FIELD INVESTIGATION OF HIGHWAY SIGN DAMAGE RATES AND INSPECTOR ACCURACY

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This study sought to create a simulation model to provide the North Carolina Department of Transportation (NCDOT) with recommendations to improve its sign inspection and replacement procedures. This research focuses on two key factors built into the model: (a) the rate at which signs are damaged beyond usefulness based on natural or man-made causes and (b) the accuracy rate of visual sign inspections based on retroreflectivity. The research team conducted nighttime rides with sign inspectors in 5 of 14 NCDOT divisions. During subsequent daytime rides, the team measured sign retroreflectivity to allow estimation of sign deterioration and inspector accuracy rates. Data were collected for white, yellow, red, and green signs and for sheeting Types I and III. About 2.3% of inspected signs (per year) were damaged to the point of needing replacement, and inspectors did not reject a large percentage of signs that had retroreflectivity values below the proposed minimum Federal Highway Administration standard.

Keywords: *sign; retroreflectivity; inspect; damage; vandalism; inspector performance*

It is imperative that departments of transportation (DOTs) have effective sign testing and replacement programs to significantly reduce the safety risks to motorists. One important aspect of sign performance for nighttime driving is retroreflectivity, measured by a coefficient of retroreflection (Ra). Ra can be understood as the ratio of the light that the sign reflects to a driver (cd) to the light that illuminates the sign (lx) per unit area (m^2).

Beginning in 1984, the Center for Auto Safety petitioned the Federal Highway Administration (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" (American Association of State Highway and Transportation Officials, 2000, p. 1). FHWA formulated two related reports in 1998. One report aimed at "evaluating

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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 & Taori, 1998, p. 1). 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 & 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. Revised standards were proposed by an FHWA contractor in 2003 (Carlson & Hawkins, 2003).

New retroreflectivity requirements will present several issues to agencies responsible for sign replacement and maintenance.

New retroreflectivity requirements will present several issues to agencies responsible for sign replacement and maintenance. In the case of North Carolina, the North Carolina Department of Transportation (NCDOT) owns and maintains approximately 78,000 miles of roadway. Primary roads contain approximately 353,500 signs, and secondary roads contain approximately 616,400 signs (Kirtley & Rasdorf, 2001; Palmquist & Rasdorf, 2002). 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 may have to develop or improve their own sign inspection and replacement procedures. 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 NCDOT. Sign condition is evaluated based on the observers' visual perception without using any retroreflectivity measurement equipment. Visual inspection is performed at night using vehicle headlights for illumination. The second method to assess retroreflectivity utilizes handheld retroreflectometers to physically measure each sign. Neither of the two methods is completely satisfying. On one hand, the accuracy of visual assessment is questionable because different inspectors have varying visual observations of the same sign, even given the same set of inspection guidelines. One the other hand, the use of handheld retroreflectometers is labor-intensive and time-consuming, requiring a technician to get out of his or her vehicle, walk up to the sign, hold up the instrument, and make multiple readings per color.

To determine, quantify, and present alternative approaches for agencies to meet FHWA's proposed minimum levels of retroreflectivity for signs, three alternatives other than the visual inspection were identified in a study at North Carolina State University (NCSU). The three alternatives were as follows:

1. Improve nighttime visual inspection procedures
2. Implement a sign inventory management system (no visual inspection)
3. A combination of the above two (Vereen, Hummer, & Rasdorf, 2002, 2004).

A research project was conducted at NCSU, sponsored by the NCDOT, in 2001-2002 (Rasdorf & Hummer, 2004). The purpose of the project was to determine the optimum strategy for sign inspection and replacement under different conditions to respond to the pending retroreflectivity requirements. After exploring the two methods described above, the researchers developed a computer simulation to investigate the effectiveness of different sign inspection and replacement scenarios (Rasdorf, Hummer, Vereen, & Cai, 2005). The simulation appeared promising, but the early version relied on a number of assumptions. It was recognized that further study could provide the required quantification to remove some of the uncertainty inherent in those initial assumptions. Three major assumptions were particularly noteworthy:

- Deterioration—the rate at which sign retroreflectivity decreases as signs weather and age.
- Damage—the rate at which signs are damaged beyond usefulness based on rather sudden natural or man-made causes (e.g., tree sap or paint balls, respectively).
- Inspection accuracy—the rate at which visual sign inspections result in errors (either false positive or false negative).

To the extent that other DOTs have signing and sign-inspection practices like those in North Carolina, these data may also help them in making decisions about inspection and replacement practices.

In 2004, the NCDOT asked the NCSU researchers to fully develop the simulation program. This entailed, among other things, collecting and analyzing data to quantify the three rates listed above on much firmer footing. The purpose of this article, then, is to report on our achievements in finding two of the three rates listed above for the case of signs in North Carolina. The findings regarding deterioration rates are discussed in another article (Immaneni, Hummer, Rasdorf, Yeom, & Harris, in press). To the extent that other DOTs have signing and sign-inspection practices like those in North Carolina, these data may also help them in making decisions about inspection and replacement practices.

Literature Review

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, McGee, Hussain, & Rennilson, 1991). Using NCDOT accounting system data, our previous study had assumed an average of 5% 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%. No factual data were 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.

INSPECTION ACCURACY

Our early simulation modeled sign inspector performance based on a study conducted in the state of Washington in 1987 (Lagergren, 1987). The Washington 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 Washington 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, 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 Texas Transportation Institute compared the results of visual sign evaluations to the minimum retroreflectivity values. In the evaluation, Texas DOT sign crews evaluated 49 signs on a 5-mile closed course. The results of the evaluations were then compared to an application of the FHWA minimum values. The results show that although only one sign did not meet the FHWA minimum values, the average ratings for the Texas DOT sign crews indicated that 26 signs were not acceptable. The researchers identified several factors that were found to affect the average rating of signs. These factors included the uniformity of the sign face, the type of sheeting material, and the retroreflectivity (Hawkins & Carlson, 2001).

Method

The literature noted above was helpful in quantifying one of the two assumptions described in the article—inspector accuracy. However, the Washington and Texas studies were limited in important ways—the Washington study examined only two signs, and the Texas study was conducted only on a closed course, for example. To achieve a better understanding of both damage and accuracy rates, the research team conducted an extensive data-collection program in the hope of further refining these values. The main element of this data-collection program involved the research team's accompanying NCDOT crews while they conducted nighttime sign inspections. During these inspections, signs identified for replacement by the crew were noted by the research team. Replacement reasons, including low retroreflectivity caused by natural deterioration, deliberate human damage (vandalism), and natural damage, were also noted. The day after the nighttime inspection, the research team measured the retroreflectivity of the inspected signs and noted their ages. The following paragraphs describe the field study method in more detail.

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DATA-COLLECTION SCOPE

The previous version of the simulation program was restricted because it relied on the Washington State study that looked at only Type I yellow and red signs. To increase the usefulness of the future simulation, we needed data on more types and colors of signs.

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 article, the minimum standards are compared to the retroreflectivity of signs observed by inspectors. The minimum standards were used as a baseline against which to compare the inspector's visual observation of retroreflectivity of signs.

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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 do 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 North Carolina and would not provide an adequate sample size from which to draw any meaningful conclusions.

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 1 in the coastal region (Division 2), 2 in the central Piedmont region (Divisions 6 and 8), and 2 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.

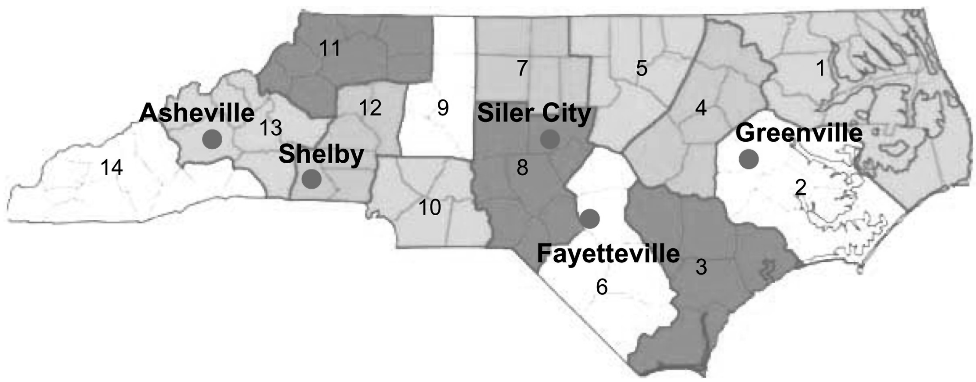

Figure 1: Regions Visited for Data Collection

RETROREFLECTOMETER

Perhaps our tool can replace these handheld devices.

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 handheld retroreflectometer that comply with the standard test method for measurement of retroreflective signs using a portable retroreflectometer as defined by the American Society for Testing and Materials. For this study, we used the RetroSign4500 (Flint Trading, 2005). This is the same model used by the major sign manufacturer in North Carolina (Correction Enterprises of Bunn, North Carolina). This was also the model used in a previous study of sign deterioration by Oregon State University (Kirk, Hunt, & Brooks, 2001). The RetroSign4500 was also advantageous because it does not have to be recalibrated when changing colors, because it has various useful options such as an extension pole (with remote trigger and display), and because we had access to a local dealer who could quickly make repairs when needed.

FIELD PROCEDURE

Data were collected from January to April 2005. Sign inspection in North Carolina is performed during the winter and early spring because of 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 slowly rode 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.

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.

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.

SIGN CREW REJECTION CRITERIA

During nighttime inspections, NCDOT sign crews typically rejected signs because of low observed retroreflectivity or because of 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 1 signs, which are red and white sheeting signs (i.e., stop, do not enter, yield, wrong way, etc.), must be immediately replaced if supplies and conditions permit. Most sign crews will replace a Code 1 sign if the sign has any noticeable mark or defect. Warning (yellow) signs are designated as Code 2 and are replaced as soon as possible. All other signs, generally including signs having white, green, brown, and blue sheeting, are assigned Code 3 and are replaced when possible.

DATA-COLLECTION PROBLEMS

The sign erection date is critical to quantifying one of the assumptions of this article. 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, which 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.

Results

In the visits to five divisions, the research team measured 1,057 signs. This was a large sign retroreflectivity data-collection effort, and the sample size of 1,057 far exceeded the samples collected in the Washington and Texas studies. Table 1 shows a summary of the measured signs by division, color, and type. Most of the signs measured were of Type I sheeting because they are the most common sheeting type found on North Carolina roads. Most of the measured signs were white and yellow.

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REJECTED SIGNS

Table 2 shows the numbers of rejected signs and includes the reason for their rejection. The reasons for rejection are grouped into three categories: low retroreflectivity, man-made causes, and

Table 1: Number of Measured Signs by Division, Color, and Type

	Sign Type and Color																
	Type I				*Type III*				*Other Types*				*All Types*				
Division Number	*W*	*Y*	*R*	*G*	*W*	*Y*	*R*	*G*	*W*	*Y*	*R*	*G*	*W*	*Y*	*R*	*G*	*Total*
2	8	70	15	9	0	8	12	0	—	—	—	—	8	78	27	9	122
6	83	129	2	18	12	30	40	0	—	—	1	1	95	159	43	19	316
8	29	78	8	3	4	1	12	0	—	—	1	—	33	79	21	3	136
12	58	27	16	11	22	12	19	14	4	—	—	—	84	39	35	25	183
13	157	47	9	5	18	28	1	32	—	—	—	3	175	75	10	40	300
Total	335	351	50	46	56	79	84	46	4	0	2	4	395	430	136	96	1,057

NOTE: W = white; Y = yellow; R = red; G = green.

Table 2: Number of Signs Rejected by Reason

Division	*# of Signs Rejected for Low Retroreflectivity*	*# of Signs Rejected for Man-Made Damage*	*# of Signs Rejected for Natural Damage*	*Total # of Signs Rejected*
2	10	1	0	10
6	58	34	19	86
8	18	15	14	31
12	15	17	5	33
13	33	11	22	37
Total	134	78	60	197

Table 3: Percentage of Signs Rejected by Reason

Division	*% of Signs Rejected for Low Retroreflectivity*	*% of Signs Rejected for Man-Made Damage*	*% of Signs Rejected for Natural Damage*
2	100	10	0
6	67	40	22
8	58	48	45
12	45	52	15
13	89	30	59
Total	68	40	30

nature. About 134 signs were rejected because of low retroreflectivity, 78 signs because of man-made causes, and 60 signs because of natural damage. The sum of the number or signs rejected because of low retroreflectivity, man-made causes, and nature damage exceeds the number of signs rejected because some signs were rejected for more than one reason.

Table 3 shows the percentages of signs rejected by reason. About 68% of the rejected signs were rejected because of low retroreflectivity. Human damage was a cause of rejection for 40% of the rejected signs, and 30% of rejected signs were rejected because of natural damage. Note that these percentages add to 138 because some signs were rejected for more than one reason.

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DAMAGE TYPES

There are three main kinds of damage caused to signs in North Carolina. 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. Although 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, and so on. Occasionally, signs are damaged by rocks or bullets that penetrate the protective outer sheeting layer and cause water to interfere with the reflective properties. The damaged area will then grow via the freeze–thaw cycle, creating dead cells or loss of retroreflectivity. All of these forms of natural damage are unintentional and, to a large extent, 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 mostly occurs during the mowing season, which is during summer and early fall. Another type of nondeliberate human damage is because of knockdowns. Knockdown damage occurs when a vehicle hits a sign post, bending or even breaking it. This type of damage does not occur often. A final kind of human damage is compression. Because of limited storage space, signs are inadvertently pressed and compacted together by field personnel when stored. Compression damages the cell structure of the sign, sometimes permanently.

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.) Because 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.

3 types of dmg:

1. Vandalism
→most prevalent

1.5 Theft

2. Nature

3. Non-intentional human damage

FIELD STUDY DAMAGE RATES

Figure 2 shows photographs of some of the damaged signs 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 some 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.

Table 4 shows the percentage of signs rejected because of vandalism and natural damage in the five NCDOT divisions during the nighttime inspection process. The total number of signs inspected in Table 4 differs from the total number of signs measured in Table 1 because not all the signs the crew inspected were measured. The overall damage rate was 2.37% 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 1, 2, and 3 years, respectively. This assumption matches the inspection rates followed by the sign crews in North Carolina.

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 suggest large differences between damage in different divisions. Division 8 had many signs that were bent because of 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 North Carolina 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 both because of differences in the standards used by inspectors and because of budgetary constraints.

Among the damage caused by humans, paint balls, gun shots, and eggs were the most common. About 66% of vandalized signs were damaged by paint balls, whereas 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 were other sign colors.

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a) Sign Cleaned of Dirt From Feed Mill

b) Sign With Tree Sap

c) Sign With Paint Ball and Egg

d) Sign With Gun Shots

e) Daytime and Nighttime Comparison of Sign Damage

Figure 2: Examples of Damaged Signs

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.

Although no field data, in terms of damage counts, have been identified, there is an alternative way that is available in North Carolina to estimate an overall damage rate. Kirtley and Rasdorf (2001; Palmquist & Rasdorf, 2002) were successfully able to determine the number

Table 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 # 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	1,681	2.37

Table 5: Total Number of Signs in North Carolina

	Blue	*Brown*	*Green*	*Orange*	*Red*	*White*	*Yellow*	*Stop*	*Totals*
Interstates, U.S. routes, North Carolina routes	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	2,927	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 center; WC = welcome center.

of signs in North Carolina on state-maintained roads for various colors of signs (blue, brown, green, orange, red, white, yellow, and stop), for all classifications of roads (interstate, U.S. route, North Carolina route, and secondary), and for urban and rural locations. Their data established the number of signs in place in the field. Table 5 shows the results of the Kirtley and Rasdorf 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 58,433. This is 6.0% of the signs owned by the NCDOT from Table 5. After accounting for sign replacement initiated by inspectors, the research team was able to estimate with confidence that about 1.9% of all signs each year are replaced outside the inspection process; about 80% of these are because of damage caused by humans. The overall sign-replacement rate because of damage, whether replacement is initiated by inspectors or others, is then 4.7% of all signs per year.

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INSPECTION ACCURACY

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 1 or 2 days later. In viewing these results, it should be noted that the data sample is slightly biased toward 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 focus on how well the inspectors did with bad signs rather than how well they did with good signs.

Table 6 shows the sign inspector validation data for Type I white and yellow signs, for which there were the largest sample sizes. The totals in this table do not match the totals in

Table 6: Sign Inspector Validation for White, Yellow, Red, and Green Type I Signs

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

a. Retroreflectivity levels below the Federal Highway Administration proposed minimum.

Tables 1 and 2 because Table 6 includes dirty signs but does not include signs rejected because of damage only. The superscripted *a* identifies retroreflectivity levels below the FHWA proposed minimum (R = 50 for Type I white and yellow signs). Type I red and green signs showed similar trends, whereas the data for Type III signs were not helpful because none of those signs was 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.

Table 6 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 because of the inspectors' being unaware of the standard, because of their having no training regarding the standard, or because of 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.

Findings

One of the initial study goals was to obtain better estimates of the vandalism and natural damage rates for North Carolina 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 irreparably damaged by humans each year, 0.9% are irreparably damaged by natural causes each year, and about 0.17% of signs each year are damaged because of 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 yellow signs were more prone to vandalism. Finally, there was a significant difference among 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 6.0% of all signs per year. The researchers estimated that 4.0% of all signs are replaced because of damage each year, and this percentage includes 1.9% of signs each year that are replaced outside the inspection process. These rates will all be valuable in the simulation program.

Another goal of the study was to model the performance of North Carolina 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%.

Based on the nighttime rides and daytime inspections, it is clear that both damage and retroreflectivity field inspections can simultaneously be conducted at night. This is important for damage inspections because it is difficult to clearly see some types of damage during the day.

Recommendations

Based on the damage and inspector accuracy study described herein, a few recommendations were formulated. First, both damage and inspector rejection rates can now be used by other researchers in their studies. The NCSU research team will continue to investigate these questions. Studies in other states would also be highly appropriate.

Second, the federal and state governments must allocate an adequate annual budget for sign replacement. Among other things, an adequate budget 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 that does not meet minimum standards without having to consider whether or not the sign budget will allow such a rejection.

The federal and state governments must allocate an adequate annual budget for sign replacement.

Third, all states should consider establishing their own minimum retroreflectivity 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 to implement the FHWA minimum standards. Presently, they are evidently using a minimum below that proposed by the 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.

Two recommendations are made regarding damage of signs. First, the divisions with higher damage rates must make an effort to more quickly replace their signs. 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, and all gunshot-damaged signs should be replaced.

Finally, signs on the secondary roads must be more frequently checked to identify and replace damaged signs as the damage rate is higher on secondary roads.

Future Research

Data from the Washington study were used in the earlier NCSU study to construct a simulation of the sign inspection and replacement process. In that simulation, untested assumptions were used for the rates at which signs deteriorate with age and the rates at which sign damage occurs. The simulation provided promising results, but they were not ready to influence policy. With the newly acquired data that have been discussed here, a more valid simulation can be constructed that the NCDOT, and perhaps other agencies, can use to optimize sign-management procedures. With the help of the simulation, a model can be produced that will

- Optimize inspection frequency
- Provide better inspector training
- Defend the inspection systems in the event of challenges
- Better match budgets with sign needs

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