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A Quantitative Evaluation of the Nighttime Visual Sign Inspection Method

A research project to determine the appropriate sign inspection and replacement procedure was conducted at North Carolina State University and sponsored by the North Carolina DOT. The purpose was to determine the optimum strategy for sign inspection and replacement under different conditions to respond to the pending retroreflectivity requirements. This paper reports on a spreadsheet tool developed to quantitatively evaluate the effectiveness of different sign inspection and replacement scenarios. The spreadsheet was designed for yellow and red engineer-grade sign sheetings, and takes into account sign vandalism and knock-downs as well as normal sign aging. The spreadsheet provides estimates of the number of signs in place that would not meet the minimum retroreflectivity standard and the cost of the sign inspection and replacement program.

The results from a number of trials of the spreadsheet show that agencies that generally conform to the key assumptions made to build the spreadsheet should consider replacing all signs every seven years, as that insures that no aged signs are in place at a relatively low cost. If total replacement is not possible, an inspection program using retroreflectometers every three years appears very competitive in its effectiveness with a program using typical visual inspection rates each year. The retroreflectometers appear to allow fewer deficient signs, while the typical visual inspection program costs are lower for a given vandalism rate. More conservative visual sign replacement rates do not appear to offer distinct advantages, because typical replacement rates with visual inspections every two or three years allow relatively high numbers of deficient signs to remain on the roads.

by William J. Rasdorf, Joseph E. Hummer, Stephanie C. Vereen and Hubo Cai

Transportation agencies such as state Departments of Transportation (DOTs) are responsible for managing roads and signs across the United States. One of the concerns of state DOTs is sign inventory and management. Statistics from the National Highway Traffic Safety Administration reveal that in 1999, there were 286,000 crashes because of stop sign issues nationwide (Congressional Information Service, 1999). The Institute of Transportation Engineers (ITE) *Traffic Sign Handbook* states, "if signing is done improperly, longer driver response times, inappropriate responses, or errors will result, all of which adversely affect safety" (Institute of Transportation Engineers, 1997). A report by the Federal Highway Administration (FHWA) reveals that the risk of dying in a crash at night, when signs are more difficult to see, is nearly three times that of dying in the daytime (U. S. Department of Transportation, 1999). It is imperative that DOTs have effective sign testing and replacement programs to significantly reduce the safety risks to motorists.

One important aspect of sign performance 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). The English unit for Ra is cd/fc/sf (candelas per foot-candle per square foot). Ra has the same value in the metric system. It is often referred to as specific intensity per unit area (SIA).

The effectiveness of retroreflective (light returned to the driver) sign sheeting has not been quantified. Beginning in 1984, the Center for Auto Safety petitioned FHWA to establish standards for retroreflectivity. In 1993, the Department of Transportation Appropriation Act stated that the U. S. Secretary of Transportation should revise the *Manual for Uniform Traffic Control Devices* (MUTCD) to include "a standard for a minimum level of retroreflectivity that must be maintained for pavement markings and signs, which shall apply to all roads open to public travel" (AASHTO, 2000). FHWA formulated two related reports in 1998. One report aimed at "evaluating the applicability and practicality of the minimum-maintained levels of sign retroreflectivity proposed by FHWA and the hand-held retroreflectometer that measures sign retroreflectivity" (McGee and Taori, 1998). The other report aimed at providing explanations and procedures to assist agencies in developing their own sign management systems to meet the minimum retroreflectivity requirements (McGee and Paniati, 1998). Although the 2000 edition of the MUTCD did not include retroreflectivity guidelines, Section 2A.09 of the MUTCD is reserved for their future addition.

New retroreflectivity requirements in the pending standard will present several new issues to state transportation agencies responsible for sign replacement and maintenance. In the case of North Carolina, the state owns and maintains approximately 78,000 miles of roadway. Interstate and primary roads contain approximately 388,000 signs and secondary roads contain approximately 605,000 signs (Kirtley and Rasdorf, 2001; Palmquist and Rasdorf, 2002). The new standard poses serious implementation challenges to the North Carolina DOT. Other state DOTs face similar challenges. 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.

To meet the proposed new standard, state DOTs have to develop their own sign inspection and replacement procedures. Current procedures will have to be examined, together with alternatives, to determine the optimum sign inspection and replacement procedure.

A research project to determine the appropriate sign inspection and replacement procedure was conducted at North Carolina State University, sponsored by the North Carolina DOT. The purpose was to determine the optimum strategy for sign inspection and replacement under different conditions to respond to the pending retroreflectivity requirements. This paper reports on some of the findings of this research project. In particular, the paper focuses on a tool developed to investigate the effectiveness of different sign inspection and replacement scenarios.

NIGHTTIME SIGN INSPECTION

Nighttime observation of signs is currently the most commonly used procedure in the United States to determine whether signs are visually adequate. Generally, in this procedure, a two-member team (a driver and a recorder) will drive a vehicle along a road observing and measuring the conditions of road signs and determining the appropriate actions to be taken such as replacement and repair.

The North Carolina DOT Nighttime Visual Inspection Method

The North Carolina DOT currently employs a nighttime visual sign inspection method to find failed signs along state-maintained roads. Sign condition is evaluated based on the observers' visual observation without using any retroreflectivity measurement equipment. Most inspectors are experienced. New or temporary employees are always paired with an experienced observer.

The North Carolina DOT inspection method is simply to follow a predetermined driving path and evaluate all signs along this path to determine if they are visually adequate. Roads are driven in both directions. However, on many secondary roads, where signs are sparse, the crew will slow the car and shine a light back on signs facing the opposite direction for evaluation. Visually, signs are evaluated at posted speed limits, using the headlights of the car as the light source. If a sign is determined to be questionable, the crew will get out of the car to take a closer look at the sign sheeting and check the sticker indicating the installation date of the sign to determine the appropriate action to be taken, such as replacement, repair, or cleaning. The recorder uses a state-issued form to inventory signs needing replacement. Signs not needing replacement, but requiring repair or cleaning, are recorded on a separate form.

During the nighttime visual inspections, conditions other than retroreflectivity that affect the visibility of the signs are also evaluated. For example, signs might be placed incorrectly or be obstructed by bushes. These conditions will also lead to appropriate actions to be taken so that proper placement and visibility are achieved.

It is noted that employee performance is also an important factor in evaluating sign conditions. The same employee may work in a county for many years, may be very familiar with the roads, and may take great pride in ensuring that the signs in the area for which he/she is responsible are in excellent condition. But some employees may not be as meticulous and new or temporary employees may not feel as great a sense of pride and responsibility for maintaining the signs. This results in a lower work standard and poor sign replacement practices.

Retroreflectivity Measurement

There are currently two main methods to assess the retroreflectivity of a sign in the field. The first is a visual assessment as is being used by the North Carolina DOT. Visual inspection can be performed at night using a bright light and the human eye. The second method to assess retroreflectivity utilizes retroreflectometers, either hand-held or mobile. Neither of the two methods is completely accurate. The accuracy of visual assessment is questionable because different individuals may have varying visual observations of the same sign, even given the same set of inspection guidelines. The use of hand-held retroreflectometers can be time-consuming, often requiring up to four readings per color. Mobile retroreflectometers are still being developed and improved. "There are currently no traceable methods in the United States to determine the accuracy of retroreflectivity measurements because national calibration standards for retroreflectivity do not exist" (AASHTO, 2000).

Mobile Measurement. The Federal Highway Administration has a prototype van able to measure sign retroreflectivity while moving at normal highway speeds. It is known as SMARTS, or Sign Management and Retroreflectivity Tracking System. The van uses a calibrated strobe lamp, mounted on its top, to bounce light off highway signs. The returned light is measured and processed by computer to account for observation angle. It is then compared to guidelines (Hatzi, 2001).

Vans like this may be a common future method for evaluating signs, but they are not ready for widespread use. Using the FHWA van to measure multiple signs in a row is difficult because a successive sign closer than 200 feet falls beneath the tracking range distance. Also, the software is programmed to look for the brightest signs. This is not ideal because out of a group of signs the one needing replacement is the one missed. When left, right, and overhead signs are located at the same milepost, multiple passes would be required to measure all of them, which could prove to be very costly.

The cost per mile to run the FHWA van is unknown. The initial cost of the SMARTS van and all of the equipment and software was about $210,000. This does not include continuous maintenance and upgrades. This van is several years old and to reproduce the same van today would cost much more. Data validating the accuracy and repeatability of measurements recorded in the van are not yet available.

Hand-Held Measurement. Hand-held retroreflectometers are instruments capable of measuring the retroreflectivity of signs, that is, the amount of light reflected back to the driver. They range in weight up to around five pounds, although newer units are lighter. They can be transported easily in the field. Most available units are equipped with rechargeable batteries, some of which are able to be charged in as little as 15 minutes. Currently there are several models available with varying capabilities. The underlying function and principle behind each model is the same. When pointed at, or placed directly against a sign, the instrument emits a beam of light and measures the amount of reflected light returned from the sign's sheeting. The unit can be operated by one person but may sometimes require an extension pole to reach tall signs. The operator must be positioned in front of a sign. Some models have to be placed directly on the sign being evaluated while others operate at ranges of around 50 to 100 feet from the sign.

To maintain accuracy, retroreflectometers are typically calibrated for each sheeting color and type before use. Most models come with a calibration standard with known retroreflectivity levels, which is used to test the instrument at a time interval determined by the manufacturer.

The reference standard is supplied by the manufacturer in a storage case that is rarely carried to the field where it may be altered by uncontrolled conditions. "Although the use of retroreflectometers is an objective measurement method, it can be expensive and time-consuming. As many as 60 measurements may be needed to evaluate the retroreflectivity of a large sign; frequently a lane of traffic must be closed to do so" (Long, 1997).

Some units are capable of data collection, storage, and download. The storage capacity varies from unit to unit. Stored measurements can later be downloaded to a computer. However, the number of measurements held by the instrument is sometimes limited to a little more than 1,000 for some models. If at least four measurements are taken per sign, then only about 250 signs can be measured before the data will need to be downloaded into a computer. Retroreflectometers cost up to $9,000, although this varies among manufacturers and models.

Comparison of Measurement Methods

The previously-mentioned methods to inspect signs have advantages and disadvantages that are summarized in Table 1. The visual inspection method is efficient compared to the others and it can identify missing and vandalized signs. However, it does not generate numerical data about each sign (signs are evaluated either as currently acceptable or as needing attention such as replacement, repair, or cleaning). Finally, visual inspection is labor- and time-intensive and its reliability and accuracy are uncertain.

Hand-held retroreflectivity measurement units are capable of providing numerical data. However, state DOTs are concerned that measurements with hand-held units would be slow. The accuracy and reliability of these instruments are also questionable. "There can be significant variability among instruments measuring the same object, and the standards do not ensure the accuracy of the instruments" (NCHRP, 2003). Currently, there are no national calibration standards for retroreflectivity, but NCHRP Project 5-16 is dedicated to this task (NCHRP, 2003).

A mobile measurement van would be able to solve many of the problems a hand-held unit cannot, particularly faster measurement. However, vans are not yet ready to be relied on for commercial use. A mobile unit will be expensive regardless of whether it is assembled independently by the state or if a service is contracted to do the work.

In North Carolina, previous studies determined that there are approximately 1,000,000 in-place signs along state-maintained roads in North Carolina (Kirtley and Rasdorf, 2001; Palmquist and Rasdorf, 2002). The North Carolina DOT does not believe that measuring all these signs using a hand-held unit is realistic because of the time required. According to a Washington State study (Lagergren 1987), a measurement rate of 10 signs per hour for ground mounted warning and stop signs located on the

Table 1: Comparison of Inspection Methods (Numerical vs. Non-numerical Generation)

Method	Advantages	Disadvantages
Van (Mobile Measurement Unit)	• Can collect at near highway speeds • Flexibility in choosing technologies • Can carry redundant systems • High accuracy possible *	• Technology not fully developed yet • If buying, requires large investment • May require several passes on a particular road • Skilled crew required *
Hand held Measurement Unit	• Provides numerical data to compare against proposed standards	• Need to stop the vehicle and become aligned with the sign • Multiple measurements required for each sign • Instrument accuracy uncertain
Visual Inspection	• Evaluation rate is fairly quick • Trained crews available	• No numerical data generated • Labor and time intensive • Does this method provide sufficient liability protection?

* (Hummer, Karimi, and Khattak, 2000)

road shoulder was established when using the hand-held retroreflectometer. Based on this measurement rate, it would require 42,500 person-hours to measure the North Carolina DOT's warning and stop signs.

QUANTITATIVE EVALUATION OF THE VISUAL INSPECTION METHOD

The previous sections revealed that using retroreflectometers to measure the traffic signs along the state-maintained roads in North Carolina, either using a hand-held unit or a mobile measurement unit (van), appears infeasible and impractical. The visual inspection method currently being used in North Carolina apparently should continue to be used to evaluate sign conditions.

However, the accuracy of the visual inspection method is questionable. As noted earlier, the human factor is critical when this method is used. Different observers will have different judgments about the condition of the sign being observed. Even the same observer might have different judgments on the same sign if it were evaluated several times during a short period when the sign condition had no significant changes. There is a need to evaluate this visual inspection method while taking into considerations factors such as the observers' accuracy in determining the signs' conditions, the inspection frequency, and vandalism.

This section describes a quantitative evaluation of the visual inspection method. The model is based on data from the Washington State Department of Transportation *Traffic Sign Retroreflectivity Measurements Using Human Observers* study (Lagergren, 1987).

Washington State Study

The Washington State 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 (Lagergren, 1987). Its purpose was to compare "the individual observer rating of the signs and the rating of the signs calculated by using retroreflectometer." 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 was placed on two road types, a rural highway containing 76 signs and an urban highway containing 54 signs. Figures 1 and 2 represent the primary results of the uncontrolled highway portion of the study using the data based on the median results of 17 observers' ratings of 86 warning signs and 44 stop signs.

Sign sheeting type was not a factor during any portion of the study. This is congruent with North Carolina sign inspection practices because sign sheeting type is not considered during nighttime visual sign inspections, only whether the sign is sufficiently visible or not. The observers in the Washington State study rated the retroreflectivity of signs based on their visual judgments using a scale of 0 to 4. Table 2 lists each rating category, the corresponding coefficient of retroreflection (RA), which is described as "specific intensity per unit area," or SIA, and a description of the category. 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

Table 2: Sign Ratings - Washington State Study

Rating	Corresponding SIA Value (cd/sf/fc)*	Description
0	0 7	Worst retroreflectivity
1	7 19	Low retroreflectivity or other defect, sign ready for replacement
2	19 37	Adequate retroreflectivity, looks okay, some defects but does not need replacement
3	37 70	Good retroreflectivity
4	>70	Brand new sign

* cd/sf/fc represents candelas per foot candle per square foot

"inconsistency among observers was averaged in the median decision" (Lagergren, 1987).

In Figure 1, of the 74% reported accuracy for warning signs, 50% was the correct decision not to replace a sign (correct negative) and 24% was 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). Thus the observers identified 44% of the signs as needing replacement (20% + 24%). Retroreflectometers identified 30% of the warning signs, whether evaluated correctly by observers or not, as needing replacement. Thus, the observers erred on the safer side (44% vs. 30%).

In Figure 2, of the 75% reported accuracy for stop signs, 32% was the correct decision not to replace a sign (correct negative) and 43% was the correct decision to replace a sign (correct positive). Of the 25% inaccuracy, 6% of the signs should have been replaced and were not (false negative) and 19% of the signs should not have been replaced and were (false positive). In this case the observers identified 62% of the signs as needing replacement (19% + 43%). A total of 49% of stop signs needed replacement as identified by a retroreflectometer, whether evaluated correctly by observers or not. Thus, as with warning signs these figures show a conservative approach taken by the observer (62% vs. 49%).

Figures 3 and 4 show the frequency distributions of the observer ratings for the warning and stop signs of the Washington State Study. The X-axis represents the sign observers' ratings and the Y-axis represents the sign ratings as determined by a retroreflectometer. Each cell represents the number of signs and the percentage of signs corresponding to the sign observers' ratings and the sign ratings determined by a retroreflectometer. For example, cell (0, 0) indicates that of the 99 signs that were categorized into category 0 by the retroreflectometer, 87% were categorized into category 0 by the observers using the visual inspection method. The data in these two figures will be used in our analysis, described in the next section.

Figures 3 and 4 merit a few additional comments. The scale on the left is the SIA code indicating the retroreflectivity of the sign. SIA is correlated with sign age due to the fact that the signs toward the top of the scale are newer and those toward the bottom are older. The sign category (0, 1, 2, 3, 4) indicates the rating the sign received by the inspector, with ratings defined in Table 2.

The small sample of observers in the Washington State Study limits the overall impact of the study's results. However, the Washington State Study was the only one available to use in our analysis.

Methodology

The methodology introduced here was developed to simulate the sign inspection and replacement process.The method has the following general assumptions:

- The inspectors in the agency of interest are as good as those in the Washington State study.
- In keeping with the fact that most signs installed on North Carolina public roads use engineer-grade sheeting, we assume that a sign has a useful life of seven years, after

Figure 1: Decision Percentages for Warning Signs • Washington State Study

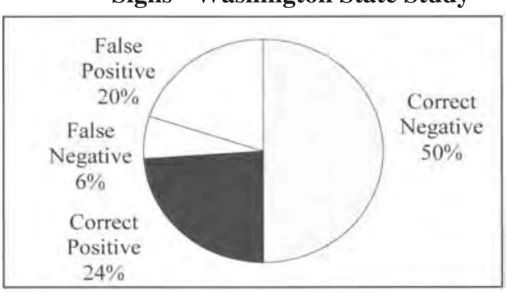

Figure 2: Decision Percentages for Stop Signs • Washington State Study

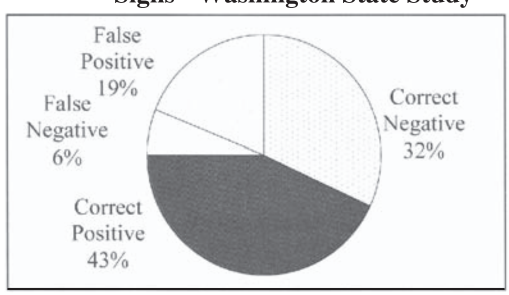

Figure 3: Frequency Distribution of Observer Ratings for Warning Signs Washington State Study

SIA	Sign Category, Retroreflectometer		0	1	2	3	4	
70	DO NOT REPLACE	4	0 (0%)	2 (4%)	6 (12%)	23 (45%)	20 (39%)	51 Observations
37	DO NOT REPLACE	3	18 (2%)	124 (15%)	314 (39%)	263 (32%)	97 (12%)	816 Observations
19	DO NOT REPLACE	2	5 (2%)	63 (24%)	125 (47%)	57 (21%)	16 (6%)	266 Observations
7	REPLACE	1	39 (20%)	110 (55%)	36 (18%)	10 (5%)	3 (2%)	198 Observations
0	REPLACE	0	86 (87%)	8 (8%)	4 (4%)	1 (1%)	0 (0%)	99 Observations
			REPLACE		DO NOT REPLACE			

Sign Category, Observer Rating

KEY
Observations (Percentage of Observations)

Figure 4: Frequency Distribution of Observer Ratings for Stop Signs Washington State Study

SIA	Sign Category, Retroreflectometer		0	1	2	3	4	
70	DO NOT REPLACE	4	1 (2%)	5 (10%)	13 (27%)	24 (49%)	6 (12%)	49 Observations
37	DO NOT REPLACE	3	1 (1%)	13 (11%)	35 (30%)	33 (29%)	34 (29%)	116 Observations
19	DO NOT REPLACE	2	1 (1%)	4 (4%)	7 (7%)	26 (25%)	64 (63%)	102 Observations
7	REPLACE	1	11 (4%)	58 (21%)	118 (42%)	76 (27%)	18 (6%)	281 Observations
0	REPLACE	0	78 (44%)	48 (27%)	25 (14%)	17 (10%)	8 (5%)	176 Observations
			REPLACE		DO NOT REPLACE			

Sign Category, Observer Rating

KEY
Observations (Percentage of Observations)

which it will need replacing. This assumption is neither a stated standard nor a written North Carolina DOT policy. However, it is an appropriate conservative estimate for engineer grade sheeting, and the results from our analysis do not change greatly with moderate changes in that useful life.

- The maximum SIA (RA) value of a new engineer grade sign is 70 (as cited in the Washington State study) and it was assumed to decrease by 1/7 each year for seven years. Based on NCDOT data, this degradation assumption is very conservative considering that signs would most likely not degrade at a linear rate and would not be at an SIA value as low as 10 in year 7. However, this conservative assumption also accounts for signs that may degrade faster than anticipated due to weather or damage.
- The assumed correspondence between sign age and SIA value is shown in the box below.

The analysis examined three key factors of an inspection program: inspection frequencies, replacement rates, and vandalism and knock-down rates. Three inspection frequencies were examined: each sign was inspected once a year, once every two years, or once every three years. These are frequencies currently used by the North Carolina DOT on various types of roadways. The replacement rates were determined based on the Washington State study: either inspectors would recommend sign replacement at the same rates as that study or more conservatively. Three different vandalism and knock-down rates were examined: no vandalism or knock downs, 5% of signs vandalized or knocked down per year, or 10% of signs vandalized or knocked-down per year. The North Carolina DOT believes that the 5% rate is appropriate for signs in urban areas while a 10% rate is appropriate for signs in rural areas. The different combinations of these factors were examined to determine their effects on the number of deficient signs (more than seven years old) that would still be in place on the road.

Replacement Rate. Our analysis required a replacement rate by sign age. Some of these rates were easy to discern from the Washington State study data, which was based on warning signs and stop signs. For example, based on Figure 3, for warning signs with roughly an SIA value of 10 (which we assume to be about six years old), the replacement rate is about 20% + 55% = 75%. (Note that the value 10 does not explicitly appear on the scale, but it can be interpolated. It simply means that the sign is performing very poorly.) That is, the observer rated 20% of the signs as category 0 and 55% of the signs as category 1 meaning that they are to be replaced. Thus, the observer recommends replacing 75% of the signs that are six years old (with SIA of 7) but does not recommend replacing 25% (18% + 5% + 2%) of these signs. However, replacement rates for other sign ages were not as apparent from the data.

In the situation where the replacement rate could not be determined directly (for example, the replacement rate for warning signs with an SIA of approximately 50, which we assume to be two years old), two approaches were taken. The "typical rate" approach assumed that the replacement rate for signs at this specific age was the same as the replacement rate of the signs at the next-younger age for which there were available data. For example, the replacement rate for two-year-old warning signs would be the same as the replacement rate for new warning signs (SIA = 70), which is 4% according to upper left part of Figure 3 (0% + 4%). The "interpolation" approach used a linear interpolation from the replacement rates of signs at the next-younger and next-older ages for which there were data. For example, the replacement rate for one-year-old warnings signs (SIA=60) could be interpolated from the replacement rates of new (SIA=70) and three-year-old (SIA=37) signs as (4% + 0%) + {[(15% + 2%) – (4% + 0%)]/3} = 8.33%. That is, the replacement rate for new signs (0 years old) is (4% + 0%) = 4% and the replacement rate for three-year-old signs (use the data for SIA=37) is (15% + 2%) = 17%. Interpolate one third of the

Sign age, years:	0	1	2	3	4	5	6	≥7
Corresponding SIA Value:	70	60	50	40	30	20	10	0

way from 4% to 17% to find the one-year-old sign replacement rate.

In addition, more conservative replacements were also examined. The "more conservative" replacement rates were based on the typical replacement rates, but assumed that inspectors were trained to look ahead several years and order sign replacement when they thought a sign would need to be replaced near the time of their next visit. More specifically, for the inspection frequency of once every year, the typical replacement rates were moved up one year to obtain the more conservative replacement rates. If the inspection frequency is once every two years, the typical replacement rates were moved up two years to obtain the more conservative replacement rates. If the inspection frequency is once every three years, the typical replacement rates were moved up three years to obtain the more conservative replacement rates. The more conservative replacement rates are illustrated in Table 3.

An example showing how these conservative replacement rates work follows. In Table 3, the "typical" replacement rate for three-year-old signs is 0.17 (top row column 4). If we are instructing our inspectors to be conservative by one year they will reject two-year-old signs at the same rate as they "typically" rejected three-year-old signs, 0.17, as the third row (column 3) of Table 3 shows. If we are instructing our inspectors to be conservative by two years they will reject one-year-old signs at the same rate as they "typically" rejected three-year-old signs, 0.17, as the fourth row (column 2) of Table 3 shows. If we are instructing our inspectors to be conservative by three years they will reject new signs at the same rate as they "typically" rejected three-year-old signs, 0.17, as the fifth row (column 1) of Table 3 shows.

Simulation Procedure. To analyze the sign inspection program variables, we developed a simple simulation program in a spreadsheet. Once the program reaches stability, the result is a prediction of the number of deficient signs (seven or more years old) in the field. Table 4 illustrates the results of the simulation program assuming an even distribution of signs ranging from new to six years old as the initial starting state. The program application in this case was for warning signs and used an inspection frequency of once per year, the "more conservative" replacement rates, and a vandalism rate of 10% per year. Only the data from the first three years of the simulation are shown. It typically took about 30 years or so for the results to stabilize (be the same from year to year) and our results shown in Tables 5, 6, and 7 are for the end of a 60-year period.

In Table 4, each row represents the results at the end of that year's sign inspection cycle. Note that Table 4 is one continuous spreadsheet illustrated in 3 parts. The rows extend over a total of 56 columns from column A to BD. Column A with the heading of "Year" indicates the year the data represents. The first group of columns (B - J) under the heading of "In place signs" represents the sign age distribution at the end of that year. Except for the first year, the

Table 3: Sign Replacement Rates

Sign Age (Years)			0	1	2	3	4	5	7	≥ 7
Replacement Rate (Warning Signs)	**Typical**		0.04	0.04	0.04	0.17	0.17	0.26	0.75	0.95
	Interpolation		0.04	0.083	0.127	0.17	0.215	0.26	0.75	0.95
	More Conservative*	**1**	0.04	0.04	0.17	0.17	0.26	0.75	0.95	0.95
		½	0.04	0.17	0.17	0.26	0.75	0.95	0.95	0.95
		1/3	0.17	0.17	0.26	0.75	0.95	0.95	0.95	0.95
Replacement Rate (Stop Signs)	**Typical**		0.12	0.12	0.12	0.12	0.12	0.05	0.25	0.71
	Interpolation		0.12	0.12	0.12	0.12	0.085	0.05	0.25	0.71
	More Conservative*	**1**	0.12	0.12	0.12	0.12	0.05	0.25	0.71	0.71
		½	0.12	0.12	0.12	0.05	0.25	0.71	0.71	0.71
		1/3	0.12	0.12	0.05	0.25	0.71	0.71	0.71	0.71

* The "more conservative" replacement rates are dependent on the inspection frequency as illustrated.
1/2 means signs inspected every other year
1.3 means signs inspected every third year

values in this group of columns depend on the inspection, replacement, and vandalism activities in the previous year. For example, the first row indicates that by the end of year 1, there are 143 new signs, 143 one-year-old signs, etc., according to the assumption of a uniform age distribution to begin the simulation. The second row indicates the sign age distribution by the end of year 2. By the end of year 2, the number of new signs is 406, which equals the total number of signs replaced due to the year 1 inspection procedure (6 + 6 + 24 + 24 + 37 + 107+ 136 + 0 = 340 signs) plus the number of signs replaced due to vandalism in the first year (66 signs). By the end of year 2, the number of one-year old signs is 123, which equals the total number of the new signs that were either not inspected (0 signs) or not replaced (137 signs) in year 1 minus the number of new signs vandalized in year 1 (14 signs).

The second group of columns (K - S) under the heading of "Inspected signs" represents the number of signs of different ages being inspected during the inspection procedure, which was assumed to happen at the end of year 1. The values in these columns are dependent on the number of in-place signs and the inspection frequency. For example, there are 143 new signs in year 1 and the inspection frequency is once per year. In other words, all these 143 new signs will be inspected and therefore, the number of inspected new signs is 143.

The third group of columns (U - AC) under the heading of "Not Inspected signs" represents the number of signs that are not inspected in that specific year. The values are obtained by subtracting the number of signs inspected in that year from the number of in-place signs in that year grouped by the sign age. Since the inspection frequency is once per year in this example, all signs will be inspected and there are zeroes in all cells of this group of columns.

The fourth group of columns (AD - AK) under the heading of "Replaced signs" represents the number of signs that are replaced due to the inspection and replacement procedure in that specific year, grouped by age. The values depend on the number of signs and the corresponding replacement rate. For example, for a new sign, the replacement rate is 0.04 and there are 143 new signs in year 1. Therefore, six (143 * 0.04) new signs were replaced due to the inspection and replacement procedure in year 1.

The fifth group of columns (AM - AT) under the heading of "Not replaced signs" represents the number of signs that are not replaced as a result of that year's inspection and replacement procedure. The values are obtained by subtracting the number of "Replaced signs" from the number of "In place signs" of the corresponding sign ages.

Column AU, under the heading of "Not inspected or not replaced," represents the total number of signs that are either not inspected or not replaced during the specific year's inspection and replacement procedure.

The final group of columns (AV - BD) under the heading of "Vandalized signs" represents the number of signs replaced due to vandalism, knockdown, or similar causes unrelated to the sign inspection program, from among those signs that were "Not inspected or not replaced," again grouped by sign age. The values are obtained by applying the vandalism rate to the corresponding "Not inspected or not replaced" signs. For example, in year 1 there are 137 new signs that are either not inspected (0) or not replaced (137) during the sign inspection and replacement procedure. With a vandalism rate of 10%, the number of vandalized new signs is 14 after rounding up (137 * 10% = 13.7).

Note that with a 0% vandalism rate, the number of new signs in year n is the number of signs replaced due to the year n-1 sign inspection and replacement procedure. If the vandalism rate is greater than 0%, the number of new signs in year n includes the number of signs replaced due to the year n-1 inspection and replacement procedure and the signs vandalized in year n-1. The simulation logic is provided mathematically below for those readers interested in replicating the calculation.

- Given the number of years between inspections, ybi;
- Given the proportion of signs vandalized in a year, pv;
- Given the proportion of signs of a given age, a, that inspectors will recommend to

Table 4: Sample Data in the Simulation Program, Inspecting All Warning Signs Conservatively Every Year and Assuming 10% Vandalism per Year

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Year	In place signs									Inspected signs								
	0yr old	1yr old	2yr old	3yr old	4yr old	5yr old	6yr old	≥ 7yr old	Total	0yr old	1yr old	2yr old	3yr old	4yr old	5yr old	6yr old	≥ 7yr old	Total
1	143	143	143	143	143	143	143	0	1000	143	143	143	143	143	143	143	0	1000
2	406	123	123	107	107	95	32	6	1000	406	123	123	107	107	95	32	6	1000
3	276	351	107	92	80	71	21	2	1000	276	351	107	92	80	71	21	2	1000

(Continued)

T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
Year	Not Inspected signs									Replaced signs							
	0yr old	1yr old	2yr old	3yr old	4yr old	5yr old	6yr old	≥ 7yr old	Total	0yr old	1yr old	2yr old	3yr old	4yr old	5yr old	6yr old	≥ 7yr old
1	0	0	0	0	0	0	0	0	0	6	6	24	24	37	107	136	0
2	0	0	0	0	0	0	0	0	0	16	5	21	18	28	71	31	6
3	0	0	0	0	0	0	0	0	0	11	14	18	16	21	53	20	2

(Continued)

AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD
Year	Not replaced signs								Not inspected or not replaced	Vandalized signs								
	0yr old	1yr old	2yr old	3yr old	4yr old	5yr old	6yr old	≥ 7yr old		0yr old	1yr old	2yr old	3yr old	4yr old	5yr old	6yr old	≥ 7yr old	Total
1	137	137	119	119	106	36	7	0	660	14	14	12	12	11	3 6	0 7	0	66
2	390	118	102	89	79	24	2	0	804	39	12	10	8 9	7 9	2 4	0 2	0 03	80 4
3	265	337	89	77	59	18	1	0	845	27	34	8 9	7 7	5 9	1 8	0 1	0 01	84 5

be replaced, RR_a (a "replacement rate" from Table 3); and

- Given a beginning distribution of in-place signs, P, in year y, by age, or a set of $P_{y,a}$:

1. Compute the number of signs of age a to be inspected in year y, $I_{y,a} = P_{y,a} / ybi$;
2. Compute the number of signs of age a **not** to be inspected in year y, $NI_{y,a} = P_{y,a} - I_{y,a}$;
3. Compute the number of signs of age a to be replaced in year y, $R_{y,a} = I_{y,a} * RR_a$;
4. Compute the number of signs of age a **not** to be replaced in year y, $NR_{y,a} = P_{y,a} - R_{y,a}$;
5. Compute the number of signs of age a vandalized in year y, $V_{y,a} = NR_{y,a} * pv$;
6. Compute the number of new signs in year y+1, $P_{y+1,0} = \sum R_{y,a} + \sum V_{y,a}$;
7. Compute the number of signs of ages one year and older, $P_{y+1,a}$ (where $a \geq 1$) $= NI_{y,a-1} + NR_{y,a-1} - V_{y,a-1}$; and
8. Return to Step 1 and repeat the computation for the next year, y + 1. Keep repeating the computation until the simulation stabilizes, which is to say that $P_{y,a} \approx P_{y+1,a}$

SIMULATION RESULTS

After the simulation program was developed, several different combinations of the replacement rates, inspection frequencies, and vandalism rates were run in the program for both warning signs and stop signs. All cases assumed a sign sample of 1,000 and, as noted above, started with a uniform distribution of sign ages, although that did not matter in the final results since we simulated a long enough time period for the system to stabilize.

The simulation program was applied to the hand-held retroreflectometer method for comparison and evaluation purposes. When using a hand-held retroreflectometer to measure the retroreflectivity of a sign, an almost perfect performance was assumed. In other words, it was assumed that the retroreflectometer could provide the operator with enough information to make a correct decision on replacement 99% of the time. The decision to replace a sign or not was made based on the sign age and the inspection frequency. For example, if the inspection frequency is once every two years, signs at ages of five years, six years, and seven years or older would be replaced 99% of the time. Signs at age of five years would be replaced even though these signs could last another year to make sure they would not stay in field while running out of their useful life before the next inspection.

To round out the field of contending inspection and replacement strategies, we analyzed a "total replacement" approach as well. This idealized situation assumed no inspection; each sign was simply replaced in the seventh year since the previous mass installation.

Table 5 provides simulation results for warning signs and Table 6 provides results for stop signs. The simulation results are useful to evaluate the various sign inspection and replacement options. The focus is on the safety risk and the cost associated with each inspection program. The safety risk is dependent on the number of grossly deficient signs in place on the roads (assumed to be signs seven years or older in this study). Generally, the more of these signs there are in the field, the higher the safety risk. The cost includes the sign replacement cost and the sign inspection cost. The cost information used in this study is from sign inventory research sponsored by the North Carolina DOT (Vereen, Hummer, and Rasdorf, 2002). The sign replacement cost for warning and stop signs is \$30/sign. The sign inspection cost of the visual inspection method is \$0.17/sign based on the previous research. The inspection cost for the hand-held retroreflectometer method is estimated to be \$2.33/sign when taking into consideration the labor costs (including salaries and benefits), travel costs, vehicle costs, and equipment cost (retroreflectometer). Table 7 summarizes the cost and the safety risk associated with each inspection method examined for warning signs.

Observations

Tables 5-7 provide several useful insights. Under the same conditions (inspection method, vandalism rate, replacement rate), the higher the inspection frequency, the higher the number of signs replaced every year, and the lower the number of signs that do not meet the requirements. In other words, the higher the inspection frequency, the higher the cost to inspect and replace signs, but the lower the safety risk. In addition, it is noted that with typical or interpolated visual inspection methods, the number of deficient signs is very high, and may be unacceptable, with every other year or every third year inspection.

Keeping the vandalism rate constant, the number of signs that do not meet requirements could be decreased somewhat using the hand-held retroreflectometer method rather than the visual inspection method, but with a significant increase in the total cost. For example, under the vandalism rate of 10%, with an inspection frequency of once every year, the cost for the visual inspection method using the typical replacement rate (item 27 in Table 7) is $7,010.00 per year, which is $1,230.00 (18%) less than the cost of the hand-held retroreflectometer method ($8,240.00, from item 36 in Table 7) for 1,000 warning signs. The estimated number of warning signs on NC roads is 373,000, which leads to an estimated total cost difference of $458,790 per year ((8,240.00 – 7,010.00) * 373). The number of signs that do not meet requirements is decreased from 13 out of 1,000 for visual inspection to one out of 1,000 for the retroreflectometer. Thus, there is very little improvement in safety risk (1.2% fewer grossly deficient signs) for a lot more cost.

For all cases, the majority of the cost comes from the replacement cost because the unit replacement cost is $30/sign while the unit cost of inspection is only $0.17/sign for the visual inspection method and $2.33/sign for the hand-held retroreflectometer method. It is also obvious that the difference in inspection costs is important. Using the same example as in the previous paragraph, item 33 in Table 7 shows that the more conservative visual inspection method calls for replacement of many more signs than the retroreflectometer (item 36) to produce the same number of deficient signs (one per 1,000). However, the greater inspection costs for the retroreflectometer give it a higher overall cost than the more conservative visual inspection method. Ways to make retroreflectometer use faster without sacrificing reliability would be helpful to the DOTs.

With the assumptions that were made, the total replacement approach turns out to be attractive when taking into consideration the cost and the number of deficient signs. When using the total replacement approach, the number of signs that do not meet the requirements is always 0, and the total program costs are among the lowest we analyzed. However, in the real world where signs are not automatically deficient after seven years and DOTs cannot count on finding vandalized and knocked-down signs without regular inspections, the total replacement approach may not be realistic.

CONCLUSION

Organizations might have different goals in sign inventory and management. For example, some organizations might seek methods to minimize the cost while tolerating a relatively large number of signs that do not meet the retroreflectivity requirements. Some organizations might seek methods to minimize the number of signs that do not meet retroreflectivity requirements while tolerating a relatively high cost. Still other organizations might seek methods to obtain a balance, i.e., both the number of signs that do not meet the requirements and the cost are reasonable. The simple spreadsheet simulation program described in this paper appears to be a way for agencies to explore the trade-offs and arrive at informed decisions on their sign inspection and replacement efforts.

For agencies that generally conform to the key assumptions made to build the spreadsheet (such as uniformly decaying signs that become deficient after seven years in the field, inspectors with error rates similar to the Washington State study (Lagergren, 1987), and virtually flawless inspections with retroreflectometers), the results in Tables 5-7 are directly applicable. Those agencies should consider replacing all signs every seven years, as that insures that at a relatively low cost no aged signs are in place, subject to the key realism checks mentioned above. If total replacement is not possible, an inspection program using retroreflectometers every three years appears very cost competitive with a program using "typical" visual inspection rates each year at either 5% or 10% vandalism rates. The retroreflectometers appear to allow fewer deficient signs, while the "typical" visual inspection program costs are lower for a given vandalism rate. "More conservative" sign replacement rates do not appear to offer distinct advantages, while "typical" replacement rates with inspections every two or three years allow relatively high numbers of deficient signs to remain on the roads.

For other agencies, they can easily change the parameters of the simulation program to different values than those used in this study. For example, if their documented vandalism rate differs from the one we used they can simply change that one parameter and retain the use of the program to generate new values for sign replacement rates. Among the parameters that can be changed to allow a wider range of applicability of the method are the following:

- Replacement of the simple linear sign deterioration function by age with a more sophisticated function,
- Changing the overall duration of the determination cycle,
- Addition of other grades of sheeting,
- Addition of data on inspector performance from other DOTs,
- Addition of other sign colors, and
- Addition of data on the error rates from retroreflectometers.

The authors plan to pursue research along several of these lines in the near future. As more of these parameters are validated for individual uses over time the sign inspection and replacement simulation program will become an increasingly powerful tool for helping DOTs save lives and money.

Table 5: Estimated Sign Age Distribution Varying the Inspection Method, Inspection Frequency, Vandalism Rate, and Replacement Rate (Warning Signs)

Item #	Inspection Method	Vandalism Rate	Replacement Rate	Inspection* Frequency	Sign Age (Years)							
					0	1	2	3	4	5	6	≥7
1	Visual	0%	Typical	1	176	169	162	156	129	107	79	**21**
2	Visual	0%	Typical	1/2	148	148	142	142	118	118	87	**96**
3	Visual	0%	Typical	1/3	123	124	124	118	118	118	87	**187**
4	Visual	0%	Interpolated	1	192	184	169	147	122	96	71	**19**
5	Visual	0%	Interpolated	1/2	153	153	140	140	116	116	86	**95**
6	Visual	0%	Interpolated	1/3	129	129	132	115	115	114	84	**180**
7	Visual	0%	More Conservative	1	205	197	189	157	130	96	24	**1**
8	Visual	0%	More Conservative	1/2	202	202	168	168	124	124	6	**7**
9	Visual	0%	More Conservative	1/3	187	187	188	139	139	138	7	**15**
10	Retroreflectometer	0%	Almost Perfect	1	148	148	147	145	140	140	139	**1**
11	Retroreflectometer	0%	Almost Perfect	1/2	150	155	153	197	196	146	1	**2**
12	Retroreflectometer	0%	Almost Perfect	1/3	151	150	215	181	181	116	1	**4**
13	No Inspection	0%	Total Replacement	-	143	143	143	143	143	143	143	**0**
14	Visual	5%	Typical	1	201	183	167	152	120	95	66	**17**
15	Visual	5%	Typical	1/2	173	163	150	141	115	106	78	**74**
16	Visual	5%	Typical	1/3	151	143	136	125	116	108	81	**140**
17	Visual	5%	Interpolated	1	217	198	172	143	113	84	59	**15**
18	Visual	5%	Interpolated	1/2	179	169	149	139	112	103	76	**72**
19	Visual	5%	Interpolated	1/3	159	150	141	121	112	104	78	**134**
20	Visual	5%	More Conservative	1	229	209	190	150	118	83	20	**1**
21	Visual	5%	More Conservative	1/2	226	213	172	160	117	99	8	**5**
22	Visual	5%	More Conservative	1/3	216	203	190	140	124	108	8	**11**
23	Retroreflectometer	5%	Almost Perfect	1	171	161	151	141	133	125	118	**1**
24	Retroreflectometer	5%	Almost Perfect	1/2	186	177	167	160	151	140	19	**1**
25	Retroreflectometer	5%	Almost Perfect	1/3	188	179	173	161	153	130	13	**3**
26	No Inspection	5%	Total Replacement	-	166	158	151	141	134	128	122	**0**
27	Visual	10%	Typical	1	228	197	170	147	110	82	55	**13**
28	Visual	10%	Typical	1/2	201	179	156	139	109	93	68	**55**
29	Visual	10%	Typical	1/3	182	163	145	127	111	97	72	**102**
30	Visual	10%	Interpolated	1	244	211	174	137	102	72	48	**11**
31	Visual	10%	Interpolated	1/2	208	185	156	136	106	90	65	**54**
32	Visual	10%	Interpolated	1/3	189	169	150	124	108	93	69	**98**
33	Visual	10%	More Conservative	1	255	220	190	142	106	71	16	**1**
34	Visual	10%	More Conservative	1/2	252	225	174	151	107	79	9	**4**
35	Visual	10%	More Conservative	1/3	246	217	190	137	110	83	8	**8**
36	Retroreflectometer	10%	Almost Perfect	1	197	175	156	139	124	110	98	**1**
37	Retroreflectometer	10%	Almost Perfect	1/2	209	188	168	151	135	121	27	**1**
38	Retroreflectometer	10%	Almost Perfect	1/3	214	193	173	155	139	106	18	**2**
39	No Inspection	10%	Total Replacement	-	192	173	155	140	126	113	102	**0**

1/2 means inspection once every two years. 1/3 means inspection once every three years

Table 6: Estimated Sign Age Distribution Varying the Inspection Method, Inspection Frequency, Vandalism Rate, and Replacement Rate (Stop Signs)

Item #	Inspection Method	Vandalism Rate	Replacement Rate	Inspection* Frequency	Sign Age (Years)							
					0	1	2	3	4	5	6	≥7
1	Visual	0%	Typical	1	182	160	141	124	109	96	91	**96**
2	Visual	0%	Typical	1/2	135	136	119	119	105	105	100	**181**
3	Visual	0%	Typical	1/3	109	109	109	96	96	96	91	**294**
4	Visual	0%	Interpolated	1	180	158	139	123	108	99	94	**99**
5	Visual	0%	Interpolated	1/2	136	136	119	119	105	105	100	**181**
6	Visual	0%	Interpolated	1/3	109	109	109	96	96	96	91	**294**
7	Visual	0%	More Conservative	1	196	172	152	133	117	112	84	**34**
8	Visual	0%	More Conservative	1/2	164	164	144	144	137	137	40	**72**
9	Visual	0%	More Conservative	1/3	143	143	143	135	135	135	39	**127**
10	Retroreflectometer	0%	Almost Perfect	1	148	147	145	140	140	139	139	**1**
11	Retroreflectometer	0%	Almost Perfect	1/2	150	155	153	197	196	146	1	**2**
12	Retroreflectometer	0%	Almost Perfect	1/3	151	150	215	181	181	116	1	**4**
13	No Inspection	0%	Total Replacement	-	143	143	143	143	143	143	143	**0**
14	Visual	5%	Typical	1	211	176	147	123	103	86	78	**76**
15	Visual	5%	Typical	1/2	163	152	130	121	103	96	87	**146**
16	Visual	5%	Typical	1/3	140	131	122	105	99	92	84	**227**
17	Visual	5%	Interpolated	1	209	174	146	122	102	89	80	**79**
18	Visual	5%	Interpolated	1/2	163	152	130	121	103	96	88	**147**
19	Visual	5%	Interpolated	1/3	139	131	122	105	98	93	85	**227**
20	Visual	5%	More Conservative	1	223	187	156	130	109	98	70	**27**
21	Visual	5%	More Conservative	1/2	190	177	151	141	128	118	40	**56**
22	Visual	5%	More Conservative	1/3	172	162	152	138	129	114	39	**93**
23	Retroreflectometer	5%	Almost Perfect	1	171	161	151	141	133	125	118	**1**
24	Retroreflectometer	5%	Almost Perfect	1/2	186	177	167	160	151	140	19	**1**
25	Retroreflectometer	5%	Almost Perfect	1/3	188	179	173	162	153	130	13	**3**
26	No Inspection	5%	Total Replacement	-	166	158	151	141	134	128	122	**0**
27	Visual	10%	Typical	1	242	192	152	120	95	75	64	**59**
28	Visual	10%	Typical	1/2	195	170	139	121	99	86	75	**114**
29	Visual	10%	Typical	1/3	173	152	134	111	98	86	75	**171**
30	Visual	10%	Interpolated	1	240	190	151	119	94	78	67	**61**
31	Visual	10%	Interpolated	1/2	194	170	139	121	99	87	75	**115**
32	Visual	10%	Interpolated	1/3	173	152	134	111	98	86	75	**171**
33	Visual	10%	More Conservative	1	253	200	159	126	100	85	57	**20**
34	Visual	10%	More Conservative	1/2	219	191	156	136	118	100	37	**42**
35	Visual	10%	More Conservative	1/3	204	180	159	138	119	95	36	**67**
36	Retroreflectometer	10%	Almost Perfect	1	197	175	156	139	124	110	98	**1**
37	Retroreflectometer	10%	Almost Perfect	1/2	209	188	168	151	135	121	27	**1**
38	Retroreflectometer	10%	Almost Perfect	1/3	214	193	173	155	139	106	18	**2**
39	No Inspection	10%	Total Replacement	-	192	173	155	140	126	113	102	**0**

*** 1/2 means inspection once every two years. 1/3 means inspection once every three years**

Table 7: Cost and Safety Risk Analysis (Warning Signs)

Item #	Inspection Method	Vandalism Rate	Replacement Rate	Inspection* Frequency	≥ 7yr Signs	Signs Inspected Every Year	Inspection Cost ($)	Signs Replaced Every Year	Replacement Cost ($)	Total Cost ($)
1	Visual	0%	Typical	1	21	1000	170	176	5280	**5450**
2	Visual	0%	Typical	1/2	96	500	85	148	4440	**4525**
3	Visual	0%	Typical	1/3	187	333	57	123	3690	**3746**
4	Visual	0%	Interpolated	1	19	1000	170	192	5760	**5930**
5	Visual	0%	Interpolated	1/2	95	500	85	153	4590	**4675**
6	Visual	0%	Interpolated	1/3	180	333	57	129	3870	**3927**
7	Visual	0%	More Conservative	1	1	1000	170	205	6150	**6320**
8	Visual	0%	More Conservative	1/2	7	500	85	202	6060	**6145**
9	Visual	0%	More Conservative	1/3	15	333	57	187	5610	**5667**
10	Retroreflectometer	0%	Almost Perfect	1	1	1000	2330	148	4440	**6770**
11	Retroreflectometer	0%	Almost Perfect	1/2	2	500	1165	150	4500	**5665**
12	Retroreflectometer	0%	Almost Perfect	1/3	4	333	776	151	4530	**5307**
13	No Inspection	0%	Total Replacement	-	0	0	0	143	4290	**4290**
14	Visual	5%	Typical	1	17	1000	170	201	6030	**6200**
15	Visual	5%	Typical	1/2	74	500	85	173	5190	**5275**
16	Visual	5%	Typical	1/3	140	333	57	151	4530	**4587**
17	Visual	5%	Interpolated	1	15	1000	170	217	6510	**6680**
18	Visual	5%	Interpolated	1/2	72	500	85	179	5370	**5455**
19	Visual	5%	Interpolated	1/3	134	333	57	159	4770	**4827**
20	Visual	5%	More Conservative	1	1	1000	170	229	6870	**7040**
21	Visual	5%	More Conservative	1/2	5	500	85	226	6780	**6865**
22	Visual	5%	More Conservative	1/3	11	333	57	216	6480	**6537**
23	Retroreflectometer	5%	Almost Perfect	1	1	1000	2330	171	5130	**7460**
24	Retroreflectometer	5%	Almost Perfect	1/2	1	500	1165	186	5580	**6745**
25	Retroreflectometer	5%	Almost Perfect	1/3	3	333	777	188	5640	**6417**
26	No Inspection	5%	Total Replacement	-	0	0	0	166	4980	**4980**
27	Visual	10%	Typical	1	13	1000	170	228	6840	**7010**
28	Visual	10%	Typical	1/2	55	500	85	201	6030	**6115**
29	Visual	10%	Typical	1/3	102	333	57	182	5460	**5517**
30	Visual	10%	Interpolated	1	11	1000	170	244	7320	**7490**
31	Visual	10%	Interpolated	1/2	54	500	85	208	6240	**6325**
32	Visual	10%	Interpolated	1/3	98	333	57	189	5670	**5727**
33	Visual	10%	More Conservative	1	1	1000	170	255	7650	**7820**
34	Visual	10%	More Conservative	1/2	4	500	85	252	7560	**7645**
35	Visual	10%	More Conservative	1/3	8	333	57	246	7380	**7437**
36	Retroreflectometer	10%	Almost Perfect	1	1	1000	2330	197	5910	**8240**
37	Retroreflectometer	10%	Almost Perfect	1/2	1	500	1165	209	6270	**7435**
38	Retroreflectometer	10%	Almost Perfect	1/3	2	333	777	214	6420	**7197**
39	No Inspection	10%	Total Replacement	-	0	0	0	192	5760	**5760**

*** 1/2 means inspection once every two years. 1/3 means inspection once every three years**

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