IMPLICATIONS FOR TRAFFIC SIGN MANAGEMENT GIVEN PROPOSED MINIMUM RETROREFLECTIVITY GUIDELINES FOR CANADA

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Introduction

Traffic signs are used on today's roadways as warnings to potential hazards within the roadway, to regulate driving behaviour, and to provide positive guidance. In order to achieve these functionalities traffic signs are required to be identifiable and comprehensible in both daytime and nighttime conditions. To meet this need they are constructed with retroreflective properties that allow the signs to reflect the light from a vehicle's headlights back to the driver so that they are as visible in nighttime conditions as they are during the day (FHWA, 2009).

The motivation behind studying the retroreflective state of signs in the province of New Brunswick stems from the implementation of a traffic sign retroreflectivity standard established in the United States in 2007, by the Federal Highway Administration (FHWA), as set out in the United States Manual of Uniform Traffic Control Devices (US-MUTCD) (FHWA, 2009). Similar minimum retroreflectivity levels are due to be published, in early 2013, as guidelines within a Transportation Association of Canada (TAC) document, entitled 'Guidelines for Selecting Sign Sheeting to Meet Minimum Retro-reflectivity Levels'. These guidelines will be referenced in the forthcoming edition of the Manual of Uniform Traffic Control Devices for Canada (MUTCD-C). The FHWA standard sets out a minimum level of retroreflectivity for different sign colours, by

sheeting grade and sign function. Since the TAC guidelines have yet to be published, the FHWA standards, for minimum retroreflectivity, were used in the evaluation of the retroreflectivity of New Brunswick traffic signs. It is anticipated that the Canadian guidelines will be nearly identical to the U.S. standards.

Ensuring that traffic signs are being maintained to meet the needs of drivers at night is becoming more important with the increasing age of the driving population. "It is expected that by 2024 approximately 1 in 4 Canadians will be older than 65" (Byszewski & Dalziel, 2002). It has been proven that nighttime vision begins to diminish at an approximate age of 45 years (Burg, 1967) and drivers over the age of 65 read signs at shorter distances (Sivak, Olson, & Pastalan, 1981; Garvey, Pietrucha, & Meeker, 1998).

Not only is it imperative that signs be maintained at a certain level in order to promote road safety, but agencies may be faced with liability given that U.S. jurisdictions are in the process of adopting the minimum standards. Canadian road agencies in particular should be concerned with retroreflectivity to ensure that they are prepared for the introduction of the minimum levels of retroreflectivity, as noted in the documents mentioned above.

The University of New Brunswick Transportation Group (UNBTG) has recently undergone a study for the New Brunswick Department of Transportation and Infrastructure (NBDTI) in order to determine the state of NBDTI's road signs with respect to the FHWA minimum levels of retroreflectivity. The results of that study are synthesized in this paper.

Minimum Levels of Retroreflectivity

Retroreflectivity has been recognized as an important property for traffic signs and pavement markings for many years. The development of the current in-service minimum levels of retroreflectivity for traffic signs was initiated in 1993, for the U.S., and have been refined and updated to the current minimum levels that were first published by the FHWA in the 2007 revision of the 2003 edition of the US-

MUTCD and have been adjusted in the 2009 edition of the MUTCD. The FHWA minimum levels of retroreflectivity are presented in Figure 1.

Sign Color	Sheeting Type (ASTM D4956-04)				Additional Criteria
	Beaded Sheeting			Prismatic Sheeting	
	I	II	III	III, IV, VI, VII, VIII, IX, X	
White on Green	W*; G ≥ 7	W*; G ≥ 15	W*; G ≥ 25	W ≥ 250; G ≥ 25	Overhead
	W*; G ≥ 7	W ≥ 120; G ≥ 15			Post-mounted
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 50; O ≥ 50			[2]
	Y*; O*	Y ≥ 75; O ≥ 75			[3]
White on Red	W ≥ 35; R ≥ 7				[4]
Black on White	W ≥ 50				–

[1] The minimum maintained retroreflectivity levels shown in this table are in units of cd/lx/m² measured at an observation angle of 0.2° and an entrance angle of -4.0°.
[2] For text and fine symbol signs measuring at least 48 inches and for all sizes of bold symbol signs
[3] For text and fine symbol signs measuring less than 48 inches
[4] Minimum sign contrast ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)
* This sheeting type shall not be used for this color for this application.

Figure 1. FHWA Minimum Acceptable Retroreflectivity Levels
(FHWA, 2009)

The numeric values seen in Figure 1 represent the minimum levels of retroreflectivity to be met for different sign colours, sheeting types, and in some cases sign size. The values denote the coefficient of retroreflection (Ra). The Ra value is the amount of light that returns from the sign divided by the amount of light that comes from the light source. Ra is most commonly expressed in candelas per lux per square meter ($cd/lx/m^2$). A high Ra value is desirable as it represents more light being reflected from the sign sheeting and better sign visibility in most cases (Bischoff & Bullock, 2002). Note 1 in Figure 1 states that the minimum maintained levels of retroreflectivity are measured at an observation angle of 0.2º and entrance angle of -4.0º. The observation and entrance angles are important as they represent a particular viewing distance and sign distance from the roadway, respectively. Most retroreflectometers used to determine an in-service signs Ra value measure retroreflectivity at these standard angles. An observation angle of 0.2º is representative of a 162-metre viewing distance, and the standard entrance angle of -4º represents signs too close to the roadway and pointing away from the perpendicular.

New Brunswick Sign Sheeting

Most of the traffic signs installed and maintained by the province of New Brunswick are made at the New Brunswick Department of Transportation Sign Shop in Fredericton, New Brunswick. 3M is the retroreflective sheeting manufacturer that supplies the NBDTI sign shop. Three different types of retroreflective sheeting currently make up the vast majority of New Brunswick road signs. They are listed in Table 1. It should also be noted that a process known as silk screening is used to manufacture a variety of the traffic signs implemented in the province. Silk screening is a process that involves adding a transparent ink over a sign sheeting material (Ré, Miles, & Carlson, 2011). In New Brunswick the silk screening process is used most frequently for the signs listed in Table 2.

Table 1. New Brunswick NBDTI Sheeting Types

Sheeting Grade	
I	3M Scotchlite Reflective Graphic Film
III	3M High Intensity 2800 series
IV	3M High Intensity Prismatic Sheeting 3930 series

Table 2. New Brunswick Silk Screened Signs

Sign Type	Sheeting Colour	Silk Screened Colour
Stop	White	Red
Yield	White	Red
Speed Advisory	White	Black
Construction	Orange	Black
Warning	Yellow	Black

Findings from Previous Retroreflectivity Studies

After reviewing a number of studies that looked at the retroreflective deterioration of traffic signs throughout the United States and Canada the following important conclusions were drawn.

All studies, looking at in-service traffic sign retroreflectivity, found that there is some correlation between sign age and retroreflectivity. However, in most cases it was found that regression was not a valid method of modeling the retroreflective deterioration of a traffic sign, as it ages, on its own. Other factors which were found to have some sort of effect on retroreflectivity in past studies included:

- Sheeting type
- Sun exposure
- Frost/Dew conditions
- Geographic Region
- Sheeting colour

Although certain studies showed some correlation between the above-mentioned factors and the deterioration of sign retroreflectivity, others did not. Sun exposure was found to have an effect on the retroreflectivity of traffic signs in the 1995 study completed at the University of New Brunswick, but this same factor was found to not be significant in at least two other studies (Bischoff & Bullock, 2002; Ré, Miles, & Carlson, 2011). This inconsistency is true for a number of other factors as well. In some cases these inconsistencies may be due to the way signs were sampled and the number of signs included in a particular sample. In any case it is important to obtain a sample that is representative of the entire sign population in question. In the case of the current study, each of the 6 NBDTI service districts (Figure 2) was included in a stratified sample, which also includes all road classes from Arterial highways to local named roads.

Another important finding is that frost and dew have a significant effect on the retroreflectivity of traffic signs (Hildebrand & Bergin, 2004). It was important that dew and frost conditions be avoided in order to not skew the data due to a factor that is already known to reduce retroreflectivity. Data collection was not completed at dusk or dawn, which tend to be the most common times for dew and/or frost to form (Hildebrand & Bergin, 2004).

There are two main failing mechanisms for sign retroreflectivity, laid out in the minimum levels of retroreflectivity, which include either the failing of an individual colour for not meeting the minimum level

for that particular colour and sheeting type, or a sign can be failed for having a contrast ratio below 3:1, for red on white signs. It has been established that the vast majority of red on white signs in New Brunswick are made through the process of silk screening. It was determined in a study by Black, Hussain, and Paniati that for signs using red silk screening it is likely that the failing mechanism will be the contrast ratio since red silk screened ink deteriorates faster than the white sheeting on which it is printed, henceforth increasing the retroreflectivity of the red portion of the sign by unveiling the retroreflective properties of the white sheeting, and in turn decreasing the contrast ratio (Black, Hussain, & Paniati, 1992).

Methodology

Signs from across the province of New Brunswick were sampled. A stratified sample was obtained covering all road classifications across all six NBDTI service districts.

Signs were sampled throughout July and August of 2012 to obtain a sample of 1,123 signs from 45 different roads throughout the province, which are highlighted in Figure 2. The retroreflectivity of all sign colours were measured on each sign, along with the following sign attributes: age, colour(s), district (location), road class, sheeting grade(s), sign type, sign material, the orientation of the sign, visual condition, and the road surface on which the sign was located. The retroreflectivity of each colour, on all signs in the sample, was measured in 4 locations in order to obtain an average retroreflectivity reading for each colour on all signs. Since a large number of signs have more than one retroreflective colour, a total of 1,460 average retroreflectivity measurements were obtained.

The sample was then organized and analyzed in order to determine the number of signs meeting the minimum levels of retroreflectivity and to determine some of the factors that might be influencing the retroreflective deterioration of traffic signs in New Brunswick.

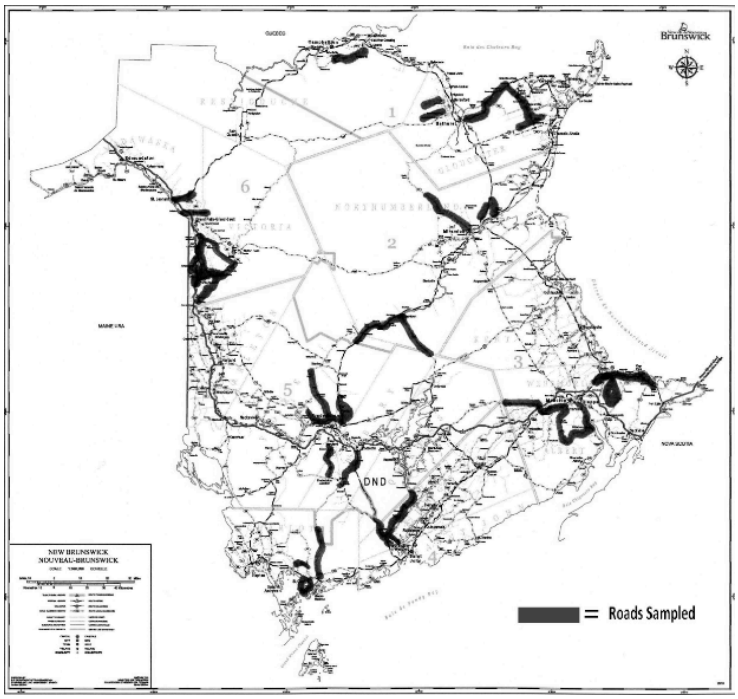

Figure 2. New Brunswick Traffic Sign Retroreflectivity Sample Area

Analysis and Results

The data in Figure 3 show that the age distribution for signs in New Brunswick follows an approximately normal distribution. The province has traditionally replaced signs at 15 years of age; however, it can be seen that a significant number of signs currently in service are over the age of 15 years. Sign age, in the sample of 1,123 signs, ranged from 0 to 53 years with a mean age of 10 years.

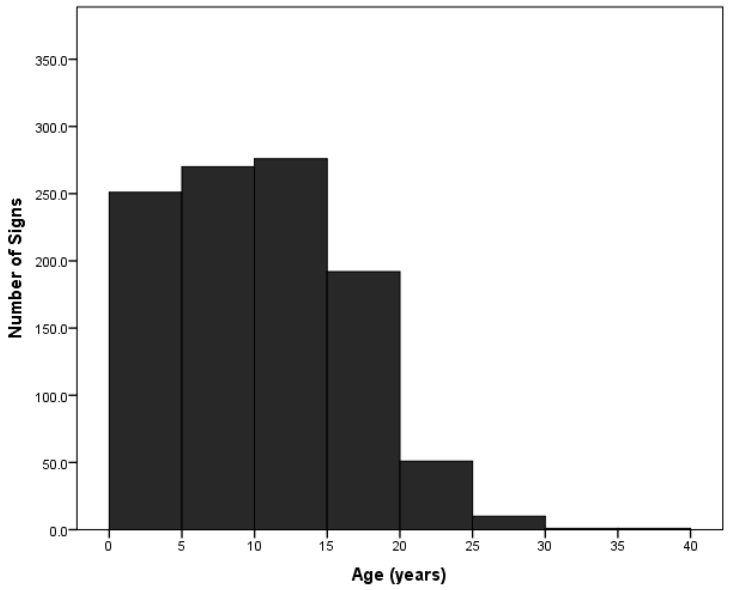

Figure 3. Age Distribution of New Brunswick Traffic Signs

New Brunswick traffic signs were found to be approximately 85% compliant to the FHWA minimum levels of retroreflectivity, which can be seen in Table 3. Table 3 is segregated by sign colour and sheeting grade in order to demonstrate the compliance of different sign types to their specific minimum level of retroreflectivity. It can be seen that for signs with Type III or IV sheeting the lowest compliance rate is 94.7% in the case of Red Type III signs, which would include red regulatory signs such as stop and yield signs. Signs with Type I sheeting vary more widely in their compliance to the minimum levels of retroreflectivity, depending on the sheeting colour. The least compliant signs are those with Type I yellow sheeting at only 3.3% compliance. The minimum levels include a note which states that yellow Type I sheeting should not be used, which explains why the compliance for yellow Type I signs in New Brunswick is so low. The next lowest compliance rate is in green Type I sheeting at 76.3%.

Table 3. Compliance of New Brunswick Traffic Signs by Colour and Grade

Sign Colour(s)	Sheet Colour	Sheet Grade	# Signs	# Passing	Compliance
Green/White	Green	I	169	129	76.3%
	Green	IV	3	3	100.0%
	White	III	115	114	99.1%
	White	IV	51	50	98.0%
Red/White	Red	III	170	161	94.7%
	Red	IV	41	40	97.6%
	White	III	170	170	100.0%
	White	IV	41	41	100.0%
White/Black	White	I	215	193	89.8%
	White	IV	68	68	100.0%
Yellow/Black	Yellow	I	152	5	3.3%
	Yellow	III	157	153	97.5%
	Yellow	IV	105	105	100.0%
	Overall:		1457	1232	**84.6%**

An Analysis of Variance (ANOVA) was completed in order to determine some of the factors that have statistical significance with respect to their effect on retroreflectivity. It can be seen in Table 4 that using a 5% level of significance the following factors are statistically significant with respect to retroreflectivity: sign age, district (location of sign), sheeting colour, sheeting grade, sign type, in-field visual condition rating and the particular road class on which the sign is located.

In an attempt to create a model that can be used to predict sign service life, using the statistically significant factors identified through ANOVA, multiple linear regression was employed. Multiple linear regression is one method of quantifying the variation which can be explained by certain factors (independent variables) on some dependent variable. The dependent variable in this particular case is the level of retroreflectivity. A variety of models were created in order to determine the "best" combination of the above-mentioned factors in the modelling of retroreflectivity. Tables 5 and 6 are two of the many models created which happen to explain a large portion of the variation in retroreflectivity. Table 5, in particular, is denoted as

Model # 1 and is a model for all signs using the independent variable of age, as well as binary "dummy" variables representing whether a particular sign has Type I, Type III or Type IV sheeting. The "dummy" variables were used so that one model could be created for all signs rather than have a separate model for each sheeting grade. The R^2 for Model #1 is 0.773, which means 77.3% of the variation in retroreflectivity is explained by the independent variables (factors) used in this model.

Table 4. Analysis of Variance (ANOVA) for All Signs

One-Way ANOVA ALL SIGNS					
Dependent Variable: Average Retroreflectivity					
Independent Variable	**SS**	**df**	**F-Value**	**P-Value**	**Effect Size**
Age	30448160.5	29	44.3	**0.000**	48.9%
District	2802754.3	5	13.2	**0.000**	4.3%
Colour	677162.8	3	5.1	**0.002**	1.0%
Sheeting Grade	50037518.7	2	2505.5	**0.000**	77.5%
Sign Type	500995.7	2	5.7	**0.003**	0.8%
Sign Orientation	179836.2	7	0.6	0.774	0.3%
Visual Condition Rating	8074146.1	2	104.0	**0.000**	12.5%
Sign Back-plate Material	5482.5	1	0.1	0.725	0.0%
Road Surface	17137.9	1	0.4	0.536	0.0%
Road Classification	1091221.4	3	8.3	**0.000**	1.7%
Bold P-Values = significant to 95%					
SS = Sum of Squares *df = degrees of freedom*					

Table 5. Model #1 – All Signs

Independent Variable	**β**	**Std. Error**	**t-stat.**	**P-value**
Constant	189.235	7.782	24.317	0.000
Age	-1.698	0.555	-3.057	0.002
Type I	-122.918	6.231	-19.725	0.000
Type IV	359.973	8.792	40.945	0.000
Dependent Variable: *Average Retroreflectivity*				
Model Details: *R^2 = 77.3 % ; Signficance = 0.000*				
Excluded variables (collinearity): Type III				

Model #1 seemed to highly overestimate the retroreflectivity of Type III signs; therefore, Model #2 was created. Model #2, seen in Table 6, is an attempt at modelling all Type I and IV signs while excluding the Type III signs. It can be seen that the R^2 increased to almost 87% when Type III signs were ignored.

Table 6. Model #2 – Type III signs excluded

Independent Variable	β	Std. Error	t-stat.	P-Value
Constant	80.488	10.618	7.58	0.000
RW	-207.738	12.746	-16.298	0.000
GW	-35.431	80185	-4.329	0.000
Type IV	532.277	10.595	50.24	0.000
Age	-1.927	0.703	-2.743	0.006
Dependent Variable: *Average Retroreflectivity*				
Model Details: *R^2 = 86.8 % ; Signficance = 0.000*				

Economic Impact

In order to get a better understanding of the monetary impact that upgrading the sign inventory would have on NBDTI, an estimate of the total number of non-compliant signs in the province was required. Unfortunately, there is currently no complete inventory for signs in the province; therefore, another method of estimating the population of signs was required. The total length of roads maintained by the New Brunswick Department of Transportation and Infrastructure (NBDTI) is 17,603 km. This number excludes any municipal or privately operated and maintained roads within the province.

An estimate of the density of signs along different road classes was calculated using the number of kilometres covered throughout the collection of the sign retroreflectivity sample and using video data obtained from NBDTI. There is approximately 1.4 signs/km/travel direction on NBDTI maintained roads, as per this estimation. Using this density estimate and the total lengths of NBDTI maintained roads the approximate cost of replacing all non-compliant signs (≈48500 signs) was found to be in the $850,000–$900,000 range.

Conclusions

Signs throughout the Province of New Brunswick, maintained by NBDTI, were found to be non-compliant in approximately 15% of cases, with respect to the FHWA's minimum levels of retro-reflectivity. It is clear that Type I signs are the least likely to meet the minimum levels, this is especially true in the case of yellow warning signs which failed in over 96% of the cases. Every sign colour with Type IV prismatic sheeting was compliant in 100% of the cases. Type III signs were compliant in at least 95% of cases for all sign colours.

An economic analysis of possible sign management programs, which are outlined within the US-MUTCD, is being completed in order to get an understanding of the most effective techniques that NBDTI can undertake in order to have their sign inventory comply with the minimum levels of retroreflectivity. The possible sign management strategies include: expected sign life replacement, blanket replacement, control sign replacement, visual nighttime inspection or through measured sign retroreflectivity using a retroreflectometer.

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