Pavement Marking Retroreflectivity: Analysis of Safety Effectiveness

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An Analysis of the Safety Effectiveness of Pavement Marking Retroreflectivity

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ABSTRACT

It has been shown in previous research that greater longitudinal pavement marking retroreflectivity levels increase drivers' visibility and detection distance. However, increased visibility may also cause drivers to feel too comfortable during nighttime conditions and drivers may then pay less attention and/or operate at unsafe speeds. Before-and-after studies have been conducted on pavement marking improvements such as repainting stripes or changing to a more durable marking material. Studies have also used models to estimate the retroreflectivity based on date of installation and vehicle exposure, or assumed a linear reduction in retroreflectivity over time. Only two studies have related field-measured pavement marking retroreflectivity to safety performance (crash data).

The study analyzed the relationship between three years of pavement marking retroreflectivity data collected by the Iowa DOT on all state primary roads and corresponding crash and traffic data. The study developed a spatial-temporal database using measured retroreflectivity data to account for the deterioration of pavement markings over time along with a statewide crash database to attempt to quantify a relationship between crashes and the quality (measured by retroreflectivity) of pavement marking. Three different sets of data were analyzed: the complete database, two-lane roads, and records with retroreflectivity values less than or equal to 200 mcd/m^2/lx only. The distributions and models of the entire database and the two-lane records did not show that poor pavement marking retroreflectivity correlated to a higher crash probability. However, when looking solely at records with retroreflectivity values of 200 or less, a statistically significant, albeit weak relationship was determined.

INTRODUCTION

Longitudinal pavement markings are a guidance tool used to delineate the traveled way. These markings include centerlines and edgelines. Longitudinal pavement markings help protect drivers by indicating where they should be on the road to prevent collisions with oncoming vehicles or vehicles traveling in the same direction, as well as run-off-the-road (ROR) crashes.

In dark, unlit conditions, pavement markings are especially important. The light from a vehicle's headlights reflect off glass beads in the markings, and some of that light is reflected back to light source. Retroreflectivity is an engineering measure of the efficiency of the marking optics to reflect the headlamp illumination incident on the pavement marking back to the driver. The standard measure of pavement marking retroreflectivity is the coefficient of retroreflected luminance (RL, mcd/m2/lux) measured in terms of brightness to the driver (luminance, mcd/m2) per unit headlight illuminance on the marking (measured in lux).

Pavement marking retroreflectivity can vary significantly (10). Potential causes of this variability include environmental conditions and the consistency and care in which the pavement markings were applied and measured. This variability makes it difficult to measure pavement marking retroreflectivity which accurately represents a roadway segment.

In Iowa, and other states with significant amounts of snowfall, the reflective beads imbedded in the paint get worn and are scraped up by snow plows. Agencies therefore need to re-stripe pavement markings on a regular basis. The question then is: How often should a marking be re-striped? With the relationship between pavement marking retroreflectivity and safety identified, agencies can evaluate the service life of their pavement markings much more efficiently. The Iowa DOT currently uses 150 mcd/m^2/lx for white markings and 100 mcd/m^2/lx for yellow pavement markings as a minimum standard for re-striping state highways.

Gaps in Research

It has been shown in previous research that greater retroreflectivity levels increase drivers' visibility and end detection distance (8,12,14,16). However, a study of permanent raised pavement markers found that the increased visibility in roadway delineation actually had a negative effect on safety (3). Only two studies have collected pavement marking retroreflectivity measurements to determine a safety/crash impact (1,11). One of the studies determined a retroreflectivity threshold based upon crash rates (1) and the other had inconclusive results due to a lack of enough target crashes (11). Before and after studies have been conducted for pavement marking improvements such as repainting the road or changing to a more durable marking material (2,5,7,9,13,15), but before-and-after analyses do not account for the deterioration of pavement markings over time. Other studies have used models to estimate the retroreflectivity based on marking characteristics (4) or assumed a linear reduction in retroreflectivity over time (6).

Previous research has not produced implementable results after attempting to evaluate the correlation between pavement marking retroreflectivity measurements and crashes. Therefore, a study utilizing measured retroreflectivity data and accounting for the deterioration of pavement markings over time was motivated. To do this, sufficient amounts of retroreflectivity and crash data were needed in order to determine a statistically reliable relationship between pavement marking retroreflectivity and safety performance.

Problem Statement

Improving the safety of rural roadways is the major motivation behind determining a relationship between pavement marking retroreflectivity and crashes. It is assumed that lower retroreflectivity values are a contributing factor is some crashes (such as night time, single vehicle, ROR crashes. However, a statistically significant relationship had not yet been determined. If a statistically reliable relationship could be identified, agencies could improve their pavement marking management programs with the goal of reducing the number of night time crashes where low pavement marking retroreflectivity may be a contributing factor.

The study of safety effects of pavement marking retroreflectivity is more complex than might be supposed. The fact that pavement marking retroreflectivity deteriorates non-linearly over time and varies significantly by location, environmental condition, and other factors (that also impact safety performance) complicates safety analysis. Simply assigning crashes spatially to road segments may seem straightforward, but combinations of line types and temporal variations of retroreflectivity at individual locations create difficulties in developing a database. For example, a location may have a combination of white edgeline, yellow centerline or yellow edgeline pavement markings. Data are collected over multiple years and at slightly varying times of year, with some years skipped – each data record needs a time stamp, and dealing with time in geospatial databases is difficult. Each record in the database therefore, must be identified by a unique combination of location, line type, direction, and time. Subsequently, each target crash record may be assigned to the appropriate “paint” record.

Because of the complexity involved in developing large spatially and temporally accurate databases, choosing the right methodology is an important step to be taken prior to starting the safety analysis. This paper focuses on the methodology for design and development of such a database, and then demonstrates the use of such a database to test the relationship between pavement marking retroreflectivity and safety performance. This reported study analyzed three cumulative years of measured pavement marking retroreflectivity data collected by the Iowa DOT on state primary roads and corresponding crash, roadway, and traffic data. The retroreflectivity data for this study included retroreflectivity levels above, equal to and lower than what is typically recommended as minimum standard. Therefore a wide range of retroreflectivity levels were available for the analysis.

DATABASE PREPARATION

Pavement Marking Retroreflectivity Data

Two pavement marking retroreflectivity databases were used in the analysis. A “spring/fall” database was developed to contain retroreflectivity measurements collected by the Iowa DOT on state primary roads in both “spring” and “fall” periods from 2004 through 2006. The Iowa DOT manages close to 10,000 centerline miles system wide. The “spring/fall” database includes over 70,000 readings (taken every 5 miles). The “spring” period includes data from approximately March through June and the “fall” period includes data from approximately July through November in each of the three years.

A second, “paint” database contains initial retroreflectivity values for corridors where pavement markings were re-striped. For each re-striping corridor, a single initial retroreflectivity value was assigned to an entire corridor which typically ranged in length between 10 and 20 miles. The “paint” database had over 40,000 initial retroreflectivity values.

Data Collection

Two different types of devices were used by the Iowa DOT to collect pavement marking retroreflectivity data. Most of the data were collected using a handheld Retrometer LTL-X®. The handheld retroreflectivity data were collected by taking 12 spot measurements over a distance of approximately 200 feet in sections ranging between 3 and 5 miles. The nearest milepost was then associated with the average of the 12 spot measurements.

The Iowa DOT also collected pavement marking retroreflectivity data using a Laserlux van. The Laserlux van collects data every tenth of a mile but the DOT averages these reading every 1 mile. The Laserlux van was used to collect pavement marking retroreflectivity data on the interstates and other high volume and 4-lane roads. It is important to note that readings taken from handheld and van-based meters may vary. However, this variation was not specifically accounted for in this study other than the fact that the statistical models were developed for both freeways (collected using the Laserlux van) and two-lane highways (collected using the LTL-X handheld) separately.

Five Mile to One Mile Retroreflectivity Data Conversion

The retroreflectivity measurements taken by the Retrometer LTL-X® were taken as representative of 5-mile sections. These 5-mile sections were then disaggregated to one mile sections and the 5-mail average readings were assigned to each one mile section. After this process, the retroreflectivity data collected by the Laserlux van could be combined.

Retroreflectivity Time Periods

Because two or three retroreflectivity measurements were collected within a single year to represent a segment of roadway, multiple approaches could be used to estimate the pavement marking retroreflectivity at a specific time. This study used *retroreflectivity time periods* as the duration of time a retroreflectivity value is representative.

Based on expert opinion and previous observations that retroreflectivity degrades little over summer months, August estimates for retroreflectivity were established as the average of the spring and fall readings. Two retroreflectivity time periods were therefore determined for each year, depending on whether the site in question was re-striped during the year.

Figure 1 illustrates the method used to establish representative readings during different retroreflectivity time periods (1, 2, 3 and 4).

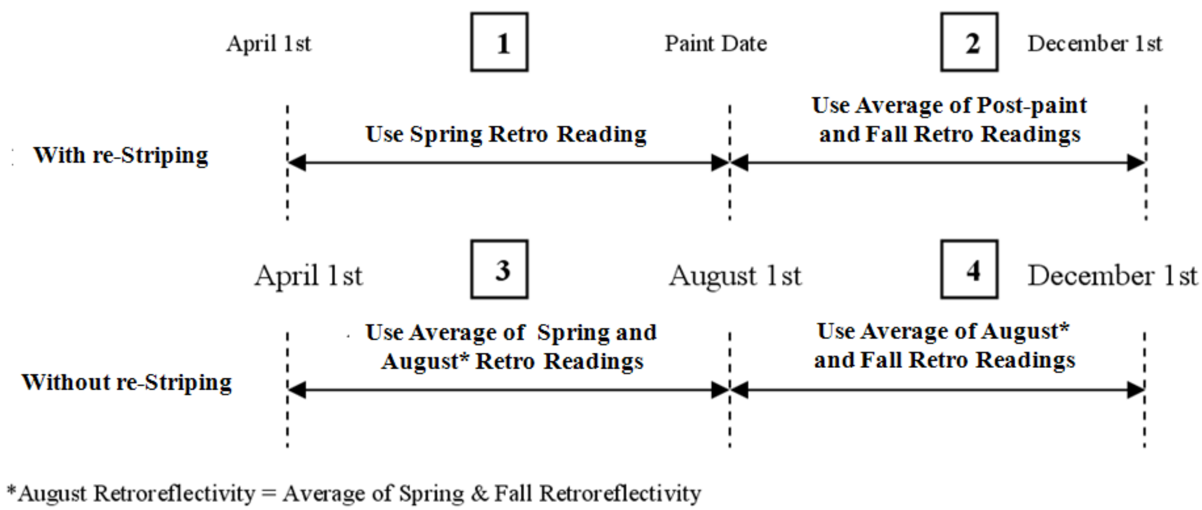

Figure 1: Assumptions for Readings for Four *Retroreflectivity Time Periods*

Target Crash/Retroreflectivity Assignment Procedure

The crash data used in this study were compiled by the Iowa DOT for the calendar years 2004 through 2006. 2006 data were preliminary at the time of this study. Crashes that could be caused or contributed to by low retroreflectivity of longitudinal pavement markings were identified as target crashes. This limited crashes to run-off-road (ROR) or cross centerline crashes only. A GIS database was used to spatially query target crashes for each pavement marking retroreflectivity section. The following is a summary of the methodology used to select target crashes, assign retroreflectivity values to target crashes, and quality control procedures.

Step 1: Target Crashes

Target crashes were identified based on the limited time period where retroreflectivity values existed (April to November). This does create a potential for biased results because wintertime crashes are excluded, but retroreflectivity readings would be difficult to measure and highly unreliable during these periods. The second criterion used was night crashes. Crashes occurring in daylight, lighted, or unknown conditions were eliminated. The retroreflectivity of a pavement marking is only important in dark conditions. Crashes during dawn, dusk, and dark conditions with no roadway lighting were therefore selected as possible target crashes. Only lane departure (ROR or crossed centerline) crashes not caused by an animal or object in the roadway, a collision with another vehicle, avoiding a collision with another vehicle, or equipment problems were selected based on the fact that the white and yellow edge lines were considered for the analysis.

In terms of location, only rural primary roads (where retroreflectivity measurements were taken) are considered. Many state primary roads in urban areas have curbs, significant side traffic, and other urban traffic characteristics that may cause crash rates to vary significantly, these crashes were eliminated.

Step II: Crash & Retroreflectivity Assignment Procedure

In order to compare retroreflectivity records with and without crashes, the crashes were assigned to a corresponding retroreflectivity time period record. The following summarizes how the crash assignment procedure was completed.

The first step in assigning the target crashes to proper retroreflectivity data record was identifying the unique locations in the spring/fall retroreflectivity database. Most of the locations have many retroreflectivity records, others have just a few. These records vary by line type and by the date of measurement. Target crashes were then assigned to the nearest unique retroreflectivity location. After assigning the target crash, the related pavement marking type was determined by the target crash characteristics. ROR right and ROR straight crashes were assumed to potentially be white edgeline related. Cross centerline and ROR left crashes were assumed to potentially be yellow center line or yellow edgeline related. Finally, the direction of travel is assigned so that the proper marking retroreflectivity number is used.

The second step involved identifying paint year target crashes. Since each target crash will be assigned to a pavement marking retroreflectivity value, it was important to identify which target crashes by location occurred during a year where the related pavement marking was re-striped. This was done for every year, line type, and direction combination using GIS pavement marking database. Those crashes where then assigned a paint date so that proper retroreflectivity values can be used.

The third step requires the assignment the proper retroreflectivity time period to the crash records. In order to assign the crashes to the retroreflectivity database, the time period of each crash must be known. Each time period was numbered 1-4 (see Figure 1). Time periods 1 and 2 occur when the pavement marking is re-striped. Crashes occurring during a paint year where assigned a retroreflectivity-time-period 1 if the crash date was prior to the paint date. If the crash date was after the paint date the crash was assigned retroreflectivity-time-period 2. The remaining crashes (occurring during years where the related pavement marking was not re-striped) were assigned a time period based on crash date only. If the crash date was before August 1st the crash was assigned retroreflectivity-time-period 3; if after August 1st the crash was assigned retroreflectivity-time-period 4. The following is the step-by-step process followed to assign retroreflectivity value to each crash:

- *Assigning a Retroreflectivity ID to Target Crashes*
- *Identifying Paint Year Retroreflectivity Records*
- *Assigning a Retroreflectivity Identification Number to the Retroreflectivity Records*
- *Combine the Retroreflectivity Identification Number with Unique Location Number*
- *Assigning the Unique Location Identification to the Paint Database*
- *Assigning a Paint Identification Numbers to the Paint & Retroreflectivity Records*
- *Assigning Paint Data to the Retroreflectivity Records*
- *Assigning Spring/Fall Retroreflectivity Values to the Temporal Retroreflectivity Database*
- *Assigning Representative Retroreflectivity Values for each Retroreflectivity Time Period*

The final step in the process requires the creation of a time period duration field. The duration of each retroreflectivity time period was calculated in order to estimate the amount of traffic on the road segment over that period of time. To calculate the duration an April 1st (beginning date) and a December 1st (end date) field were added to the records. The duration of time period-1 records were calculated as the paint date minus the beginning date. Retroreflectivity-time-period-2 records were calculated as the end date minus the paint date. Retroreflectivity-time-periods 3 and 4 were assigned a duration of 122 days, the number of days between April 1st and August 1st as well as between August 1st and December 1st. Finally, a "final_id" field was used to assign crashes to the proper location by retroreflectivity time period. Some of the "final_id" numbers were assigned multiple crashes. Only 21 crash records had a common "final_id" value. After entering the number of crashes in the temporal retroreflectivity records where multiple crashes occurred, the records where a single crash occurred were assigned

DATABASE MODIFICATIONS

Some database modifications were necessary to allow for a more robust safety analysis. The following is a description of the different modifications made to the database.

Assign a Road Type

Creating a road type field was another modification made to the temporal retroreflectivity database. Instead of analyzing the roadway segments in the database by the number of lanes, median type, median width, access control, and federal function characteristics as individual variables, they were combined into a road type characteristic field. This simplified the analysis considerably without eliminating the effects of roadway characteristics. All of the records were assigned a road type of "freeway", "multilane divided", "multilane undivided", or "two lane".

Select Rural Records

A further modification made to the database was to eliminate non-rural records, as target crashes were limited to rural crashes only. All of the records which had corresponding milepost coordinates that were within a polygon representing a city of 2,000 or more were eliminated.

Create a VMT Field

A final modification made to the temporal database was creating a vehicle miles traveled (VMT) field. The VMT field was calculated as the product of half the "AADT" field and the "duration" field. Assuming that the directional split is even, one half of the AADT is the daily VMT since each record represents a 1 mile section. Then by multiplying the daily VMT and the duration (number of days) the result is the VMT for the entire retroreflectivity time period. In the analysis the VMT field is labeled as the "traffic" parameter.

DATABASE ERROR

Records with Incongruent "Spring/Fall" & "Paint" Data

The sections of roadway with incongruent "spring/fall" and "paint" data are erroneous. The "spring/fall" measurements were collected every 5 miles and assigned to the roadway within 2.5 miles in both directions. When a roadway was re-striped, sometimes the re-striping ended in the middle of one of the 5-mile "spring/fall" sections; causing the retroreflectivity assigned to be invalid. Figure 2 illustrates the problem.

For Sections A and C, in the figure, all of the 1-mile segments are either re-striped or not re-striped just as the milepost where the retroreflectivity measurements were collected. For these sections the fall retroreflectivity value is valid. For Sections B and D the 1-mile segments are either re-striped or not re-striped opposite of the location where the retroreflectivity was measured. For these sections the fall retroreflectivity is invalid, as well as any "spring/fall" retroreflectivity values assigned afterwards.

Eliminating this error would be difficult and time intensive. The estimated maximum number of records that could be invalid due to this error is 10,512 or about 8.5% of the database. This maximum value was estimated by multiplying the number of roadway sections re-striped (2,628) by 4, the maximum number of invalid segments per re-striping section.

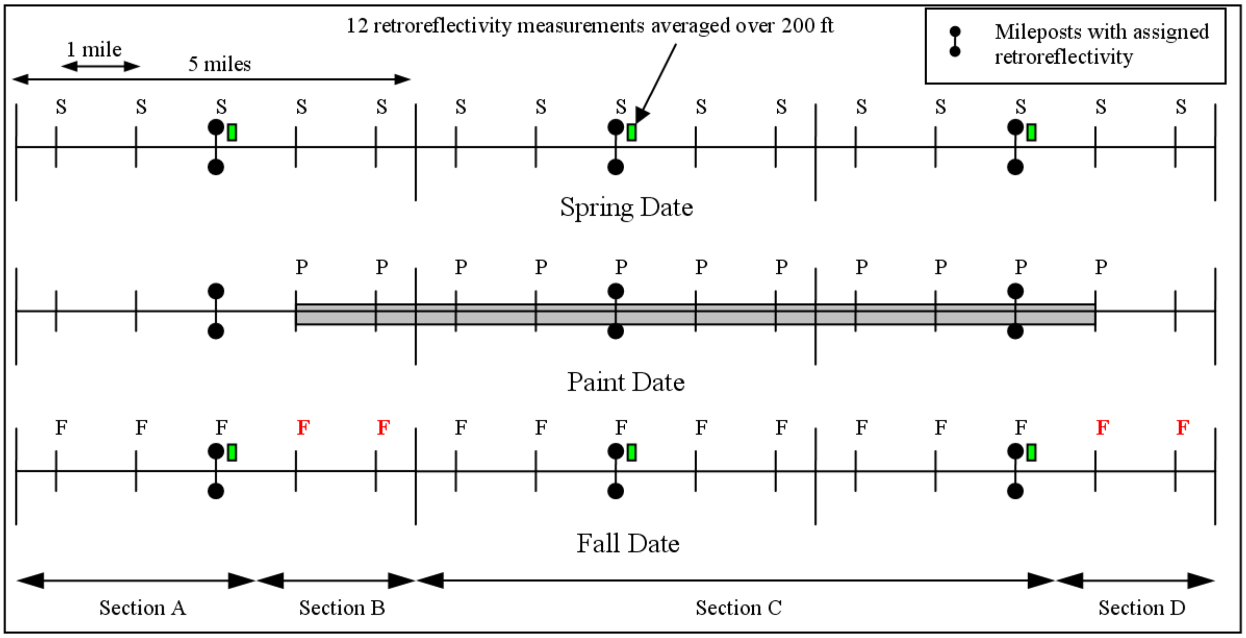

Figure 2: Illustration of Incongruent Sections

Records with Crashes Occurring During Wet Conditions

When water covers pavement markings the visibility and retroreflectivity are significantly reduced. This effect creates a retroreflectivity assignment error in the data where target crashes occurred during wet conditions. Because all of the retroreflectivity measurements were taken during dry conditions, all of the data records containing crashes which occurred during wet conditions were assigned a retroreflectivity value that is too high. In the database, 75 of the 821 (9.1%) target crashes occurred during rainy weather conditions.

MODELING THE DATA

The data were modeled in SAS 9.1. The entire database and records with retroreflectivity values ≤ 200 mcd/m2/lx were modeled using a logistic regression model. A logistic regression model allows for the prediction of a discrete outcome, crash or no crash, from a set of variables that included both continuous (retroreflectivity and traffic) and discrete (line type and road type) variables. The logistic regression model estimates the logit, which is the log of the crash probability. From this output the crash probability can be calculated. The baseline categorical parameters in the model were yellow edgeline for line type and two-lane for road type. The two-lane data only were also modeled using logistic regression to eliminate the effect that high volume freeways had on the database and to account for the variability between the LTL-X and Laser Lux van data. Figure 3 gives the logistic model equation and format.

RESULTS

Model of the Complete Database

The results of modeling the complete database suggest that pavement marking retroreflectivity does not have a statistically significant effect on crash probability. The p-values from the model indicated that all of the parameters are statistically significant except for retroreflectivity. The p-value for the retroreflectivity parameter was 0.24 (a p-value of ≤ 0.05 is required for the 95% confidence level). The β value for the retroreflectivity parameter was only -0.0005. The negative sign indicates a negative correlation between retroreflectivity and crash probability. This means that as retroreflectivity increases the crash probability decreases. However, because the retroreflectivity β value is so small it has little effect.

The goodness of fit of the model can be judged by the deviance value divided by the degrees of freedom. That value for this model was 0.0064. If the data were modeled differently this value could be compared to see which model fit the data better. This value is later compared to the corresponding ≤ 200 mcd/m2/lx retroreflectivity model value.

$$\log it[P(crash)] = \log\left(\frac{P(crash)}{1 - P(crash)}\right)$$
$$= \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9$$

Where:

β_0	= Intercept	*P(crash)*	= Probability of a Target Crash
β_1	= Retroreflectivity Coefficient	x_1	= Retroreflectivity Value
β_2	= White Edgeline Coefficient	x_2	= 1 or 0
β_3	= Yellow Centerline Coefficient	x_3	= 1 or 0
β_4	= Yellow Edgeline Coefficient	x_4	= 0
β_5	= Freeway Coefficient	x_5	= 1 or 0
β_6	= Multi-lane Divided Coefficient	x_6	= 1 or 0
β_7	= Multi-lane Undivided Coefficient	x_7	= 1 or 0
β_8	= Two-lane Coefficient	x_8	= 0
β_9	= Traffic Coefficient	x_9	= Traffic Value (VMT)

Figure 3: Logistic Model Format

Model of Two-lane Records

The results of only the two-lane records are similar. The p-value of the retroreflectivity parameter was 0.2803, well out of the required range for statistical significance. The retroreflectivity parameter estimate was 0.000596, indicating a very small positive correlation between retroreflectivity and crash probability.

The goodness of fit of the two-lane model can be judged by the percent of concordant pairs. All of the records are compared to each other and are said to be concordant if the record with the lowered ordered response (0 for no crashes, 1 for one or more crashes) has a lower ordered predicted response (the predicted likelihood of a crash). A pair is discordant if the record with a crash has a predicted crash probability lower than that of a record not containing a crash. For the two-lane model, 52.2 percent of the pairs were concordant, 24.4 percent were discordant, and 23.5 percent tied.

Model of ≤ 200 mcd/m2/lx Retroreflectivity Records

The model of only the low retroreflectivity records (≤ 200 mcd/m2/lx) found a statistically significant correlation between retroreflectivity and crash probability. The p-value of the retroreflectivity parameter for this model was 0.0406. The retroreflectivity parameter estimate was -0.0021. The goodness of fit of the model was better for low retroreflectivity records than it was for the entire database. The deviance value divided by the degrees of freedom was 0.0059. Figure 4 shows the logistic model results for the below 200 mcd/m2/lx.

For freeways, this translates to a 35 percent increase in crash probability for a decrease in retroreflectivity from 200 mcd/m2/lx to 50 mcd/m2/lx. For two lane roads, a similar decrease in retroreflectivity results in a 37 percent increase in crash probability. The models are very sensitive to retroreflectivity levels when these levels are lower than 200. However, we have less confidence in the two-lane model because the effect of traffic is not what we would expect for a model of two-lane crash probability. We will explore better models in a follow-on project which has already been funded.

Eliminating all records with a retroreflectivity value greater than 200 mcd/m2/lx reduced the database to 79,228 records, a 36% reduction. The number of records with one or more crashes was reduced from 803 to 472, a reduction of 41%. This is still a very large database.

Figures 5 through 8 show the relative crash probabilities from the low retroreflectivity model by line type and road type (freeway or two-lane).

Parameter	Estimate (β value)	p-value
Intercept	-5.7401	< 0.0001
Retroreflectivity	-0.0021	0.0406
Line Type: White Edgeline	0.5088	< 0.0001
Line Type: Yellow Centerline	0.8112	< 0.0001
Line Type: Yellow Edgeline	0.0000	---
Road Type: Freeway	1.1701	< 0.0001
Road Type: Multi-lane Divided	0.3936	0.0080
Road Type: Multi-lane Undivided	0.7205	0.0052
Road Type: Two-lane	0.0000	---
Traffic	4.87E-7	< 0.0001

Figure 4: Logistic Model Results for the Below 200 mcd/m2/lx

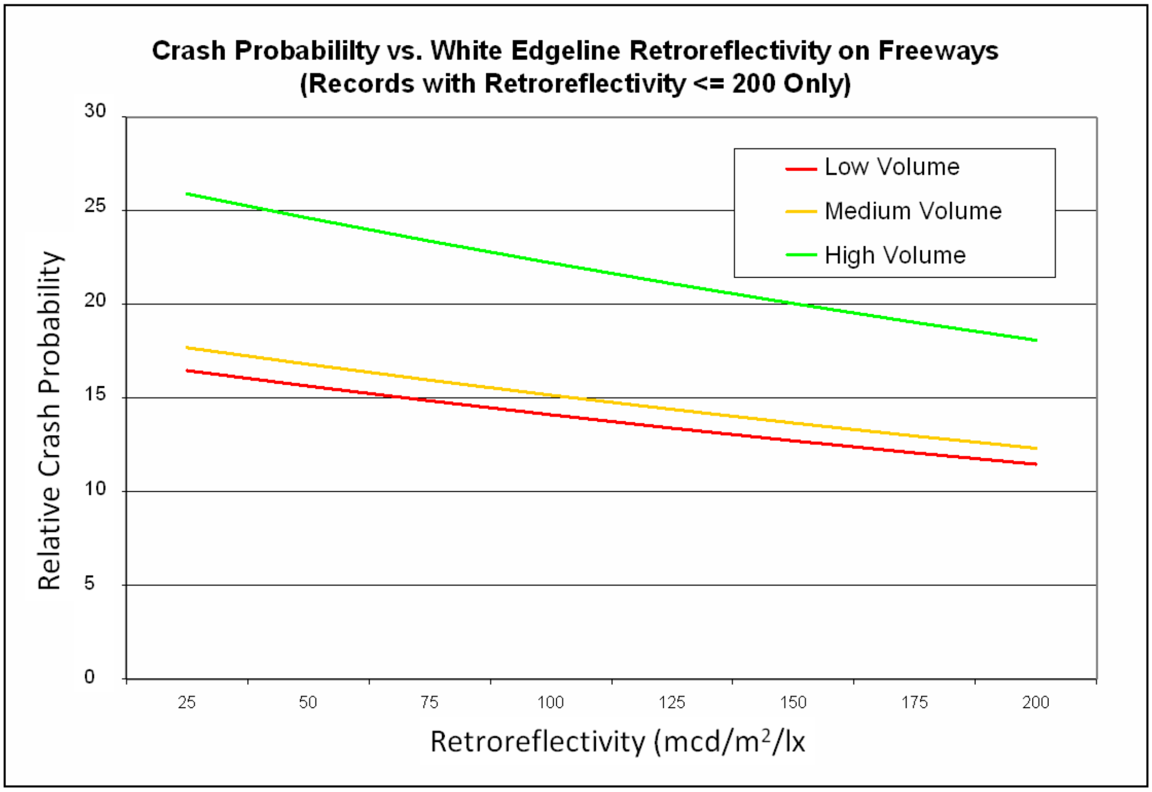

Figure 5: Relative Crash Probability vs. Low Retroreflectivity on Freeways – White Edgelines

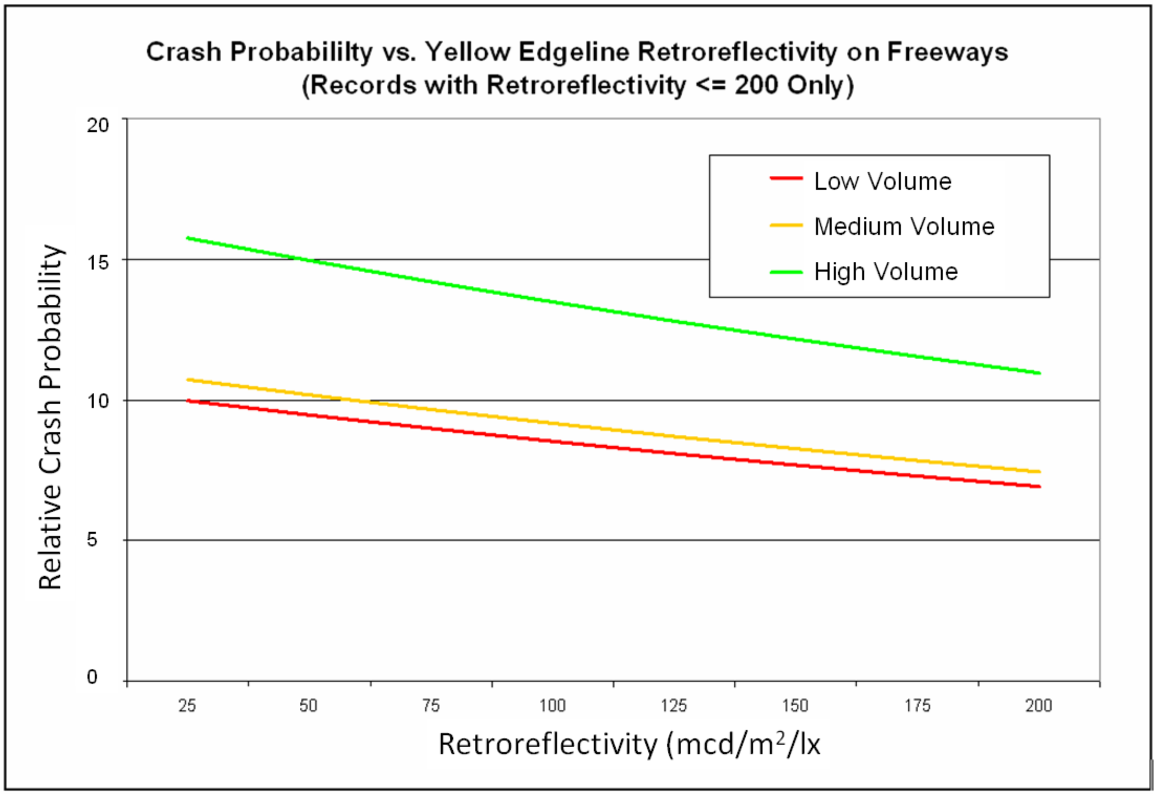

Figure 6: Relative Crash Probability vs. Low Retroreflectivity on Freeways – Yellow Edgelines

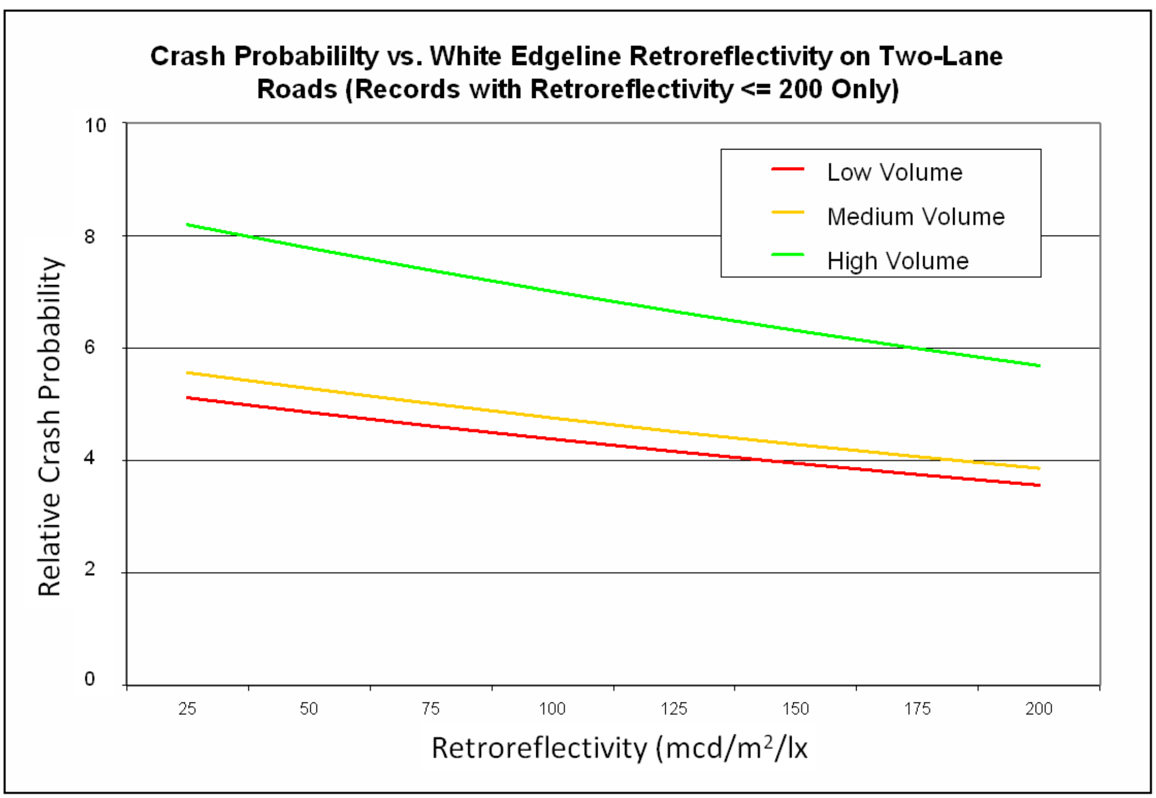

Figure 7: Relative Crash Probability vs. Low Retroreflectivity on Two-Lane Roads – White Edgelines

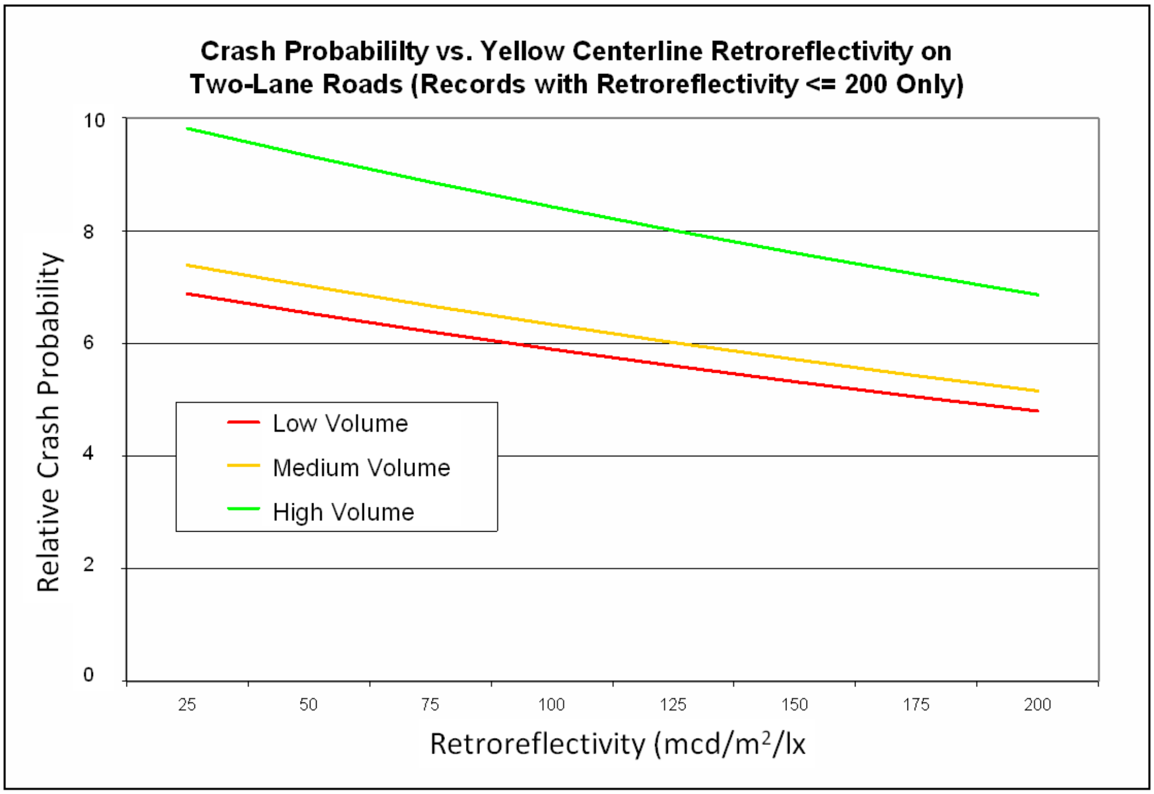

Figure 8: Relative Crash Probability vs. Low Retroreflectivity on Two-Lane Roads – Yellow Centerlines

CONCLUSION

This study focused on testing the correlation between longitudinal pavement marking retroreflectivity and safety performance. It has been shown in previous studies that the presence of edgelines, compared to no edgelines, significantly increases safety performance. From this, intuition leads one to assume that pavement marking visibility and retroreflectivity would also have a positive effect on safety performance. However, the distribution and models of the entire database and the two-lane records did not show that lower pavement marking retroreflectivity correlating to a higher crash probability. But, when records with only low retroreflectivity values were analyzed (≤ 200 mcd/m2/lx), a negative correlation was found to be statistically significant.

There are some limitations to this study of crash and retroreflectivity data. First, Target crashes selected were assumed to be related to pavement marking retroreflectivity. Second, the retroreflectivity data were sampled at one mile intervals (several readings averaged over about 200 feet). These spot measurements were then assumed to be representative of an entire 5 mile segments, even though pavement marking readings can vary significantly over several miles of highway. Third, it was assumed that pavement marking retroreflectivity changes little over the summer months. Finally, there is a certain amount of uncertainty (or even bias) that may result from correlating a very random and complex event such as a crash with retroreflectivity data that is widely known to be highly variable with time, measurement instrument, traffic wear, environmental, etc.

This study identified a statistically significant relationship between low pavement marking retroreflectivity levels and safety performance. With this new information, it is hoped that agencies can make more informed decisions about their pavement marking management programs and achieve the ultimate goal of reducing the number of night time crashes where low pavement marking retroreflective values are a contributing factor.

The database development methodology described in this paper is an example of how dynamic roadway characteristics can be tested against crash performance over time. This type of spatial-temporal database has the potential to be applied elsewhere such as when conducting assessments of the effectiveness of sign management or winter weather maintenance programs.

RECOMMENDATIONS

In order to better understand the relation between pavement marking retroreflectivity and safety performance the following research is recommended for the future.

1. The addition of future data to the database developed in this study would help further define the correlation between pavement marking retroreflectivity and safety performance.
2. A replication of this study in other states would help verify the results and/or identify differences among states. Similar data resources would be necessary.
3. An investigation of the level of inconsistency in pavement marking retroreflectivity should be known in order to achieve a certain level of accuracy in assigning retroreflectivity values to more than a single spot location. How much does the retroreflectivity a typical pavement marking vary over a certain distance? What causes this variation? How much does the angle at which the retroreflectivity is measured effect the resulting value?
4. An examination of the types of crashes retroreflectivity levels affect would allow for more accurate results. The database created in this study could be used to test crash types, other than ROR and cross centerline which were tested in this study, versus pavement marking retroreflectivity.
5. An examination of the effects of paint cycle on crash performance. If determining when to re-stripe a road is the driving force behind determining a relationship between pavement marking retroreflectivity and crash performance, a comparison of two homogeneous roadway segments with different striping cycles could offer a solution.
6. A human factors study on the impact of pavement marking retroreflectivity and speed. Does speed increase due to drivers feeling more comfortable with higher retroreflectivity values? Previous research has suggested this possibility.
7. A study analyzing the effect of retroreflectivity on safety performance at high crash locations or on horizontal curves. Does limiting a retroreflectivity-crash analysis to certain crash locations affect the results?

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