Pavement Marking Materials and Markers: Testing the Relationship Between Retroreflectivity and Safety

DETAILS

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PAVEMENT MARKING MATERIALS AND MARKERS: TESTING THE RELATIONSHIP BETWEEN RETROREFLECTIVITY AND SAFETY

This digest summarizes key findings from NCHRP Project 17-28, "Pavement Marking Materials and Markers: Safety Impact and Cost-Effectiveness," conducted by iTRANS Consulting, Ltd. The digest is an abridgement of portions of the project final report authored by the principal investigator, Geni Bahar, as well as Maurice Masliah, Tara Erwin, and Errol Tan, all of iTRANS Consulting, Ltd., and Ezra Hauer. The full final report is available online as *NCHRP Web-Only Document 92*.

The objective of NCHRP Project 17-28 was to develop guidelines for use of pavement marking materials and markers based on their safety impact and cost-effectiveness. A key component of the research was the attempt to correlate the safety impact of pavement markings and markers with their performance, principally measured in terms of their retroreflectivity. If such a correlation were found, it would be possible to estimate cost-effectiveness and then develop the desired guidelines since retroreflectivity is a direct function of the costs of marking materials and their application.

Thus, the project sought to test the null hypothesis that the safety impact of pavement materials and markers and their level of retroreflectivity are not significantly correlated. If the null hypothesis were rejected, it would be possible to conclude that greater retroreflectivity translates into greater safety, thereby justifying the costs of maintaining higher levels of retroreflectivity.

The project was hindered by a lack of datasets of sufficient depth and breadth to test this hypothesis. The research team performed a pilot analysis with the most comprehensive dataset available (the dataset from California), and, in this instance, it found that the null hypothesis was accepted: *no statistically significant relationship was found between safety and the retroreflectivity of pavement markings and markers*. This preliminary result, if sustained, could substantially alter the frequency of application, and therefore the cost, of pavement markings and markers. Thus, the cost-effectiveness equation for pavement markings and markers could also be altered.

The remainder of this digest summarizes the final report of the project. It reviews the methodology used for the analysis of the California data, its limitations, and key findings. Though preliminary, these findings offer "food for thought" for state highway agency personnel tasked with selecting and maintaining pavement markings and markers to provide safe operating conditions. The full final report (available online as *NCHRP Web-Only Document 92* at http://trb.org/news/blurb_detail.asp?id=6475) offers guidance to

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states that may wish to carry out similar analyses for their own conditions.

BACKGROUND

Longitudinal pavement markings are found on nearly all freeways and highways in the United States. Previous research has emphasized the importance of quantifying the impact of different pavement marking material types on safety, but no such quantification has yet been achieved. This study takes a different approach from previous research by focusing on quantifying the relationship between retroreflectivity and safety over time, independent of the marking or marker material type.

METHODOLOGY

This study examined the safety effect of retroreflectivity of longitudinal pavement markings and markers over time on non-intersection locations during non-daylight conditions. For this study, safety is defined as the number of crashes by severity per unit of time and distance.

The National Transportation Product Evaluation Program (NTPEP), a service provided by the American Association of State Highway and Transportation Officials (AASHTO), collects data and evaluates pavement markings and markers (among other products) using a formal and detailed work plan. For this study, NTPEP data were assembled into a database and used to derive mathematical models of retroreflectivity performance as a function of age, color, marking material or marker type, climatic region, and level of snow removal. As a result of this modeling, a significant contribution of this study is the generation of retroreflectivity performance models as a function of various factors. These models have not previously been achieved using other datasets. The models were used to estimate the retroreflectivity of pavement markings and markers on state-maintained freeways and highways in California for 1992–1994 and 1997–2002, covering more than 5,000 miles of road segments.

The innovative study approach solved for multipliers that represented the change in the expected number of crashes as a function of retroreflectivity. Safety effect multipliers were solved for yellow and white pavement markings separately and in combination, and for pavement markers for different road types and crash severity, using the retroreflectivity models and California's data of over 118,000 non-intersection, non-daylight (night, dawn, and dusk) recorded crashes.

DISCUSSION OF RESULTS

A review of the literature on the safety effect of the retroreflectivity of markings and markers leads to the following conclusions:

1. The safety effect of pavement marking and marker retroreflectivity is very hard to detect.
2. The safety effect of pavement marking and marker retroreflectivity is most likely very small.

This study addressed the difficulty of measuring a hard-to-quantify safety effect by applying an innovative time series approach that allowed the use of historical data covering more than 118,000 crashes and 5,000 miles of highways and freeways with 8 years of known marking installation data. Safety effect multipliers were computed for different retroreflectivity ranges that represent markings of different brightness. The scope of this study is believed to be larger than any previous work on the safety effect of the retroreflectivity of pavement markings and markers. The size of the present study, combined with the innovative time series methodology, was used to look for a hard-to-find, overall average safety effect of retroreflectivity.

The retroreflectivity safety effects of the following factors were estimated: marking and marker combinations, road type, and crash severity. *This study concludes that the difference in safety between new markings and old markings during non-daylight conditions on non-intersection locations is approximately zero.* No measurable safety effect was ascertained on multilane freeways, multilane highways, or two-lane highways as a function of the relative retroreflectivity of either white or yellow pavement markings, or for pavement markers. The sample for pavement markers available for California was too small to be conclusive to examine combinations of markers and markings.

This study did not identify any change in safety with low marking or marker retroreflectivity, nor did it identify any change in safety with bright marking or marker retroreflectivity, with respect to non-daylight, non-intersection locations. The safety of pavement markings during non-daylight conditions for non-intersection locations appears to be independent of whether the markings are new or deteriorated to the average level found on roads in California.

According to the findings in the literature, the presence of lane lines is important. In addition, the literature clearly identifies that there is a strong driver preference for brighter pavement markings. But do brighter markings—that is, markings with brighter retroreflectivity than that of old markings in California—lead to increases in safety? According to the current study, they do not. Although drivers prefer higher retroreflectivity markings and markers—which may therefore allow them to drive more confidently—the overall safety difference in the number of crashes when compared with driving with less bright markings is approximately zero.

As established by several studies, when sight detection distance is reduced, as it is during non-daylight hours and adverse weather, lane control becomes more difficult and driver work load increases, causing drivers to compensate by reducing their speed. The increase in sight detection distance due to higher retroreflectivity of pavement markings and markers may cause drivers to maintain higher speeds, thereby increasing the possibility of a crash under certain geometric conditions. In other words, driver adaptation to road conditions may be minimizing any improvement in safety due to greater sight detection distances from retroreflectivity markings and markers. According to extensive analysis of pavement marking and marker data, roadway inventory data, and crash data, the best estimate of the joint effect of retroreflectivity and driver adaptation is approximately zero for non-intersection road segments during non-daylight hours.

Questions about the validity of the study and its limitations are discussed in the following sections.

HOW DO WE KNOW THAT THE METHODOLOGY IS CORRECT?

The methodology for estimating maximum likelihood simultaneously estimates the seasonal effects and the pavement marking and marker effects. "Seasonal effects" refers to the variations in number of crashes that fluctuate from month to month but that repeat from year to year. The seasonal effect must be estimated in order to separate the safety effect due to markings and the effect due to the season. The seasonal effect parameters obtained in this study are very similar, even across road types. In every estimation of the safety effect of markings, the estimate of the seasonal effect is very reasonable: there are more crashes during the winter months and fewer crashes during the summer months.

The seasonal effects of this study are reasonable because the values are very similar to other published seasonal effects. For example, the seasonal effects of this study are similar to those found by Hauer et al. (*1*) for data from New York State (see Table 1). However, the seasonal factors by Hauer et al. are 24-hour seasonal factors, whereas this study focuses on non-daylight crashes only. The number of non-daylight hours per month in this study changes from a high

Table 1 New York State seasonal factors from Hauer et al. (*1*) and California non-daylight hours

Seasonal Effect	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
New York seasonal factors	1.25	0.97	0.97	0.79	0.84	0.89	0.96	0.98	0.85	0.95	1.15	1.40
California non-daylight hours	14.8	13.9	12.4	11.2	10.0	9.1	9.0	9.8	11.0	13.0	13.3	14.7
California non-daylight hours/ California average non-daylight hours (CMF)	1.2	1.2	1.0	0.9	0.8	0.8	0.8	0.8	0.9	1.1	1.1	1.2
New York seasonal × California CMF	1.6	1.1	1.0	0.7	0.7	0.7	0.7	0.8	0.8	1.0	1.3	1.7

CMF = Crash modification factor.

of 14.8 hours in January to a low of 9.0 hours in July (based on sunrise and sunset times for Redding, California), as shown in the third row of Table 1. A non-daylight crash modification factor (CMF) for California may be estimated by dividing the number of non-daylight hours by the average number of non-daylight hours (11.9 hours) for Redding, California, which is shown in the fourth row of Table 1. The product of the New York seasonal factors and the California non-daylight CMF is shown in the fifth row of Table 1, and they range from a high of 1.7 to a low of 0.7. This last row of Table 1 can now be compared with the seasonal factors estimated in this study. In both cases, the magnitude of the seasonal effects are very similar and the highest number of non-daylight crashes occur during January, November, and December.

WHAT IF THE RETROREFLECTIVITY MODELS ARE INACCURATE?

In the second month of installation (which is the first full month of new markings, the month where the retroreflectivity effect is supposed to be greatest), there was no measurable effect on safety. Therefore, independent of what the on-the-road retroreflectivity may actually be, the safety difference between old and new markings is essentially zero. This result remains valid regardless of how accurate the retroreflectivity models may be.

HOW SMALL MIGHT THE SAFETY EFFECT OF PAVEMENT MARKINGS BE?

When crashes are artificially added to the data during the first full month of installation, the safety effect of markings is less than 300 crashes spread over 8 years and 1,388 miles of road on multilane freeways. This conclusion may be drawn from Figure 55 in the full report, which shows that an additional 300 crashes occurring on roads with markings with the same retroreflectivity (markings within the same bin range) would have resulted in a safety effect of 1.05. A safety effect of 1.05 is large enough to have been detected as significant. In other words, the current study is sensitive to a difference of about 300 out of approximately 90,000 total crashes, or 0.3% sensitivity. The purpose of this sensitivity test is to demonstrate that the scope and design of this study are sufficiently large and robust for the researchers to confidently conclude that the safety effect of retroreflectivity during non-daylight conditions on non-intersection locations is approximately zero.

LIMITATIONS OF THE STUDY

This study does not address the safety effect of pavement markings or markers themselves; rather, the focus has been on the safety effect of retroreflectivity. This study cannot be used to quantify the safety effect of the presence or absence of pavement markings and markers. This study also cannot be used to quantify the safety effect of retroreflectivity greater or less than the ranges modeled for California.

There are associated limitations in defining precisely what the true retroreflectivity ranges are for California. The retroreflectivity values used in this study are estimates from model data based upon NTPEP test deck retroreflectivity measurements. The modeled retroreflectivity estimates have not been calibrated for California. This means that the true retroreflectivity of markings and markers in California may differ from the modeled NTPEP retroreflectivity. The applications of pavement markings and markers at NTPEP test decks may be more carefully applied than average highway installations, in which state department of transportation crews have tighter deadlines and budgets. However, state departments of transportation may be choosing marking and marker materials and types that perform above the average NTPEP performance. The average retroreflectivity found on NTPEP test decks may differ from the average retroreflectivity found on state roads. It is not known if the retroreflectivity found on California highways and freeways is higher or lower than the retroreflectivity found on NTPEP test decks. Therefore, while there is certainty that the difference in safety between new markings and old markings during non-daylight hours at non-intersection locations is approximately zero, there is uncertainty regarding the value of retroreflectivity of new and old markings in California.

Another limitation of this study is that very few states maintain a pavement marking management system like the one currently used in California. It may be that the very existence of a marking management system leads to an improved marking and marker program, thus causing very few roads to have relatively low levels of retroreflectivity (below the proposed FHWA minimum of ~100 mcd/m^2/lux). A pavement marking management system may be a leading factor in having better-than-average pavement markings on the road. Therefore, it is possible that California is not a representative state if the condition of its markings are better than average. It may be that the absolute brightness level does not have a major effect on safety if the agency has a management system and the roads are maintained above a "minimum." The only way to test this possibility would be to compare the results for California with the results for an agency that does a poor job of maintaining its system. Unfortunately, such an agency, if existent, would not have the data records to conduct the current study.

FINDINGS

This research study investigated the safety effect of the retroreflectivity of pavement markings and markers on state-maintained multilane freeways, multilane highways, and two-lane highways in California. An innovative approach was developed that analyzed historical pavement marking and marker installation data over time, thereby making use of large quantities of data that otherwise could not be analyzed using traditional before-after methods. By converting the age of pavement markings into their corresponding retroreflectivity, the study could compare different marking material types with one another using retroreflectivity as a common metric. This approach is based on the assumption that different pavement marking material types at the same retroreflectivity—for example, waterborne and thermoplastic both at 150 mcd/m^2/lux—have the same level of safety. Safety was examined as a function of different ranges of retroreflectivity brightness.

Retroreflectivity performance of pavement markings and markers was based on NTPEP data. A database was built using published NTPEP retroreflectivity measurements, and mathematical models were built that computed retroreflectivity as a function of age, color, material type or marker type, climate region, and amount of snow removal. These retroreflectivity models provided the average retroreflectivity performance for pavement markings and markers (tables are provided in Appendix A of *NCHRP Web-Only Document 92,* which is available online at http://trb.org/news/blurb_detail.asp?id=6475). These models may be useful to jurisdictions seeking estimates of their pavement marking and marker retroreflectivity or for comparing the performance of new products with the average performance of a particular material type. The retroreflectivity models were applied to convert California installation date data into retroreflectivity data. The safety effect of retroreflectivity of pavement markings (which deteriorates over time) was studied by examining the change in the number of non-intersection, non-daylight (nighttime, dawn, and dusk) crashes over a period of 8 years and over 118,000 crashes.

The analysis methodology used in this study solved for multipliers representing the safety effect for different retroreflectivity ranges (i.e., bin ranges). Because a time-series approach was used, it was necessary to separate out the monthly seasonal effect from the cyclic pattern of pavement marking and marker installation. Multipliers for the seasonal effect showing higher crash counts in January, November, and December provide support for the validity of the analysis methodology. No conclusions were drawn regarding the safety effect of the retroreflectivity of pavement markers because the sample size was too small. For pavement markings or markers, the difference in safety (measured during non-daylight hours at non-intersection locations) between time periods with high-retroreflectivity markings and time periods with low-retroreflectivity markings is approximately zero for roads that are maintained at the level implemented by California. California's level of maintenance appears to be frequent: pavement markings are installed on high-volume highways up to three times per year with waterborne paint or every 2 years with thermoplastic markings.

What appears to be important is that markings are present and visible to drivers, but what is less important with respect to safety is whether the markings are "new marking bright" or "old marking bright." One hypothesis is that drivers compensate for lower visibility by reducing their speed and take advantage of higher visibility by maintaining higher speeds. Therefore, any effect of the level of brightness of pavement markings may be minimized by driver adaptation to road conditions. In other words, the best estimate of the joint effect of retroreflectivity and driver adaptation is approximately zero for non-intersection road segments during non-daylight hours.

The approach used in this study was found to be reliable and straightforward to implement and is recommended for safety treatments that change one way or another over time. The approach allows for maximum inclusion of historical data and does not have the same sampling problems of traditional before-after studies.

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