and studies in other states would also be highly appropriate.

Second, the NCDOT must allocate an adequate annual budget for sign replacement. Among other things doing so will ensure that inspector performance is based on retroreflectivity and damage considerations rather than on budgetary considerations. That is, inspectors should be able to reject a sign which does not meet the proposed FHWA minimums without having to consider whether or not the sign budget will allow such a rejection.

Third, all states should establish their own minimum standards before implementation of the FHWA minimum standards. This will help the states in implementing a sign replacement procedure to reduce the number of signs below their minimum. When such procedures are successfully implemented in the states, a transition to the common FHWA minimums will be far easier than might otherwise be the case.

Fourth, the inspectors in all of the NCDOT divisions must be retrained in order to implement the FHWA minimum standards. Presently they are using a minimum below that of FHWA. It is recommended that studies be conducted to determine how inspectors are performing in other states. If indeed they too are performing at a similar level then strategies need to be developed to improve this performance. Training may be only one of a number of approaches that could be taken.

Finally, a common standard must be established statewide to train inspectors to reduce variability of inspector performance by division.

11.4 Sign Inventory Management Simulation

The team created sign management simulations using real factors from the NCSU field study in 2005 and 2006. After that, the team developed various simulation scenarios to find best sign management strategy. Based on the results of simulation for each sign colors and the final result of scenarios provided in Table 9.62 and Figure 9.39, the team made several recommendations for sign management improvement for the NCDOT.

- Current Type III sign installation policy should be kept to decrease the number of signs below the proposed FHWA minimum standard while spending in the long run almost the same budget as with a zero percent conversion rate.
- When current cohort of relatively young Type III signs lose retroreflectivity in 20 years or so, the NCDOT should prepare for a sudden increase in the budget and also a sudden decrease in sign condition. Even if it is difficult to expect exact life cycle for Type III signs, a majority of Type III signs installed at similar times are likely to have an equivalent lifetime, so the NCDOT should prepare for the demise of these Type III signs.
- From the strategies evaluated in Table 9.62, our intent is to recommend a practical sign management strategy which remains within a reasonable budget. Within around a 10

percent increase in the budget, the team recommends strategies 9 and 13. In both strategies, the NCDOT keeps the current inspection frequency to prevent confusion and trains its inspectors to adopt rejection thresholds of 40 or 50 cd/lux/m^2. Following one of those strategies, the NCDOT can expect to reduce the number of signs below the proposed FHWA minimum standard by half. Overall sign conditions improve from 19 percent of below the standard signs to around 8 percent.

- Sign inspection using retroreflectometers provides about the same sign conditions as changing the visual inspection rejection threshold. However, sign management costs increase up to $1 per sign per year. Considering total number of signs in NC, the team cannot recommend using retroreflectometers to inspect every sign in the field. In lieu of that, it does appear favorable to use retroreflectometers for the purpose of training sign crews to judge signs during nighttime inspection.
- An effective training system should be developed for sign crews to consistently reject signs that have a retroreflectivity value below the threshold that NCDOT determines. As long as sign crews perform nighttime inspection, repeated and continuous training should be considered necessary to minimize error.

11.5 NCDOT Sign Inspection Procedure

From discussions with sign crews and their supervisors, as well as experiences in the field, the following NCDOT sign inspection procedure recommendations were developed:

- Sign dating and labeling needs to be standardized across all 14 Divisions. Some Divisions are using punch stickers, while others are using a marker or pencil to mark the date, if it is marked at all. This study recommends that all signs should be marked using the standard punch sticker, which is independent of individual handwriting, long-lasting, and easy to locate on the sign.
- The punch sticker can be supplemented with a large date sticker like in Division 6 or a large date written in marker, like in Division 8.
- In the case of two signs ‘sandwiched’ together, the old punch sticker on the sign being used as the backing should be either removed or crossed out, and a new punch sticker for the newly installed sign should be placed on the back of the new sign AND on the back of the sign being used as the backing. Without this measure it is very difficult to ascertain the age of the new sign because its back face cannot be seen.
- Sign inspection frequencies are also not standardized across NC, often because the amount of miles each sign crew must cover varies. The standard of yearly inspections for interstate/limited access roads, inspection every 2 years for primary roads, and inspection every 2-3 years for secondary roads should be followed. More frequent inspections can be conducted at the discretion of the Division Traffic Services Supervisor.
- NCDOT needs to standardize the level of damage that causes a sign to be rejected. The standard should address what areas of the sign and its message need to be obscured by damage in order for the sign to be rejected. The level of acceptable damage could vary based on different kinds of damage, such as tree sap or paintballs.
- NCDOT needs to improve its replacement of Action Code 2 and 3 signs. One hundred percent of Code 2 signs and 60% of Code 3 signs should be replaced within one year.

Code 3 signs on highly traveled roads, such as interstate, should receive higher priority. This improved replacement scheme may necessitate an increase in the sign budget.

- NCDOT needs to reevaluate how signs are budgeted. The current system of individual budget line items for interstate, primary, and secondary roads results in one budget line item being expended and then no more sign maintenance can be performed on that road type for the rest of the fiscal year. NCDOT should look towards a more needs-based budgeting scheme, based on simulation results.
- NCDOT needs to expand its financial bookkeeping to keep better record of how many signs are replaced each year and why, not just the cost or square footage of these signs. Increasing the number of function codes to better capture deterioration, knockdowns, natural damage, and vandalism will help NCDOT better evaluate its budgetary needs.

11.6 Future Research

During the process of this study, there was information that would have been useful to the study's analyses if it were available. The future research ideas listed below would make more information available for sign management research in NC.

- A sign farm (group of typical road signs installed in a controlled outdoor location) could be established to measure how sign retroreflectivity varies with age and sign orientation. The sign farm would eventually address the paucity of Type III deterioration data.
- A data collection program could be initiated that would track and regularly measure Type III signs that are 10 years old or greater. This program could include signs meeting this criteria from this study as well as additional signs in the field. A sticker could be placed on the back of signs involved in this program that designates them as part of a NCDOT research program, instructs divisions to notify NCSU when the sign is replaced or removed, and warns to not discard the sign until NCSU approval is received.
- The signs measured as a part of this study could be re-measured in the future in order to track trends in retroreflectivity deterioration, the distribution of Type I and Type III signs, sign damage, and sign replacement.
- The effectiveness of additional training for nighttime sign inspectors could be explored.
- The spreadsheet simulation developed as a part of this study could be made more user-friendly.
- The simulation could be modified so that its use can be extended to other agencies.

12.0 IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The following outlines how NCDOT and other groups can use the products developed as part of this research to improve sign management in North Carolina and beyond.

12.1 Identify Research Products

The research products developed as a result of this research project include:

- Thirty-eight sign management scenarios with resulting costs and sign quality.
- Set of recommendations given in Chapter 11 of this report.
- Field sign data collected in five NCDOT Divisions.
- Sign data tables developed as a result of field sign data analysis.
- Deterioration model developed from retroreflectivity vs. sign age plots.
- Four journal papers:
    - Immaneni, V. P., Rasdorf, W., Hummer, J. E., and Yeom, C., "Field Investigation of Sign Damage Rates and Inspector Accuracy," Journal of Public Works Management and Policy, American Public Works Association (2006). Submitted 3-8-06.
    - Immaneni, V. P., Hummer, J. E., Rasdorf, W., Yeom, C., and Harris, E. A,, "Synthesis of Sign Deterioration Rates Across the US," Journal of Transportation Engineering, American Society of Civil Engineers (2006). Submitted 4-25-06.
    - Hummer, J., Rasdorf, W., Yeom, C., and Harris, E. A., "Sign Management Improvement Using a Simulation Program," Elsevier, International Journal of Transportation Research (Part A: Policy and Practice) Submitted 2006.
    - Harris, E. A., Rasdorf, W., Hummer, J. E., and Yeom, C. "Analysis of Traffic Sign Asset Management Scenarios," Transportation Research Record, Transportation Research Board, Submitted 8-1-06.

12.2 Research Products Users

The following groups within the NCDOT can apply the research products to inform and improve their decisions and policies:

- Signing Section
- Division Traffic Services
- State Road Maintenance Unit
- Asset Management
- Work Zone Traffic Control Unit

In addition, the research products can be useful to other departments of transportation, the FHWA, and to researchers in the areas of road signs and asset management.

12.3 Research Products Applications

The NCDOT and others outside the department can use the research products named in Section 12.1 to advance sign management and other areas. The NCDOT and other departments can use the 38 sign management scenarios to enhance sign quality through improved sign maintenance strategies. The report recommendations can be applied across the NCDOT to inform sign maintenance budgeting and sign management, such as how often to inspect and replace signs.

The field data collected as part of this research as well as the analyzed data are valuable to the FHWA and those involved in research on sign deterioration and maintenance for other departments and academic organizations. The analyzed data tables are a tool that NCDOT can use to evaluate current sign maintenance performance and target areas for improvement. The NCDOT Work Zone Traffic Control Unit can use the process to develop the deterioration model as a guide to analyzing their own pavement marking retroreflectivity data. The deterioration model can also be used to project sign deterioration in NCDOT asset management models. Finally, the journal papers written as a result of this research disseminate NCDOT research both within the department as well as to the rest of the research community. The research team is willing to meet with any NCDOT group that would like to learn more about the products of this research.

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14.0 APPENDICES

14.1 Retroreflectivity Versus Age Plots

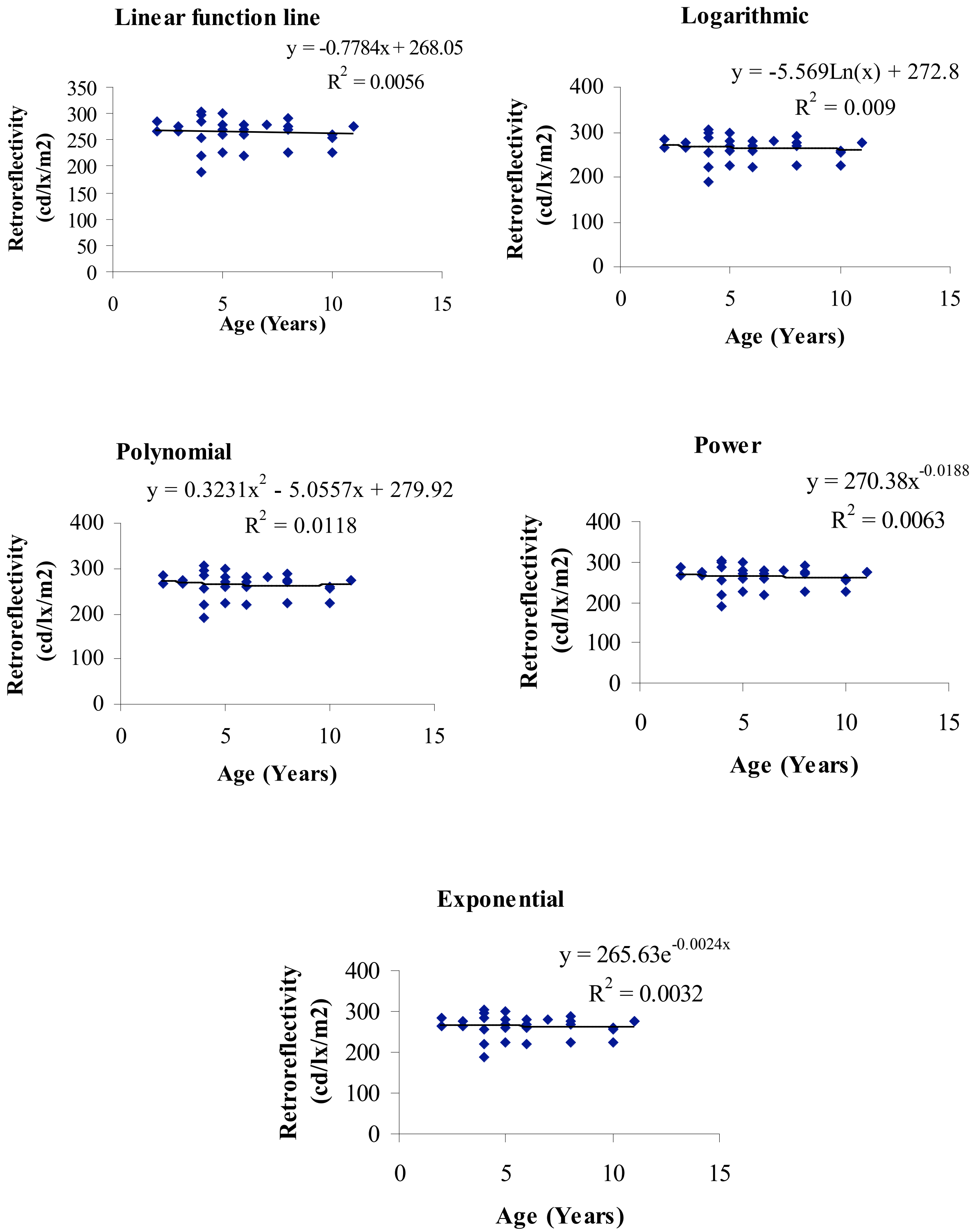

Figure 14.1. Curve Fitting for Type III White Signs (OR Study)

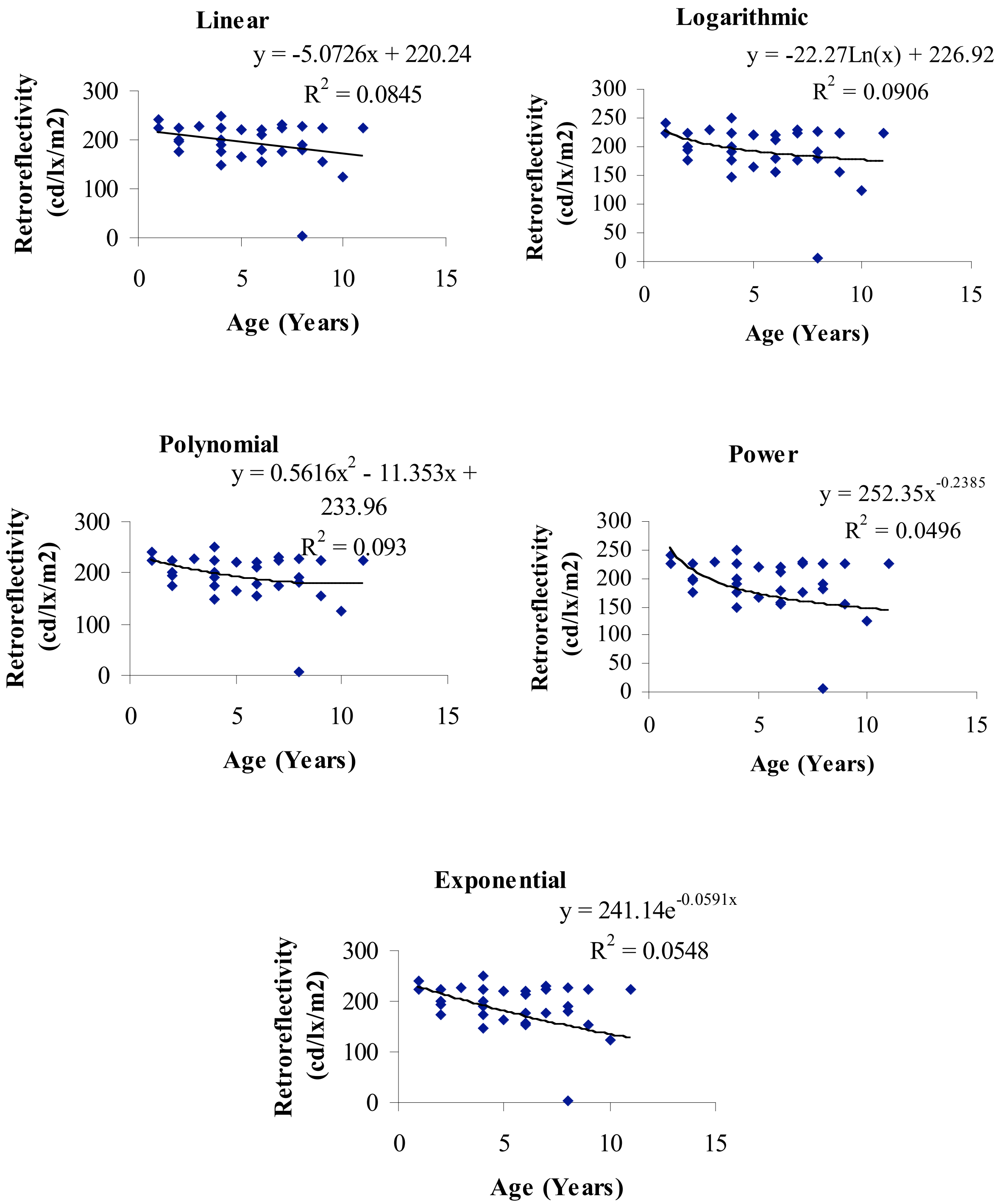

Figure 14.2. Curve Fitting for Type III Yellow Signs (OR Study)

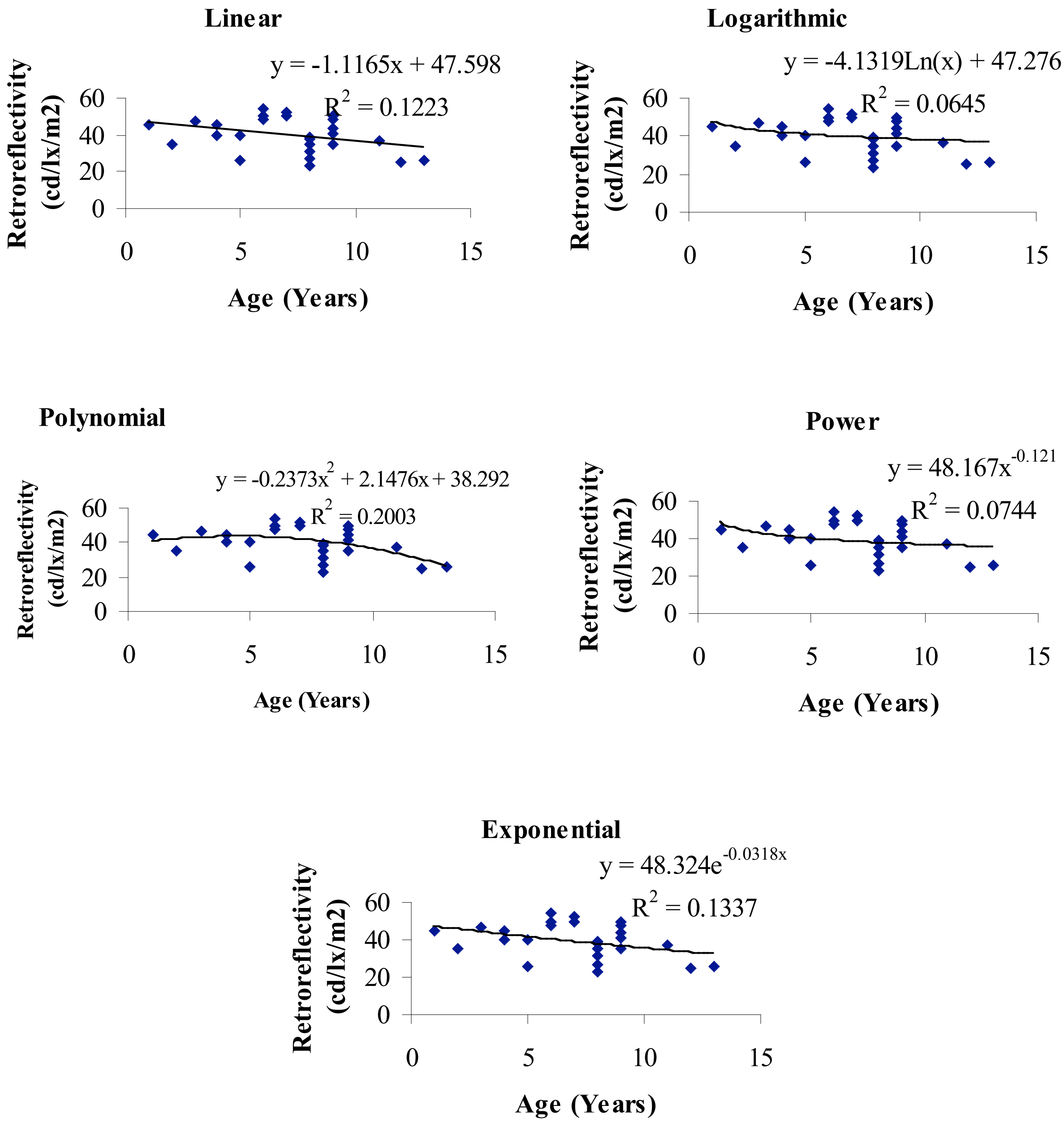

Figure 14.3. Curve Fitting for Type III Red Signs (OR Study)

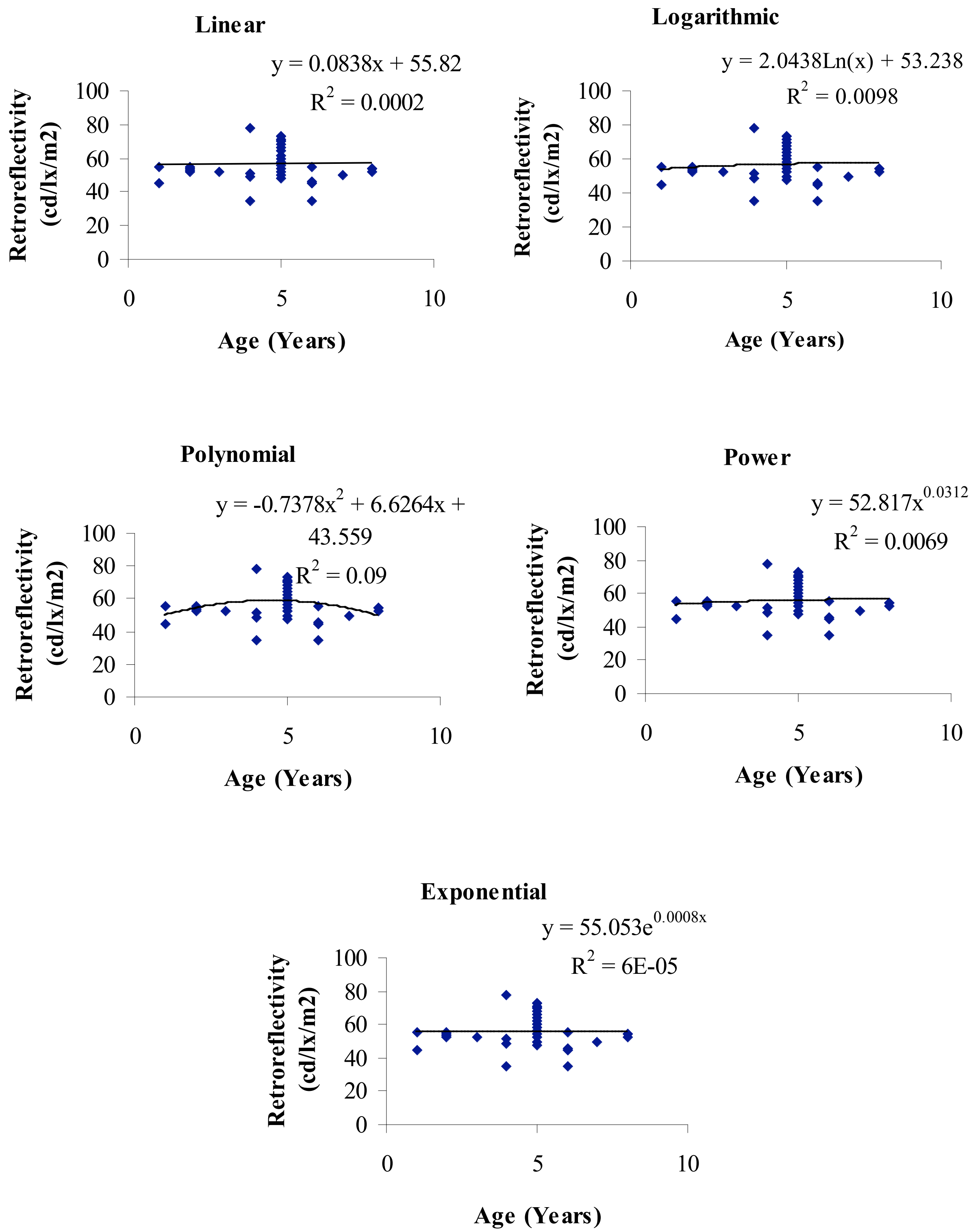

Figure 14.4 Curve Fitting for Type III Green Signs (OR Study)

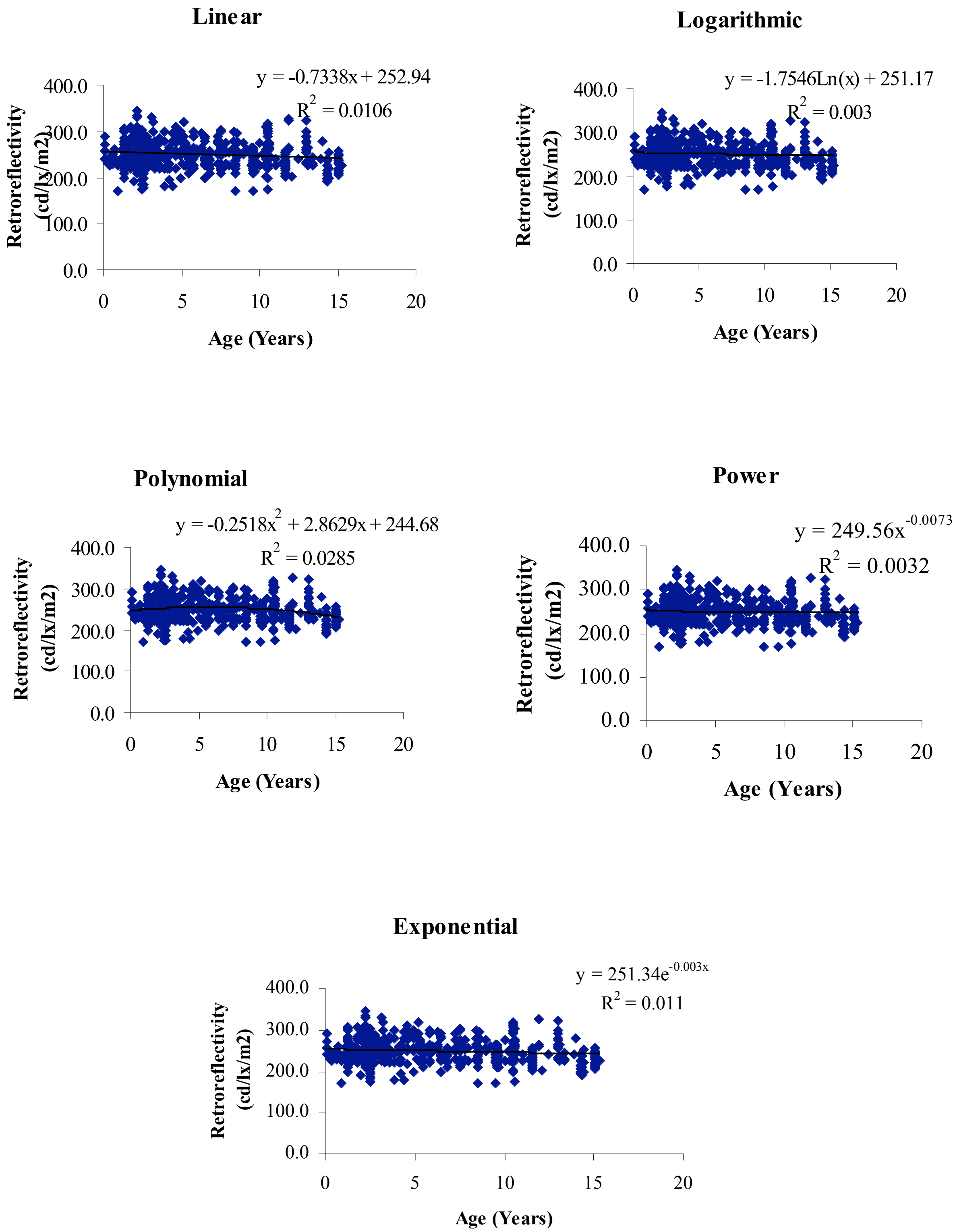

Figure 14.5. Curve Fitting for Type III White Signs (Purdue Study)

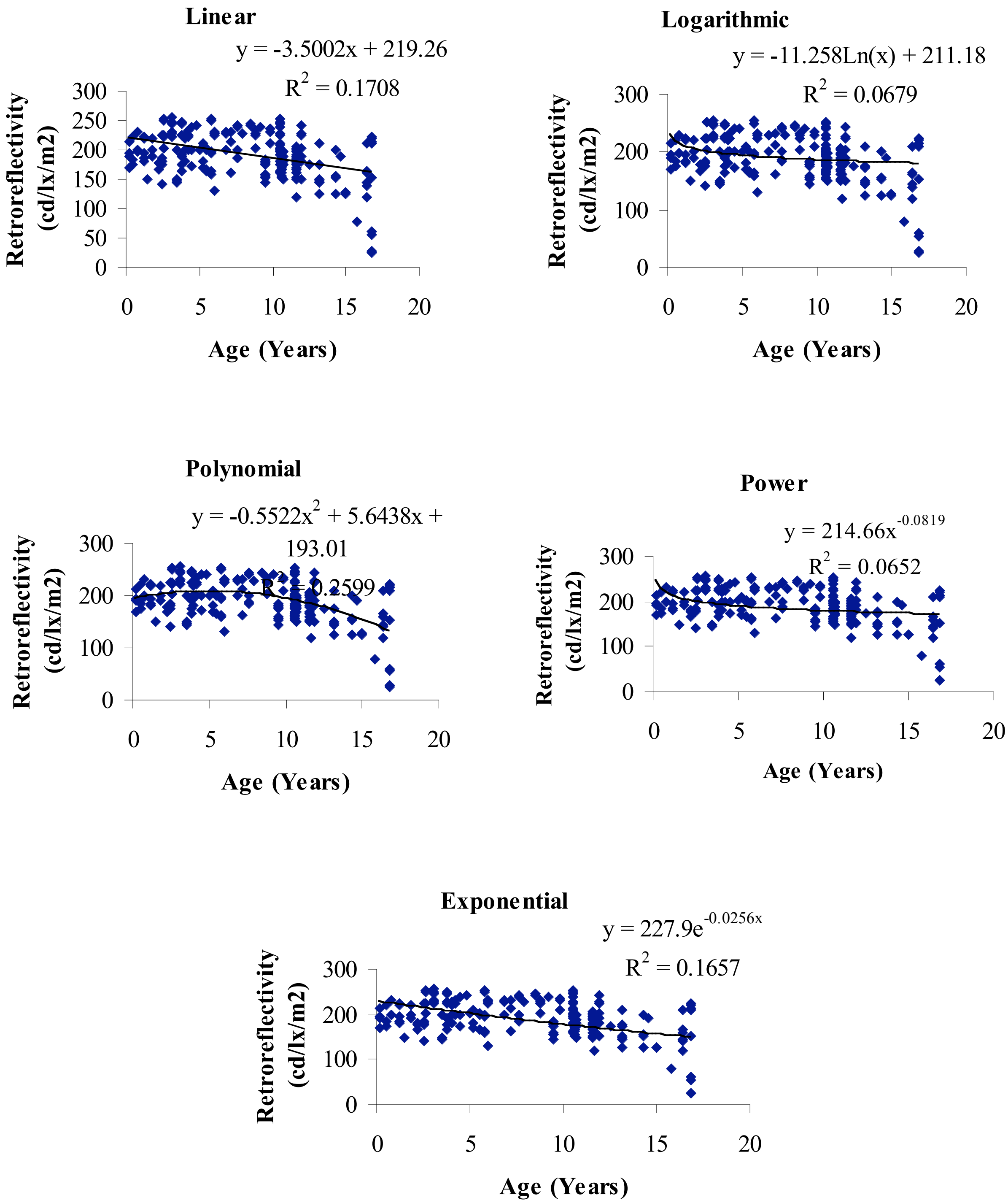

Figure 14.6. Curve Fitting for Type III Yellow Signs (Purdue Study)

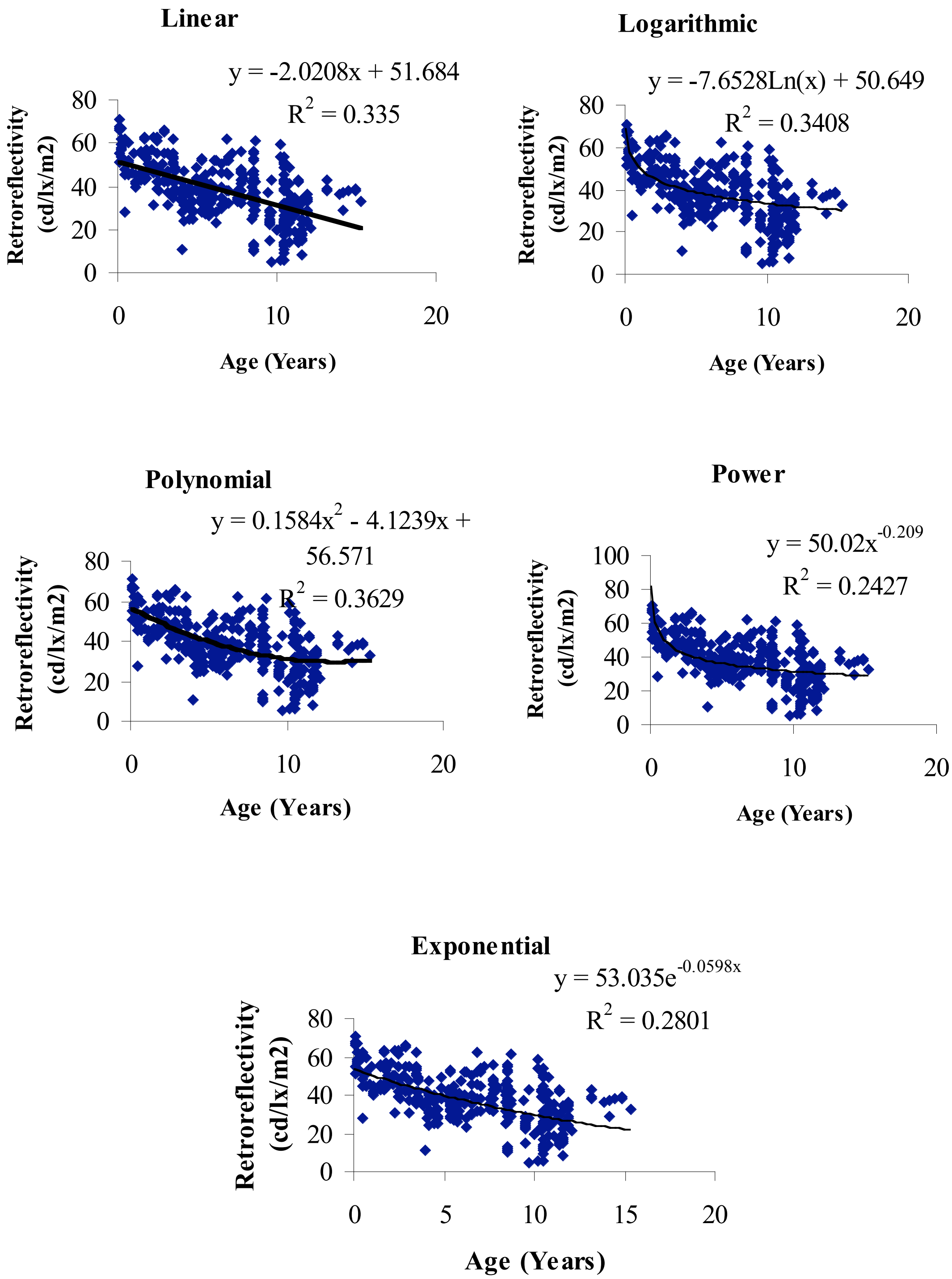

Figure 14.7. Curve Fitting for Type III Red Signs (Purdue Study)

14.2 Trip Reports

The following trip reports provide detail about trips conducted for the purpose of this research project.

14.2.1 Correction Enterprises Sign Plant

Friday, Sep. 24, 2004 (10:00 a.m. to 12:00 p.m.)
Franklin Correctional Facility, Bunn, NC
Contacts: Danny Stanley, Sign Plant Manager
(919)496-3095, email: dstanley@doc.state.nc.us

Visit Summary

Attendees**:** Professor Hummer, Elizabeth Harris, Pavan Immaneni, Chunho Yeom

- NC DOT will no longer install type I rule road signs (Engineering Grade – 7 years lifetime) and switch to type III signs (High Intensity – 12 years lifetime) by 2005.
- A retroreflectometer from Flint Trading (RetroSign® 4500) is used to check the initial retroreflectivity for all project signs at the center and corners of each panel. Rule road signs are checked at random for retroreflectivity.
- The sign plant etches date information (either day/month/year or month/year) on the back of each sign. For example, '8 24 04' means 'August 24, 2004.' (Picture 4)
- The sign plant uses 3M sheeting with pressure sensitive adhesive.
- All project signs are made using high intensity (Type III) sheeting.
- Type IX, "Diamond Grade" fluorescent orange sheeting is used for work zone signs, with an expected lifetime of 5 years due to rough handling. It is used less frequently because of its high cost, approximately $4/ft^2.
- The sign plant keeps paper records on-site for 12 years for all completed sign orders.
- 3M Scotchlite process color sign ink used to screen designs on sheeting is transparent (except for black) and has a lifetime of 12 years.
- The plant produces approximately 30,000 ft^2 of signs a week, and 1 million ft^2 of signs a year. 20,000 to 25,000 stop signs are produced each year by the plant.
- The materials and testing division of NCDOT also tests the project signs initially for retroreflectivity using a spotlight
- Completed signs must be stored upright (75-95° angle) so the glass beads in the sheeting do not crush under high pressure, losing some of their retroreflectivity.

14.2.2 Division 6 Traffic Services

December 16, 2004, 1:00 – 2:30 p.m.
Division 6 Compound, 558 Gillespie St, Fayetteville, North Carolina

Attendees: Elizabeth Harris (NCSU), Pavan Immaneni (NCSU), Chunho Yeom (NCSU), Lee Jernigan (NCDOT Div 6, Assistant Division Traffic Engineer), Kent Langdon (NCDOT Div 6, Traffic Services Supervisor)

Discussion:

Div 6 inspects signs over a 30 day period, from mid January to mid February. All documentation on the signs marked for replacement/maintenance is sent to state office in Raleigh by March 1st. The documentation is sent in the form of a spreadsheet for each division in the county. It lists what signs were marked for replacement, along with their size and type (warning, regulatory, etc.) Every year's data is kept on diskette by the division. Kent Langdon will provide the research group with a copy of this spreadsheet in digital form (it is basically the field sheets aggregated in spreadsheet form by county).

Controlled-access highways are inspected every year by supervisory personnel, such as Kent and Lee. They use a 500,000 candlepower spotlight to check the large expensive project signs along the controlled-access highways. They ride in a state passenger car or Tahoe to do this inspection, starting usually after work at 5pm. Sign maintenance crews inspect the urban, primary, and secondary roads at a frequency of every year to every three years depending on how the county is divided and the number of road miles in the county. Signs are at a maximum inspected every three years, most commonly every two years. Routes that have been inspected are highlighted on the county map. There is no recording on the map of individual signs inspected.

Generally, the sign erector evaluates the visual nighttime retroreflectivity of the sign with the erector's helper drives the F450 utility truck. The headlights on this truck are used to illuminate the sign (similar in height to SUV headlights). The retroreflectivity is observed from approx. 700 ft to up to 50ft from the sign. The average speed of inspection is around 45mph in the lane closest to the signs when not slowing to check questionable signs. A flashlight is used to inspect signs that are far from the right of way and are not adequately illuminated by the headlights. Div 6 in 2004 started a system of placing a large year date sticker on the back of signs so inspectors do not need to get out of the vehicle to check the age of the sign. If a sign is newer, but questionable, it will often be left out for an additional year.

The 2-person sign crew will work generally from 2pm to 10pm doing the nighttime inspection. This is usually done Monday night through Thursday night. Warning signs that are marked for replacement are generally replaced the next day by another sign crew working the 9-5 shift or are replaced ASAP. Other signs marked for replacement, such as warning and informational signs, are replaced as labor availability and budget allows. If a sign needs replacement, a dot is painted in the lower left hand corner. The color of the dot corresponds to the calendar year the sign was determined to need replacement. This aids in prioritizing which signs are replaced.

Replacement due to vandalism is treated as a separate "functional area" for charging labor and material expenses. The NCDOT only knows the dollar amount spent replacing vandalized signs, not the actual # of signs vandalized or the cause of the vandalism. Replacement of signs due to collisions has its own functional area code. A new materials tracing system put into place in 2004 might have the square feet of signs replaced due to vandalism. Painball guns are the major cause of vandalism in Div 6, especially along I-95 in Harnett Co.

Signs are only cleaned to improve retroreflectivity in special circumstances, such as when tree pollen/residue has coated the sign or if dirt kicked up from construction has obscured the signs. Water is the preferred cleaning method.

14.2.3 Division 6 Data Collection

NIGHTTIME SIGN INSPECTION AND FIELD CREW VALIDATION
NCDOT Division 6, Cumberland County, Fayetteville, NC

Nighttime Sign Inspection: Wednesday, January 26, 2005 (5:30 p.m. to 10:00 p.m.) and Thursday, January 27, 2005 (5:30 p.m. to 10:00 p.m.)
Field Crew Validation: Thursday, January 27, 2005 (8:00 a.m. to 4:30 p.m.), Friday, January 28, 2005 (8:00 a.m. to 1:30 p.m.), and Friday, February 4, 2005 (12:00 p.m. to 5:00 p.m.).

Contact: Kent Langdon, Traffic Services Supervisor
(910) 486-1452, email: klangdon@dot.state.nc.us

Trip Summary

NCSU research team	Elizabeth Harris, Pavan Immaneni, Chunho Yeom
Sign crew (yrs. experience)	Leon Gross (14), Ben Cain (1.5)
Crew vehicle	Ford F150 Pickup Truck
Ride location	Night 1: Southwestern Cumberland Co. SR Night 2: Hope Mills area SR
Number of signs measured by NCSU	316

Trip Observations

- Division 6 uses the date punch sticker to mark day, month, and year of installation on the back of signs. A sticker has also been used since 2004 to mark the last two digits of the installation year on the back of the sign so the date can be seen from the sign truck.

- Division 6 is in the process of replacing all type I warning signs with type III. If the sign crew saw a type I warning sign with only a slight loss in retroreflectivity or slight vandalism (that might otherwise be permissible to let remain), it was marked for replacement with a type III sign.

- During the NCSU team's daytime sign measurement on Friday, January 28, their NCDOT-loaned retroreflectometer developed an error that required it to be returned to Flint Trading. The NCSU team received a substitute retroreflectometer during the following week, but had to drive to Flint Trading in Thomasville, NC on Friday, February 4 so the remote trigger on the retroreflectometer could be repaired. Once the repair was complete, the NCSU team drove to Fayetteville and finished their daytime inspections.

- Division 6 ignores no parking, no litter, and adopt-a-highway signs during nighttime inspection. The sign crew said that they are removing the no litter and bridge freezes before road signs over time because they have little function and only clutter the roadside.

14.2.4 Division 13 Data Collection

NIGHTTIME SIGN INSPECTION AND FIELD CREW VALIDATION
NCDOT Division 13, Buncombe County, Asheville, NC

Nighttime Sign Inspection: Monday, February 7, 2005 (6:00 p.m. to 8:30 p.m.) and Tuesday, February 8, 2005 (6:00 p.m. to 8:30 p.m.)
Field Crew Validation: Tuesday, February 8, 2005 (8:00 a.m. to 5:00 p.m.), Wednesday, February 9, 2005 (8:00 a.m. to 4:00 p.m.)

Contact: Roger Arrowood, Sign Supervisor, (828) 298-0094

Trip Summary

NCSU research team	Elizabeth Harris, Pavan Immaneni, Chunho Yeom
Sign crew	Roger Arrowood, Brent King
Crew vehicle	Chevy 1500 crew cab pickup truck
Ride location	Night 1:Southeastern Buncombe Co. SR and primary roads Night 2: Future I-26 and US 70
Number of signs measured by NCSU	300

Trip Observations

- Division 13 primarily uses pencil to mark day, month, and year of installation on the back of signs. Many signs did not have any date marked on them, so the date of manufacture was recorded if it could be found.
- On future interstate 26, several new signs had been installed on top of older signs, making it impossible to determine the installation date and age of the sign.
- Most large project signs on the interstate had no date sticker or other date visible to the NCSU team on them. However, exit signs, which were recently installed, had date stickers that were visible.
- In the rural areas, tree sap is a common cause of low nighttime sign visibility.
- Division 13 checked the nighttime visibility of adopt-a-highway signs.
- On future I-26, several right merging traffic signs had a dim region in the middle at night.
- Three rejected signs on future I-26 could not be measured because there was no nearby place for the sign crew to park safely and exit the vehicle.
- Division 13 uses the term “bad sheeting” to describe signs with low retroreflectivity due to aging alone.
- The majority of SR signs in division 13 are type I. Type III sheeting was only found at stop signs, and along some primary roads and the interstate.

14.2.5 Division 8 Data Collection

NIGHTTIME SIGN INSPECTION AND FIELD CREW VALIDATION
NCDOT Division 8, Chatham County, Siler City, NC

Nighttime Sign Inspection: Wednesday, February 23, 2005 (6:00 p.m. to 9:30 p.m.)
Field Crew Validation: Friday, February 25, 2005 (8:00 a.m. to 5:00 p.m.)

Contact: Wayne Williams, Sign Supervisor
(910)947-3930, email: gwwilliams@dot.state.nc.us

Trip Summary

NCSU research team	Elizabeth Harris, Pavan Immaneni, Chunho Yeom
Sign crew (yrs. experience)	H.T. McCrimmon (9), Clyde Spinks (9)
Crew vehicle	Ford F450 XL Superduty sign truck (new, only 500 miles on it) "SIGN 83"
Ride location	Southwestern Chatham Co. SR and primary roads
Number of signs measured by NCSU	136

Trip Observations

- Division 8 uses the date punch sticker to mark day, month, and year of installation on the back of signs. Black marker is also used to mark the last two digits of the installation year on the back of the sign so the date can be seen from the sign truck.

- On Old US 421, the sign crew mentioned that signs there often were coated by a film of dirt kicked up by trucks as they travel too and from large hog feed mills along the road. The sign crews try to use a mixture of soap, water, and Windex to clean dirty signs to see if there retroreflectivity can be restored. If the sign has good retroreflectivity after cleaning, it is left up.

- The NCSU team used glass cleaner to clean some of the signs indicated by the sign crew of having poor retroreflectivity because they were dirty. Most of the signs that the team cleaned had almost no retroreflectivity prior to cleaning but one they were cleaned, their retroreflectivity often was above the FHWA standard.
- The sign crew said that many signs were often bent by roadside mowers, even though they have been installing the signs at a higher height to avoid this.
- The crews said that they only do nighttime visual inspection of rural SR areas every 5 years, as opposed to the typical rotation in other divisions of 2-3 years. This sign crew is careful to not replace all poor retroreflectivity signs in their area at the same time so that years later all of the signs installed lose their retroreflectivity at the same time. The Division 8 sign crew says that although they only do inspection every 5 years, they are constantly looking for missing, knocked-down, bent, vandalized, or dirty signs during their shifts.
- The sign crew also checked stop signs on side streets that intersected the major roads during the nighttime inspection run.

14.2.6 Division 12 Data Collection

NIGHTTIME SIGN INSPECTION AND FIELD CREW VALIDATION
NCDOT Division 12, Cleveland County, Shelby, NC

Nighttime Sign Inspection: Wednesday, March 9, 2005 (6:00 p.m. to 9:30 p.m.)
Field Crew Validation: Thursday March 10, 2005 (8:00 a.m. to 5:30 p.m.)

Contact: Phil Eaker, Acting Traffic Services Supervisor
(704) 480-5423, email: peaker@dot.state.nc.us

Trip Summary

NCSU research team	Elizabeth Harris, Pavan Immaneni, Chunho Yeom
Sign crew (yrs. experience)	Jason Bivens (10), Justin Loaces (1)
Crew vehicle	2003 Ford F150 XL Truck
Ride location	Southeastern Cumberland Co. SR and primary roads, I-85
Number of signs measured by NCSU	183

Trip Observations

- Division 12 uses the date punch sticker and black marker to indicate the day, month, and year of sign installation. The black marker is used because it is easier to read from sign crew trucks on the road.

- The sign crew thought that their job could be made easier and more efficient if the sign trucks had GPS units that could map their location and link to a database of sign type and location. This would be especially helpful in the situation where a sign is missing and the sign crew is not sure what type of sign was originally there.

- Division 12 has mostly exhausted its inventory of type I signs, and is primarily installing Type III signs on the roads.

- When asked if they had observed right merging traffic signs on the interstate having dim regions at night similar to Division 13, the sign crew said that they had observed this with several signs, which they consequently replaced.

14.2.7 Division 2 Data Collection

NIGHTTIME SIGN INSPECTION AND FIELD CREW VALIDATION
NCDOT Division 2, Pitt County, Greenville, NC

Nighttime Sign Inspection: Wednesday, April 20, 2005 (7:30 p.m. to 9:30 p.m.)
Field Crew Validation: Friday April 22, 2005 (8:00 a.m. to 3:30 p.m.)

Contact: Jim Evans, Traffic Services Supervisor
(252) 830-3493, email: jfevans@dot.state.nc.us

Trip Summary

NCSU research team	Elizabeth Harris, Pavan Immaneni, Chunho Yeom
Sign crew (yrs. experience, age)	Chad Mills (3,30), Donta Person (5,24)
Crew vehicle	Ford F150 XL Truck
Ride location	Southwestern Pitt Co. SR and primary roads
Number of signs measured by NCSU	120

Trip Observations

- Division 2 uses the date punch sticker to indicate the day, month, and year of sign installation.
- There is a high emphasis on maintenance in the division, and cooperation between the division and the 911 signage and State Highway Patrol in the area of notifying the division of damaged or missing signs.
- According to the sign crew, in a previous year roadside mowers caused $1200 damage to road signs in one day in Pitt Co.
- Division 2 only removes “Bridge Ices Before Road” signs on straight road sections. The signs remain near curved road sections.
- Division 2 uses square wood posts instead of u-channels to post nearly all of their signs. Division 2 has found the wood posts to lean less than steel in their soils.
- Division 2 does make an effort to maintain adopt-a-highway signs, but they are a low priority.
- Division 2 uses a pink cleaner obtained from Correction Enterprises to clean signs.
- The sign crew estimates that 85% of stop signs in Pitt County have been converted to high intensity sheeting so far.

14.2.8 TRB Asset Management Conference

TRB 6th National Asset Management Conference
October 31 to November 2, 2005
Kansas City, Missouri

Sessions Attended

- Developing and Implementing Pavement Preservation Within Asset Management: Network-Level Issues, Part 1
    - A good presentation was given on how improving pavement surface condition improves road safety
    - NCDOT has a pavement management system in place
- Developing and Implementing Pavement Preservation Within Asset Management: Network-Level Issues, Part 2
    - Basic definitions of Asset Management: objective of better decision making based upon quality information
    - There is cost associated with collecting quality asset data
- Exploring Resources
    - This session focused on training and resources available for encouraging asset management within an organization.
    - Assets have a condition of good/fair/poor, set a condition target
- The Role of Maintenance in Transportation Asset Management: The Buck Stops Here
    - This was the session that I presented at. There seemed to be good interest in the topic of sign lifetime/deterioration.
    - I learned more about how Virginia DOT conducts random condition assessments in each of their divisions yearly to determine the condition of their signs (1/10 mile segments of interstate, primary, and secondary roads).
    - Virginia DOT also has a database of all large overhead signs
    - There is a need to determine how assets are failing
    - The City of Portland, Oregon has a GIS-based inventory of all of their signs (along with other assets).
    - Portland uses an age-based system to rate their assets as good, fair or poor.
    - Asset data is expensive and needs to be constantly managed and maintained.
- Transportation Asset Management Applications in Large, Complex Organizations
    - North Carolina DOT has a maintenance management system (MMS) in addition to a pavement management system, they are trying to relate the two.
    - The NCDOT MMS tracks the condition of signs, mostly just the time sheets/work orders showing how much money is spent
- Facilitated Discussions on Issues in Large, Complex Organizations
- *All conference presentations will be available on the TRB website.*

Contacts Made

- David Hutson, dave.hutson@pdxtrans.org, City of Portland Sign Asset Manager
- Doyt Bolling, doyt@cc.usu.edu, Sending me a copy of sign asset management software and GIS system he uses
- Charles Pilson, cpilson@agileassets.com, works with NCDOT MMS and PMS

- Phebe Greenwood, Virginia DOT, Maintenance Division, interested in how to do retroreflectivity measurements

Issues

- Since NCDOT is so large (like Virginia DOT), it is difficult to do a complete sign inventory for the state
- If/When we revise the inspector training and inspection procedure, we should look to add data collection that will support state-wide asset management efforts
- Better creation of a signs budget through asset management could help relieve the road-class related (interstate, primary, secondary) budget pressures in the divisions that affect the sign inspection/replacement process

14.2.9 TRB Annual Meeting 2006

January 22-26, 2006
Washington D.C.

Sessions and Meetings Attended

- **Traffic Control Devices Committee**
    - Committee identified developing a TCD management system and TCD lifetime issues as priority issues
    - Will possibly arrange a PhD student dissertation session annually
- **Infrastructure Management: Papers from 2005 First Annual Interuniversity Symposium on Infrastructure Management**
    - Presentation on how to quantify the benefits of asset management using before and after, regression, and benefit-cost analysis
    - Presentation on knowledge management (capturing tacit knowledge inside people's heads)
- **Prospects for Reducing Heavy-Duty Emissions and Fossil Fuel Use**
    - Presented on GIS truck stop electrification site selection method
- **Signing and Marking Materials Committee**
    - FHWA trying to create bibliography of all retroreflectivity research
    - This meeting mostly focused on pavement markings this year
    - Learned about upcoming 2006 NTPEP meeting in Wilmington, NC
    - Considering developing minimum retro standards based on a human factors performance-based requirement (by roadway classification, sign location, and when driver needs to see sign)
    - Presentation on analysis of cost of minimum retro standards for pavement markings could be used to calculate cost for sign sheeting
- **Transportation Asset Management Committee**
    - FHWA is pushing roadway safety hardware management, picked up their publications on this topic
    - The next TRB asset management conference will be in 2007

Contacts Made

- Ken Opelia, ken.opiela@fhwa.dot.gov, FHWA
- David Burns, dmburns@mmm.com, 3M Traffic Safety Systems
- H. Gene Hawkins, gene-h@tamu.edu, TRB TCD Committee, Texas A&M