Building Tomorrow's Society
Bâtir la Société de Demain

Fredericton, Canada
June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

THE DETERIORATION OF PAVEMENT MARKING RETROREFLECTIVITY: ARE WE READY TO ADOPT MINIMUM STANDARDS?

Carly MacEacheron[1], Eric Hildebrand[2,3], and Trevor Hanson[2]
[1] WSP Canada Group Ltd., Canada
[2] University of New Brunswick, Canada
[3] edh@unb.ca

Abstract: Pavement markings with retroreflective properties provide delineation and safety benefits for drivers during nighttime conditions. Many road authorities do not have a history of retroreflectivity performance for pavement markings throughout their life-cycles. This makes it difficult to assess the impacts of potential minimum retroreflectivity standards such as those proposed by the Federal Highway Administration (FHWA) or to adopt performance-based specifications. A year-long study of pavement markings on 24 sampled road sections was performed to better understand the state of pavement markings in New Brunswick and the causes/rates of their deterioration. Analyses found the factors that have a statistically significant effect on pavement marking retroreflectivity include age, traffic volume, road class, season when the marking was applied, and paint colour. Analyses of the sampled retroreflectivity values found that they generally deteriorate over time, and that white markings consistently produce higher readings than yellow markings through their life-cycle even though white markings deteriorate more quickly. Overall, 27% and 38% of sampled pavement markings met the 2014 or 2017 proposed FHWA minimum retroreflectivity standards at the time of their replacement, respectively. These findings suggest that the current pavement marking maintenance schedule used in New Brunswick (which is consistent with many other jurisdictions) would be inadequate if minimum standards consistent with the FHWA were to be adopted. It is recommended that road authorities develop pavement marking policies that will improve compliance with an adopted set of minimum retroreflectivity standards or guidelines.

1 INTRODUCTION

Longitudinal pavement markings are among the most important traffic control devices for their ability to delineate roadways and provide safety benefits to drivers. To provide the same benefits during nighttime and inclement weather conditions, pavement markings must have retroreflective properties to be adequately visible. Retroreflectivity, defined as "a measure of an object's ability to reflect light back towards a light source along the same axis from which it strikes the object" (FHWA 2007), is usually achieved in pavement markings by applying glass retroreflective beads onto the marking material's surface. Resulting retroreflective properties allows vehicles' headlights to by reflected approximately back towards the driver's eyes.

Retroreflectivity of pavement markings is most commonly measured using the Coefficient of Retroreflected Luminance (R_L). It is the ratio of luminance (the total amount of light reflected back to the driver) and normal illuminance (the illuminance of the headlights on the marking) and is measured in millicandelas per lux square metre (mcd/m^2/lx). Measurements are taken using a retroreflectometer, which emits a light at an angle considered to represent standard geometry, as defined by ASTM Standard E1710-11, and measures the amount of light reflected back. This simulates what an average driver would see during nighttime and inclement weather conditions.

The United States Manual on Uniform Traffic Control Devices (US-MUTCD) requires that pavement markings be retroreflective but does not currently specify any minimum retroreflectivity standards. In reaction to this, the U.S. Federal Highway Administration (FHWA) proposed minimum pavement marking retroreflectivity standards in 2014 to be published in the Manual on Uniform Traffic Control Devices (MUTCD), outlined in Table 1.

Table 1: Recommended MUTCD standards for minimum retroreflectivity levels of longitudinal pavement markings (FHWA 2014)

	Posted Speed (mph)		
	≤ 30	35 - 50	≥ 55
Two-lane roads with centerline markings only	n/a	100	250
All other roads	n/a	50	100

More recently, the FHWA (2017) issued for comment a simpler, much more lenient proposed standard whereby a minimum retroreflectivity of 50 mcd/m^2/lux is required if posted speeds exceed 35 mph, and 100 mcd/m^2/lux where posted speeds exceed 70 mph. The new proposed standard only applies to road with an AADT of 6,000 or above. It is unknown whether this supplemental 2017 proposal will ultimately be adopted, but this study includes consideration for the potential adoption of either standard.

The adoption of minimum standards by U.S. jurisdictions may lead to similar standards or guidelines in Canada, but little if any research has explored prospective impacts on Canadian jurisdictions that adopt minimum retroreflectivity standards. The New Brunswick Department of Transportation and Infrastructure (NBDTI) operates a pavement marking program that is based on traffic volume-based repainting thresholds detailed in its pavement marking specifications, which resulted in the striping of 7,100 km of the Province's 18,000 route-km of paved roads in 2015-2016 (GNB 2016). The only retroreflectivity standard specification employed by NBDTI concerns material type (e.g. markings embedded with glass beads) and minimum retroreflectivity levels for new markings as a quality control measure. The introduction of retroreflectivity-based thresholds for in-service markings has the potential to significantly impact re-striping operations, though the degree of this impact is unclear. Like many road authorities, NBDTI does not have historical retroreflectivity data that describes pavement marking deterioration over their life-cycles in practice and, as such, it would be difficult for NBDTI to make any informed decision regarding adopting minimum retroreflectivity standards without further research.

A year-long study was undertaken to monitor the retroreflectivity of pavement markings on 24 sections of various classes of New Brunswick roads to develop an understanding of the rates and causes of pavement marking deterioration in the province and to assess compliance with FHWA's proposed minimum standards. The results of this study will be of interest to all Canadian highway agencies in advance of the possible adoption of minimum retroreflectivity standards or for the development of performance-based specifications.

2 BACKGROUND

2.1 Factors Affecting the Deterioration of Pavement Marking Retroreflectivity

Factors identified in the literature that are known to cause pavement marking retroreflectivity deterioration include: marking material, marking colour, traffic volume and heavy vehicle percentage, application methods, lateral line location, directionality, winter maintenance, and road surface type and condition. The causes and magnitude of the major contributing factors are described below.

Pavement marking materials are generally grouped in either a durable or non-durable category. Non-durable materials include traffic paints that have shorter service lives than more durable materials such as thermoplastics and preformed tapes. Paints have the shortest service lives of all pavement marking materials and have much lower costs, resulting in many road authorities including New Brunswick to use paints despite their lack of durability. NBDTI primarily uses waterborne paints for pavement marking application since oil-based paints can only be used between mid-October and May in Canada due to volatile organic compound (VOC) emission standards. The two traffic paints have been found to have comparable service lives and retroreflectivity levels throughout their life-cycle. Additionally, white pavement markings have been shown to produce significantly higher retroreflectivity readings than yellow markings (Migletz *et al.* 1999). White markings have been found to degrade more rapidly than yellow markings, but white markings' higher initial values usually offset their faster degradation rate and yellow markings remain at lower R_L values throughout their life-cycle (Bahar *et al.* 2006).

It is generally accepted that traffic volume and composition affect the deterioration of pavement marking retroreflectivity. This is because tires passing over the lines lift and scatter the retroreflective beads or abrade them enough for them to eventually lose their retroreflective properties. As such, pavement markings on roads with higher AADTs have generally been found to have higher rates of pavement marking retroreflectivity deterioration (Migletz *et al.* 1994). Marking location and road geometry are also determining factors of how significant the effect of traffic volume is on retroreflectivity degradation. Centreline and lane line retroreflectivity has been found to degrade more quickly than edge lines due to higher numbers of traffic crossovers at the centre of a road compared to the edge (Craig *et al.* 2007). Road geometry characteristics such as lane width, horizontal curvature, and the presence of driveways have also been found to cause pavement marking degradation due to vehicle crossovers (Migletz *et al.* 1994; Bowman & Abboud 2001).

Winter maintenance activities are generally considered to have the largest effect on pavement marking retroreflectivity compared to any other factor, creating a substantial issue for jurisdictions with snowfall (Scheuer *et al.* 1997). Deterioration from winter maintenance is primarily caused by snowplow blades scraping the markings, which lifts and abrades the beads as well as the marking itself. Similar effects can be found with studded tires, which are prevalent during winter seasons. Salts and other de-icing agents can cause retroreflectivity deterioration through chemical disintegration of the marking material and/or loosening of the bond between the marking and pavement. Sand can also act as an abrasive that degrades the translucent quality of the retroreflective beads (Bowman & Abboud 2001). Studies have found that yellow and white traffic paint markings' retroreflectivity readings can deteriorate up to 21% and 62%, respectively, over a winter season (Lu & Barter 1998). It appears to be the consensus in literature that paint pavement markings do not exhibit adequate durability for use in regions with significant amounts of snowfall such as New Brunswick.

The more texture a road surface has, the poorer the retroreflectivity of its pavement markings. This is because irregularities in the road surface may allow marking materials or retroreflective beads to sink into voids and aggregates to cast a shadow on them, making them less visible to drivers. This applies to chip seal surfaces with their large proportion of surface voids, and cracked or uneven asphalt surfaces. Retroreflectivity readings have been found to be 23% and 38% lower for white and yellow thermoplastic markings, respectively, on chip seal compared to hot-mix asphalt surfaces (Gates *et al.* 2003).

2.2 Service Life and Degradation of Pavement Markings

The performance of pavement markings is usually described in terms of "service life", the time expended between application and the point at which retroreflectivity readings are below a pre-determined minimum level. Literature indicates that service lives for paint pavement markings are highly variable and range from six months and two years.

Pavement marking retroreflectivity deterioration is usually described as the relationship between retroreflectivity and age, but a consensus has not yet been reached on the graphical form of this relationship. This is likely due to the highly variable nature of the rate of deterioration and its dependence on various factors. There is therefore no defined method of predicting pavement marking retroreflectivity levels over time and there is great value in individual road authorities having historical retroreflectivity data available to determine re-striping frequency.

2.3 NBDTI Re-Striping Practice

NBDTI employs a traffic volume-based warrant to guide its re-striping program. NBDTI's pavement marking specifications stipulate that roads with volumes above 1,000 AADT are re-striped yearly, and those with volumes between 500 and 1,000 AADT are only required to be re-striped every two years; roads with volumes below 500 AADT are not striped.

3 METHODOLOGY

3.1 Data Collection

A sample of 24 local, collector and arterial NBDTI highways were chosen to represent selected categories of traffic volumes and road surface type (asphalt and chip seal). All sample locations were approximately within a 30-minute drive of Fredericton, New Brunswick based on the assumption that they were representative of climate conditions, winter maintenance and pavement marking application methods throughout the province. Sample location selection was primarily based on capturing full pavement marking life-cycles over a year-long data collection period. Since the sampling period was only a year, samples representing roads re-striped biennially were selected with some in their first year and some in their second year since the last pavement marking application piecing together a two-year cycle.

Data from the 24 sample locations were collected monthly between December 2014 and November 2015, with the exception of the three month period between January and March of 2015 when constant salt, sand and/or ice on the roads prevented the dry, clean surface required for accurate retroreflectivity readings. A Mirolux Plus 30-metre handheld retroreflectometer was used as per the requirements of ASTM E1710-11. Three retroreflectivity readings were taken longitudinally at each of the edge lines, centrelines and/or lane lines, depending on the marking configuration at that sample location, providing an average reading for each pavement marking.

3.2 Data Analyses

Analyses of sampled data included graphical analysis examining the deterioration of the sampled pavement markings' retroreflectivity over time and their compliance with FHWA's proposed minimum standards, followed by a modelling effort to identify factors contributing to the deterioration of the pavement markings' retroreflective properties.

Scatter plots of pavement marking retroreflectivity readings versus age were plotted for the sampled data over their one or two-year life-cycles. Data sets were fit with linear trend lines representing the deterioration curve over time. Different plots were made according to marking configuration and speed limit to compare to different proposed minimum values in the standards. The sample analysis then included a multiple linear regression analysis to test the effects of independent variables including age, season, road class, surface material, traffic volume, and paint type on the dependent variable, retroreflectivity.

4 RESULTS

4.1 Graphical Analysis

The analysis included scatter plots of retroreflectivity values over time at individual sample locations to develop an understanding of the general rate of pavement marking deterioration over a full installation cycle. The readings generally drop over time, but a significant amount of variability was seen with some locations even having slightly higher retroreflectivity readings at times before resuming in a downward trend. This anomaly may be due to inherent variability in using a handheld retroreflectometer, or because of sampling variability associated with meter placement (despite best efforts to remain consistent and the use of averages for readings to alleviate such issues). Similar variability in pavement marking retroreflectivity data has been identified in several other studies (Scheuer *et al.* 1997; Kopf 2004). Note, any 'negative' retroreflective values can be attributed to retroreflectometer calibration variability.

All data points from the 24 test sections were combined into Figure 1 to develop an overall trend of retroreflectivity over time. Linear trend lines were fit to all data points, and specifically to white (edge line) and yellow (centreline) markings separately. Trend lines helped to develop a general understanding and comparison of deterioration rates over time. Sampled white pavement markings consistently had higher retroreflectivity readings than yellow, but white markings appeared to deteriorate more quickly than yellow as shown by the model slopes. White readings were high enough compared to yellow upon initial application that the higher deterioration rate still led to the white markings being higher through most of their life-cycle.

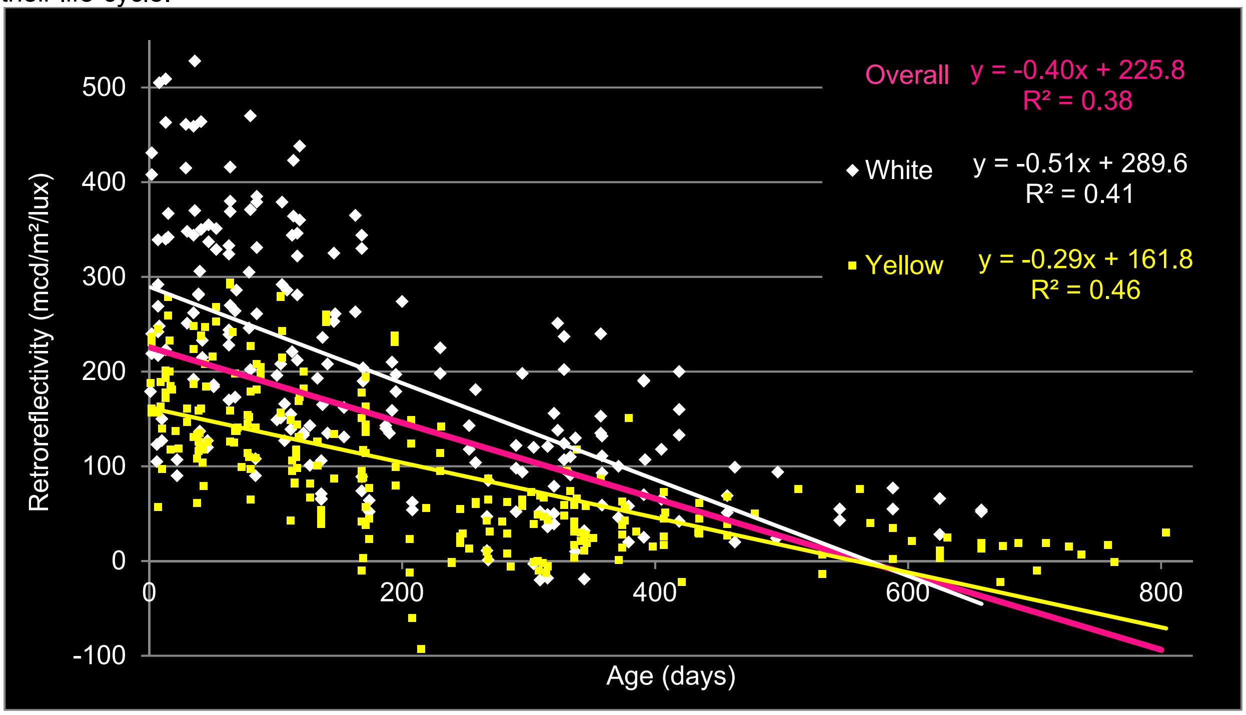

Figure 1: Retroreflectivity deterioration of white, yellow (and overall) sampled markings over time

4.1.1 Comparison to Proposed FHWA Standards

The data were then compared to FHWA's 2014 and 2017 proposed minimum retroreflectivity standards by grouping the sampled pavement markings by speed limit and configuration (consistent with the standards) and plotting them over time. The plots include a horizontal line representing the proposed minimum retroreflectivity level for that given speed zone and marking configuration to compare the data to the FHWA standards.

Retroreflectivity data from samples with centrelines only and a posted speed limit between 35 and 50 mph (56 to 80 km/h) are plotted against age in Figure 2. The red and blue horizontal lines in the graph represent the 2014 and 2017 minimum standards of 100 and 50 mcd/m^2/lux, respectively. A linear trend line was fit to the data, showing a negative slope that falls below the 2014 minimum standard just beyond 100 days following application, and below the 2017 standard just beyond a year. It is noteworthy that apart from the fitted regression line, many of the sampled sites show retroreflectivity levels below either proposed standard beginning at approximately 150 days after installation. This is well short of their current intended life-cycles of either 1 or 2 years.

Sampled roads with centrelines only and speed limits between 55 and 70 mph (90-110 km/h) are plotted in Figure 3 comparing their compliance with the 2014 and 2017 minimum retroreflectivity standards of 250 and 50 mcd/m^2/lux, respectively. There was only one sample road section included in the study that fit this category because road sections with higher speed limits typically also have edge lines in New Brunswick.

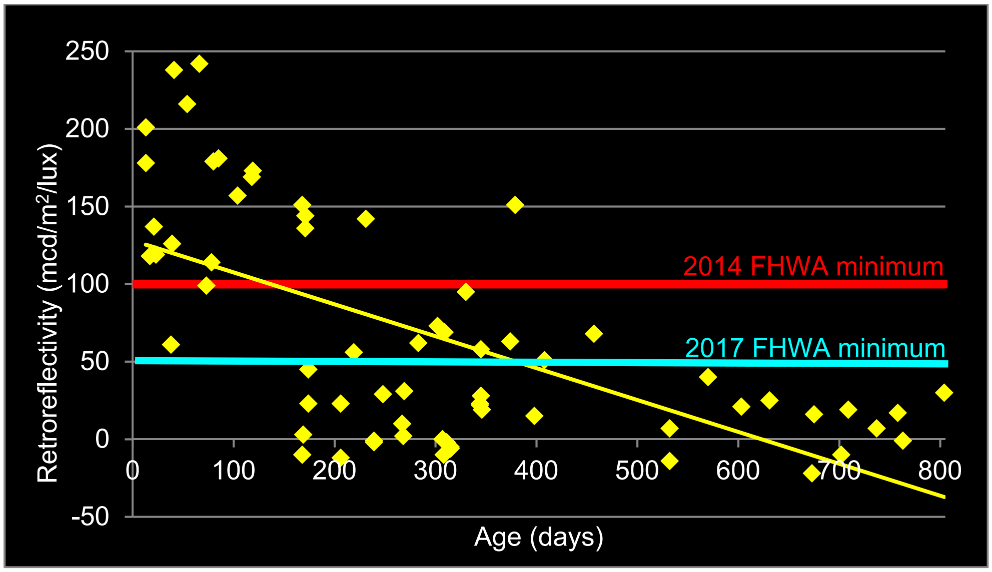

Figure 2: Compliance to FHWA's minimum retroreflectivity standards (centreline markings only and speed limits 35-50 mph)

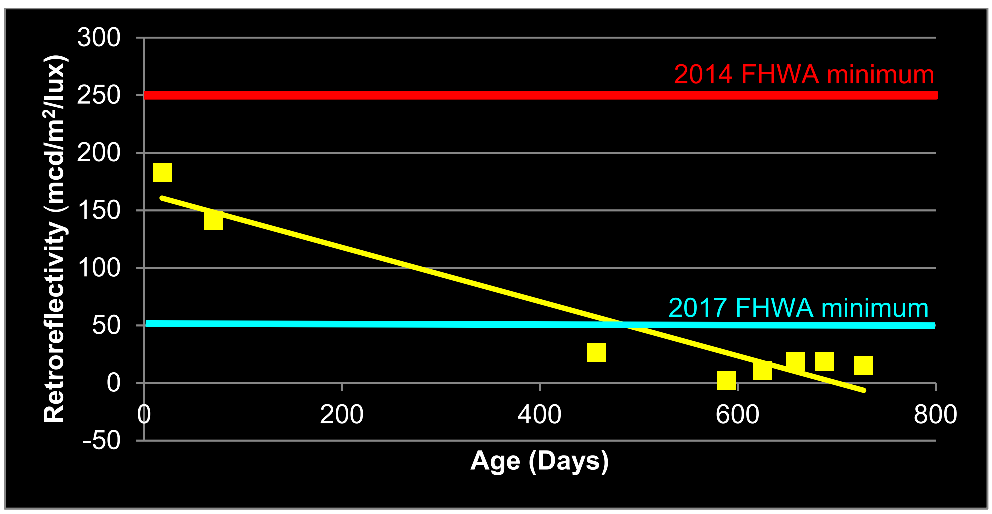

Figure 3: Compliance to FHWA's minimum retroreflectivity standards (centreline markings only and speed limits 55-70 mph)

Observed retroreflectivity values at this sample section are well below the minimum retroreflectivity standard of 250 mcd/m^2/lux throughout its entire life-cycle but fall below the 50 mcd/m^2/lux threshold more than a year following re-striping. NBDTI's quality control standards require that yellow pavement markings are at a minimum of only 200 mcd/m^2/lux two to four weeks after installation, making it unlikely that markings in this category meet the FHWA standard of 250 mcd/m^2/lux even at the beginning of their life-cycle, let alone throughout one or two-year cycles. If the 2014 standard were put into place, a modification of retroreflectivity requirements at the time of application or a change in marking configuration for sections in this category would need to be implemented by NBDTI.

Sample sections categorized as "all other roads" by the FHWA, or, in the case of this study roads with edge lines as well as centrelines, and having speed limits between 35 and 50 mph (56-80 km/h) are plotted and compared to their minimum standard of 50 mcd/m^2/lux (proposed in both 2014 and 2017) in Figure 4. The sample dataset complies well with minimum standards, with the yellow trend line reaching below the minimum standard at approximately a year and the white at close to 500 days. The compliance with the standard is likely because it is a low standard compared to the initial retroreflectivity readings of 200 and 250 mcd/m^2/lux required by NBDTI's quality control standards for yellow and white lines, respectively.

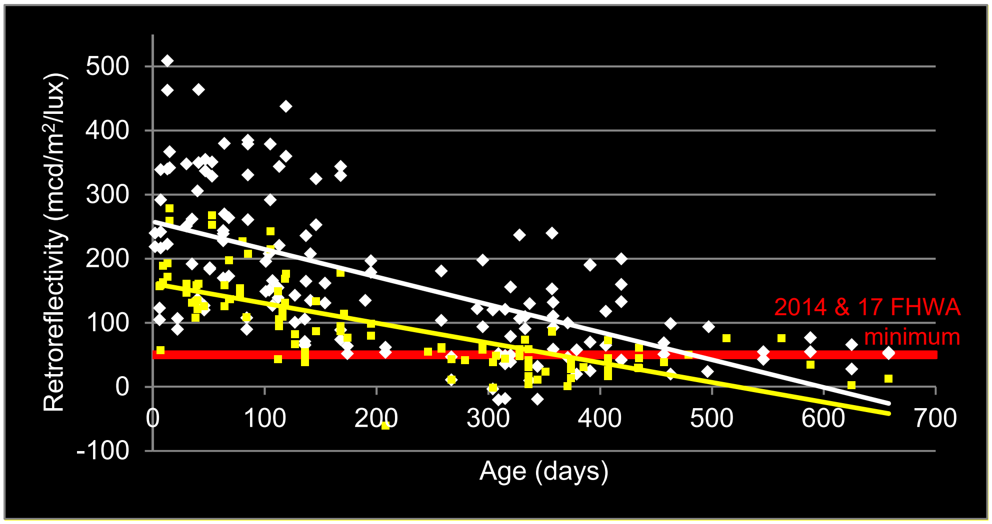

Figure 4: Compliance to FHWA's minimum retroreflectivity standards
(centreline and edge markings and speed limits 35-50 mph)

Yellow centrelines and white edge lines from sample sections in the all other roads with speed limits between 55 and 70 mph are plotted with their 2014 and 2017 minimum standards of 100 and 50 mcd/m^2/lux, respectively, in Figure 5. White markings comply well with both sets of standards, while the yellow trend line reaches both the minimum standards within a year.

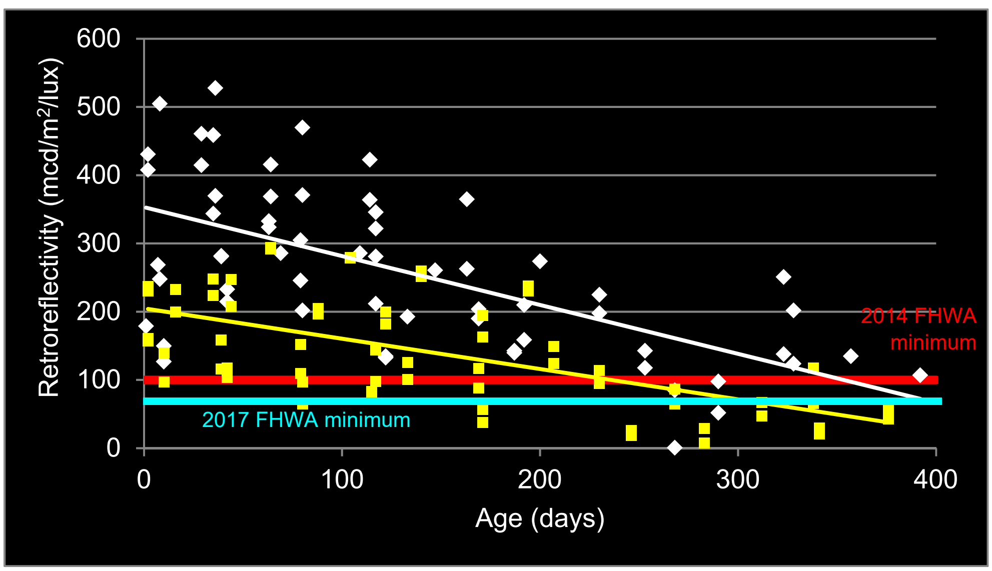

Figure 5: Compliance to FHWA's minimum retroreflectivity standards
(centreline and edge line markings and speed limits 55-70 mph)

Results of the graphical analysis were summarized according to the percentage of all sample sections complying with 2014 FHWA's proposed minimum retroreflectivity standards over time in order to develop an understanding of the overall compliance to the proposed standards and to provide service life estimates. Cumulative percentages of sampled markings complying with the standard over three, six, and twelve month intervals were recorded for each marking configuration/speed category in Table 2.

Table 2: Sampled pavement markings passing FHWA's 2014 proposed minimum retroreflectivity standards

Marking configuration and speed (mph)	Paint Colour	Sample size	% Passing at 3 months	% Passing at 6 months	% Passing at 1 year
Centreline only (35-50)	Yellow	7	71%	71%	0%
Centreline only (≥ 55)	Yellow	1	0%	0%	0%
Centreline and edge line (35-50)	White	20	100%	100%	65%
	Yellow	13	100%	77%	23%
Centreline and edge line (≥ 55)	White	7	100%	100%	43%
	Yellow	8	75%	50%	13%
Overall	W&Y	56	91%	82%	36%

Overall compliance of the sample sections were then compared to the 2017 FHWA proposed minimum standards. A minimum retroreflectivity level of 50 mcd/m^2/lux was applied to all sections, since all samples were taken on roads with speed limits between 35 and 70 mph. Sampled roads with AADT values below 6,000 were included in the analysis despite being excluded from the new proposed standards because it is considered important to maintain some level of retroreflectivity on the Province's roads. Most New Brunswick roads do not have AADTs that exceed 6,000 and, given the more lenient standards, it would be achievable maintain the standards on roads currently included in the Province's re-striping schedule. The analysis found improved compliance to the new proposed standard, with all markings conforming at three months, 82% at six months and 51% at a year from their re-striping date.

Observing the proportion of markings passing both sets of minimum standards over a year, it appears that compliance within a 1-year cycle is low even with the more lenient 2017 standards. Only 38% of sampled markings met the 2017 standard at the time of their replacement (compared to 27% compliance to the 2014 standards). Compliance with both sets of standards appeared to drop off between six months and one year (46% and 31% of samples based on 2014 and 2017 standards, respectively), often because the winter season occurred during that period. The 2014 standard indicates that yellow lines are less compliant than white, with only up to 23% of yellow markings passing after a year, and yellow markings on road sections with edge lines also last longer than roads with centreline(s) only. Comparing individual sampled markings' compliance with overall compliance described by the trend lines in Figures Figure 2 through Figure 5, it appears that better compliance is exhibited when analyzing data grouped by category compared to estimated service lives of individual markings. For example, the trend line for yellow markings in Figure 4 shows a service life of approximately one year, but individual analysis of markings in the same category found only 23% complied within a year. This suggests that if a pavement marking management plan were to be implemented at a network level, individual sections of road would have markings below minimum standards. Road agencies may consider implementing a management plan that considers more specific road characteristics, such as AADT or road class, to maximize compliance.

Findings from the graphical analysis suggest that the current pavement marking maintenance schedule would be inadequate if either of the proposed FHWA minimum retroreflectivity standards were put into place in New Brunswick. Assuming the 7,100 route-kilometres re-striped in the 2015-2016 NBDTI re-striping program is the typical annual value, increasing the frequency of pavement marking maintenance at this magnitude to meet the standards would likely represent a substantial increase in resource requirements.

4.2 Modelling Analysis

A multiple linear regression analysis was performed on the data to evaluate which of the independent variables (age, volume, road class, striping season, and surface type) have a statistically significant effect on the dependent variable, retroreflectivity. Several models including various groupings of data based on pavement marking colour were created with the goal of creating an explanatory model for retroreflectivity. Such an exercise should be undertaken by any road authority considering implementing a pavement marking management plan in order to meet minimum standards or guidelines.

All variables were found to be significant except the asphalt surface type (compared to chip seal). Age and traffic volume were found to have negative effects on retroreflectivity as expected. White pavement markings were found to produce significantly higher readings than yellow pavement markings, and arterial and local functional road classes both model higher effects on retroreflectivity than collector roads. Retroreflectivity readings were shown to be higher the earlier in the year they were re-striped (beginning in May), which reflects the increased deterioration that occurs during the harsh winter conditions.

Results of the multiple regression model generally output the relationships between independent variables and retroreflectivity as expected based on the literature review, with the exception of the road class and road surface type variables. It was expected that collector roads would produce higher readings than local roads because they are generally re-striped more often, but the results were that arterial and local roads produce higher retroreflectivity readings than collector roads. It is suspected that correlation between traffic volume and road class led to this result. It was also expected based on the literature review that pavement surface would have a significant effect on retroreflectivity values, but it is predicted that this result was not shown in this model because of correlation between road class and pavement surface material, since most chip seal surfaces are found on local roads.

5 CONCLUSIONS AND RECOMMENDATIONS

A sample of pavement marking retroreflectivity in New Brunswick over a year-long period revealed information on rates, causes, and characteristics of deterioration over time that will be beneficial to many jurisdictions considering implementing minimum standards (as proposed in the U.S.).

Scatter plots of sampled data found that pavement marking retroreflectivity generally decreased over time. White markings produce retroreflectivity readings over 120 mcd/m^2/lux higher than yellow markings upon their initial installation and generally continue to produce higher readings through their life-cycle, though white markings deteriorate more quickly than yellow markings. Reading variability/uncertainty is an issue given current retroreflectometer technology that should be considered with any plan implementation.

Graphical analysis comparing sampled retroreflectivity data to FHWA's proposed minimum standards found that only 27% of the pavement markings sampled complied with the 2014 standard at the time of their replacement. This value increased to 38% when compared with the more lenient 2017 proposed standards. With many markings having a service life of six months to one year, NBDTI's current maintenance schedule of re-striping roads every one to two years would therefore be inadequate if FHWA's retroreflectivity standards were to be adopted.

Modelling analyses of the sampled data found factors that have a statistically significant effect on pavement marking retroreflectivity to be age, traffic volume, road class, season in which the marking was applied, and paint colour. Age and traffic volume were found to have a negative effect on retroreflectivity readings. Functional road classification has an impact as does the season of marking application.

Based on the sampled pavement markings' overall noncompliance, major modifications to NBDTI's current pavement marking management plan would be required to meet any minimum standards. It is likely than many other road authorities would be in a similar position. Any management plan should incorporate road characteristics found to be statistically significant in the regression model in order to improve compliance over a network-wide plan. Paint pavement markings should be re-striped at least once a year on all roads, and the use of more durable pavement marking materials should be considered if more infrequent maintenance is desired. Other efforts that may be taken to maximize the service life of pavement markings include re-striping pavement markings on road sections that are more prone to deterioration, such as high-traffic roads, as early in the season as possible to offset the effects of the winter season. Management plans may be amended pending publication of an approved set of standards, but in the meantime, these recommendations may be carried forward by NBDTI and other road authorities in a staged approach to create pavement marking management plans and policies that may improve compliance with FHWA's proposed minimum standards, ultimately improving the safety performance of the road network.

Acknowledgements

The participation and support of the Traffic and Engineering Branch of NBDTI toward the design and completion of this research study is greatly appreciated. The study would not have been possible without funding provided by the Natural Sciences and Engineering Research Council of Canada.

References

American Society for Testing Materials (ASTM). 2011. *ASTM Standard 1710-11: Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry using a Portable Retroreflectometer*. ASTM International, West Conshohocken, PA.

Bahar, G., Masliah, M., Erwin, T., Tan, E., & Hauer, E. 2006. *Pavement Marking Materials and Markers: Real-world Relationship between Retroreflectivity and Safety over Time*. National Cooperative Highway Research Program Project 17-28. Transportation Research Board, Washington, D.C.

Bowman, B. & Abboud, N. 2001. *Estimating the Effective Life of Pavement Markings based on Crash History*. Auburn University Department of Civil Engineering, Auburn, AL. Available from http://www.eng.auburn.edu/files/centers/hrc/IR-01-02.pdf [accessed 4 June 2015].

Craig, W.N., Sitzabee, W.E., Rasdorf, W.J. & Hummer, J.E. 2007. Statistical Validation of the Effect of Lateral Line Location on Pavement Marking Retroreflectivity Degradation. *Public Works Management & Policy*, **12**(2): 431-450. doi: https://doi.org/10.1177/1087724X07308773.

Federal Highway Administration (FHWA). 2007. *Updates to Research on Recommended Minimum Levels for Pavement Marking Retroreflectivity to meet Driver Night Visibility Needs*. U.S. Department of Transportation, McLean, VA.

Federal Highway Administration (FHWA). 2014. *Summary of the MUTCD Pavement Marking Retroreflectivity Standard*. U.S. Department of Transportation, McLean, VA.

Federal Highway Administration (FHWA). 2017. *Pavement Markings Regulations / Standards, Supplemental Notice of Proposed Amendment (SNPA).* U.S. Department of Transportation, McLean, VA. Available from https://safety.fhwa.dot.gov/roadway_dept/night_visib/pavementreg.cfm [accessed 29 Jan 29 2018].

Gates, T.J., Hawkins, H.G. & Rose, E.R. 2003. *Effective Pavement Marking Practices for Sealcoat and Hot-Mix Asphalt Pavements*. Texas Transportation Institute, College Station, TX. Available from http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4150-4.pdf [accessed 24 June 2015].

Government of New Brunswick, 2016. *Annual Report 2015-2016* Transportation and Infrastructure, Fredericton, NB. Available from http://www2.gnb.ca/content/dam/gnb/Departments/trans/pdf/en/Publications/2016AnnualReport.pdf [accessed 23 Jan 2018].

Kopf, J. 2004. *Reflectivity of Pavement Markings: Analysis of Retroreflectivity Degradation Curves*. Washington State Transportation Center, Seattle, WA. Available from http://www.wsdot.wa.gov/research/reports/fullreports/592.1.pdf [accessed 21 May 2015].

Lu, J.J. & Barter, T. 1998. Evaluation of Traffic Markings in Cold Regions. *Journal of Transportation Engineering*, **124**(1): 42-51.

Migletz, J., Fish. J.K. & Graham, J.L. 1994. *Roadway Delineation Practices Handbook*. U.S. Department of Transportation, Washington, D.C.

Migletz, J., Graham, J.L., Bauer, K.M. & Harwood, D.W. 1999. Field Surveys of Pavement-Marking Retroreflectivity. *Transportation Research Record*, **1657**: 71-78. doi: https://doi.org/10.3141/1657-10.

Scheuer, M., Maleck, T.L., & Lighthizer, D.R. 1997. Paint-Line Retroreflectivity over Time. *Transportation Research Record*, **1585**: 53-63. doi: https://doi.org/10.3141/1585-08.