PAVEMENT MARKINGS AND INCIDENT REDUCTION

Richard Storm
Center for Transportation Research and Education
Iowa State University

INTRODUCTION

Pavement markings come in many different forms, but the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) defines the two general categories of pavement markings as longitudinal and transverse markings (*1*). A classic example of longitudinal markings would be the center and edgeline markings along a roadway. Traditional transverse markings include crosswalk lines, stop lines, and symbol markings. Pavement markings may also have as many different meanings. Regardless of their meaning, however, pavement markings are used to inform and warn drivers, pedestrians, and bicyclists of local and federal regulations and potentially hazardous locations (*1*). Possibly the greatest advantage to using pavement markings is that they allow drivers to focus their attention where the hazard is most likely to be located; on the roadway (*1*).

There are nearly an unlimited number of situations in which a crash may occur. Pavement markings may best be suited as a means for incident reduction in only a select few. The objective of this report is identify the areas where pavement markings may be most beneficial for crash reduction and to investigate how pavement markings have been used to reduce the number of accidents in these areas. A literature review showed that pavement markings can be effective in the areas of horizontal curvature, turning movements, and pedestrian crosswalks.

The remainder of this report is a review of the limitations of pavement markings and a discussion about their use in each of the following areas: horizontal curvature, turning movements, and pedestrian crosswalks. The discussion in each area also includes general recommendations for use of pavement markings as determined from the results of the reviewed studies. The report concludes with a summary of the limitations and use of pavement markings to increase the motorist and pedestrian safety.

PAVEMENT MARKING LIMITATIONS

Despite versatility and easy recognition of pavement markings by drivers, pavement markings as a means for crash reduction must be carefully considered before the final decision to use is made. First, one must determine if pavement markings are even appropriate in the particular situation. Second, other alternatives should be considered to find the best solution for the problem.

Use of Pavement Markings

Pavement markings are often placed in anticipation of improvement of the roadway safety at known hazardous location. Often these hazardous situations are due to a poor geometric design that violates driver expectations. Pavement markings may be successfully utilized to temporarily increase driver awareness at such locations, but they may not be the best solution. Often, the most effective action would be redesign and reconstruction of the roadway geometry to meet the driver expectations (*2*). Roadway redesign may not be utilized due to funding restrictions or a roadway redesign may be for the long-term. If reconstruction is not planned for the near future, pavement markings could be part of a temporary solution (along with signing, signing in conjunction with pavement markings, traffic calming, and others). If properly used, pavement markings can be a good short-term solution because of their low installation and maintenance costs. For example, the installation of transverse markings at a sharp horizontal curve was estimated to have a benefit-cost ratio of 45.9 due to a large reduction in crashes that resulted (*3*).

Determining Accident Reduction Factors

When considering improvement alternatives, trying to determine the safety benefit (i.e., predicted reduction in the number of crashes) of pavement markings may be the most difficult part. Al-Masaeid, et al. investigated the safety effectiveness of pavement markings on rural undivided highways (*4*). The stated purpose of the pavement markings were "…to delineate the travel path and improve visibility (*4*)". In their analysis, accident reduction factors were calculated for 100 improved roads in Indiana (*4*). The accident reduction factor was defined as the "…proportion of change in the accident rates from the before to the after period" (*4*). The analysis resulted in accident reduction factors ranging from -0.762 to 0.592 (a negative accident reduction factor indicates an increase in the number of crashes).

One may not expect the inclusion or improvement of pavement markings to increase the accident rates, but this result was evident in several other studies reviewed by Al-Masaeid (*4*). Al-Masaeid, et al. identified that the variability in calculated crash reduction factors may be due to three factors (*4*). First is before-and-after studies may overestimate the crash reduction potential. Second, crash reduction factors are often treated as an absolute value, but actually may have a range of values. Third, previous studies had ignored crash severity and the extent to which improvements were made.

Further analysis by Al-Masaeid, et al. study revealed that sites with accident rates above the mean (defined as hazardous sites) had an average crash reduction of 13.5 percent (*4*). This is a significant accident reduction benefit when compared to the average crash reduction factor for the entire study (-3.4 percent). The increase in the crash reduction factors at non-hazardous sites may be due to the random nature of accidents. At a site with a low crash rate, one more crash in the after period than in the before period could result in a high negative crash reduction factor. The additional crash may just be a random occurrence, rather than the negative impact from the inclusion of pavement markings.

HORIZONTAL CURVATURE

A sharp horizontal curve is a perfect example of where redesign and reconstruction of the roadway would be the preferred alternative, but pavement markings can produce beneficial results if it is not feasible. Retting, et al. reported that excessive speeds are a significant factor in the number of crashes on curves and the severity of these crashes (*2*). Therefore, Retting, et al. proposed that pavement markings should be used to reduce the vehicle speed on the tangent section prior to the points of horizontal curvature (*2*).

To effectively reduce vehicle speeds on the tangents, safety engineers must understand the proper use traffic control devices and then consistently use traffic control devices to meet driver expectations. For example, the use of curve warning signs before moderately sharp horizontal curves will allow drivers to assume that the next curve warning sign will be followed be by a moderately sharp horizontal curve. If instead, the curve warning sign precedes a significantly sharp horizontal curve, the driver may not decelerate sufficiently to safely navigate the curve. Special warning devices, such as pavement markings, could be used to inform the driver of the unusually sharp curve.

Two studies that used innovative pavement marking design to alert drivers of an unusually sharp horizontal curve are discussed in the following paragraphs. The first study report used left curve arrow and text to warn drivers of the approach curve (*2*). The second report used transverse pavement markings to give the driver the appearance of acceleration on the curve approach (*3*).

Left Curve Arrow and Text

In Virginia, Retting, et al identified a sharp left curve after a long tangent section (*2*). The traveled way width was reported as approximately twenty feet, with one lane of traffic in each direction. The posted speed limit of the roadway was 35 miles per hour (mph) and the posted speed limit for the curve was 15 mph.

To warn the drivers of the sharp curve, an experimental pavement marking was placed 220 feet prior to the curve. The experimental pavement marking included the word "SLOW" in eight-foot white letters and an eight-foot left curve arrow (See Figure 1). Speed measurements were taken at two locations, 90 feet and 650 feet prior to the curve. Speed measurements at both sites were done before the placement of the pavement markings and two weeks after the pavement marking was installed.

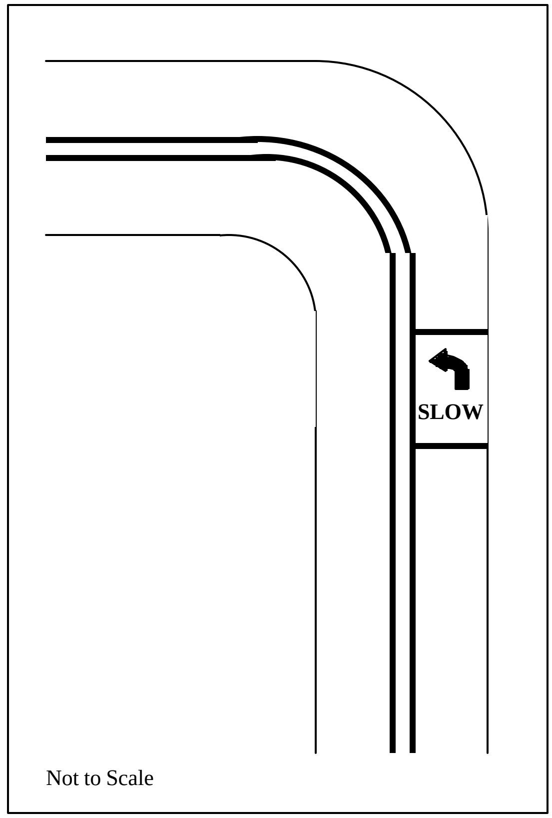

Figure 1. Arrow and Text Placement (*2*)

The speed results for were reported for three different times of day: daytime (10:30 a.m. to 5:00 p.m.), evening (9:00 p.m. to midnight), and late night (midnight to 3:00 a.m.). The results for all three time periods are summarized in Table 1. As can be seen from Table 1, the mean speed at the location just prior to the curve dropped for all three time periods. For the location just prior to the curve, Table 1 also shows a reduction in the percentage of vehicles traveling faster than 35 mph, 40 mph, and 45 mph; regardless of whether the upstream site mean speed increased or decreased. Retting, et al. concluded that the experimental pavement marking resulted in a net speed decrease for all time periods (*2*). A seven percent decrease in the mean speed was reported for the daytime period (three percent decrease near the marking plus a four percent increase upstream). The evening time period had a two percent decrease in the mean speed (five percent decrease near the marking minus a three percent decrease upstream). Finally, a seven percent decrease in the mean speed was reported for the late night period (ten percent decrease near the marking minus a three percent decrease upstream).

Table 1. Speed Measurement Results (*2*)

Time of Day	Distance Prior to Curve	Before or After	Mean Speed (mph)	Percentage > 35 mph	Percentage > 40 mph	Percentage > 45 mph
Daytime	90 feet	Before	34.3	41	9	0.8
		After	33.2	34	4	0.2
	650 feet	Before	40.2	85	54	18
		After	41.7	91	66	26
Evening	90 feet	Before	33.5	36	9	2.0
		After	31.9	25	3	1.2
	650 feet	Before	40.1	84	49	14
		After	39.1	78	39	14
Late Night	90 feet	Before	35.1	49	19	2.0
		After	31.7	22	2	1.6
	650 feet	Before	40.3	87	63	20
		After	39.1	98	74	28

There were two shortcomings to this research study. First, this experiment was performed at one site. Secondly, a follow-up study was not performed to determine whether the marking had any long-term impact on mean speeds.

Transverse Pavement Markings

In a study similar to the one described previously, Agent also used experimental pavement markings to decrease vehicle speeds before entering a sharp horizontal curve (*3*). A high-accident location site was located on US-60 in Meade County, Kentucky. This curve had a total of 48 accidents in the six years pervious to the installation of the pavement markings, 46 of which had been an eastbound vehicle that left the roadway or crossed the centerline and collided with a westbound vehicle. Thirty-six of the accidents listed excessive speed as a contributing factor. Failure of conventional signing and marking led authorities to try a new approach until reconstruction could be performed. The posted speed limit for the roadway was 55 mph and the horizontal curve had a rated speed limit of 35 mph.

To reduce vehicle speeds, experimental transverse markings were placed on the eastbound approach lane. The transverse markings were spaced such that a driver had the appearance of acceleration towards the curve. This was accomplished by placing the transverse markings at an ever-closer spacing. Drivers that slowed to acceptable speeds would see the transverse markings at a constant rate, and therefore would not experience the sensation of acceleration.

Due to resurfacing of the roadway, researchers were only able to gather crash data for one year after placement of the pavement markings. In addition to the crash data, speed data was gathered prior to, one week following, and six months after the striping of the roadway. Speed measurements were taken at the beginning and end of the transverse markings. Table 2 summarizes these speed measurements.

As can be seen from Table 2, the transverse markings lowered the mean speeds in both the daytime and nighttime conditions. However, the six-month follow-up did show that speeds increased slightly when compared to the measurements taken immediately after striping, but these speeds were still lower than the prior condition. In addition to the decrease in the mean speed, the speed reduction through the pavement markings and the percentage of vehicles exceeding the posted speed limit show similar results.

In the year after the placement of the transverse markings there were only three reported accidents. This is a significant decrease over the average eight accidents per year in the six years prior to striping (*3*). Of the three accidents that occurred after striping, two reported alcohol as a contributing factor and speed was only mentioned as a factor for one accident The major shortcoming to this experiment was that is was only performed at one location.

Table 2: Effect of Transverse Markings on Speeds (*3*)

Time of Day	Before or After	Mean Speed	Average Speed Reduction through Markings	Percentage > 35 mph
Daytime	Prior to	41.3 mph	8.5 mph	90
	One Week After	33.9 mph	15.3 mph	40
	Six Months After	34.9 mph	12.3 mph	Not Reported
Nighttime	Prior to	40.5 mph	2.4 mph	81
	One Week After	35.1 mph	9.3 mph	43
	Six Months After	39.1 mph	6.8 mph	68

TURNING MOVEMENTS

Various studies have shown that rear-end collisions account for 18 to 23 percent of all crashes, and up to 20 percent of all injury crashes (*5*). Ten percent of rear-end collisions involved a vehicle making or preparing to make a turning movement (*5*). With rear-end collisions such a large percentage of all crashes, it is easy to see why researchers are trying to reduce this type of crash.

Much like the sharp horizontal curves, a violation of driver expectancy can be a reason for a large number of accidents involving turning movements. It is not the roadway geometry that is violating driver expectations, but the action of other drivers. When drivers slow or come to a stop to make a turning maneuver, the following driver may be unprepared for the vehicle in their path and the result can be a rear-end collision. This is especially true were sight distances are limited. In such circumstances, pavement markings can possibly be used to alert drivers of locations with a large number of turning vehicles.

The following studies review the results of pavement markings about the safety of turning movements. The first report used pavement markings to alert drivers of vehicles turning right into a commercial driveway (*5*). The second study discusses pavement markings at freeway lane drop exits (*6*).

Commercial Driveway Entrances

Retting, et al. identified several key driver factors that led to rear-end collisions at commercial driveway entrances (*5*). These factors included inattentive drivers, short following distances, and a low use of the right turn signal. To offset these factors, the authors identified two methods of remediation. The preferred method was the construction of right turn lanes. In some instances, this method is not feasible due to right-of-way restrictions and high construction costs. The second method (which was the focus of the study) is the use of pavement markings to alert drivers at locations with a high incident rate.

The experiment included the addition of the standard through arrow accompanied by a right-turn arrow at four commercial driveways (*5*). The driveways were to a bank, a post office, a shopping center, and a fast food restaurant; all of which are located in Virginia.

To record the data, a concealed camera was placed near each business entrance. When the videotapes were later reviewed, a potential conflict was recorded each time a vehicle making a right turn was followed by another vehicle by less than four car lengths on low speed roadways. For high speed roadways, the trailing vehicle had to be less than five car lengths to be included in the study sample. Through observation of the trailing vehicle taillights, each potential conflict was classified into one of three categories. The category called *abrupt braking* was considered to be a rear-end conflict. In order for the trailing vehicle to be classified in the *abrupt braking* category, a rapid rate of deceleration and one of the following criteria had to be met: squealing of the tires, visible rise and fall of the vehicle's rear end, or pulling of the vehicle to the left or right.

The research showed that the pavement markings were effective in increasing the average car following distance. At the post office, bank, and fast food site, there was a small decrease in the number of potential conflicts and a large decrease in the number of rear-end conflicts. Unfortunately, the number of potential conflicts and rear-end conflicts actually increased at the shopping center. The results of the Retting, et al. study may have been more conclusive if enough time was available to collect crash data versus conflict data (*5*). The results are based upon conflict data, and previous studies do show that a reduction in crashes does correlate to conflict reduction (*5*).

Freeway Lane Drop Exits

Freeway lane drop exits are defined as a location where one or more freeway lanes are eliminated at an exit (*6*). Such locations can cause confusion when the driver does not expect the lane to exit; leading to an increased number of lane changes and erratic maneuvers (*6*). In a study sponsored by the Texas Department of Transportation, Fitzpatrick et al. (*6*) studied the effects of lane drop markings at three locations. Lane drop markings are larger-width lane striping that starts approximately 0.5 miles before the gore (the area between the through lanes and an exit ramp (*7*)) along with a solid, eight inch wide white line for 300 feet before the gore. At the three chosen locations, the exiting lane existed for at least a mile before the exit and there was minimal influence from either nearby entrance ramps or poor geometric designs. In addition to the lane drop markings, white left turn arrows were placed in the dropped lane.

Through the use of video cameras, 1200 to 1900 feet of roadway was observed. At each experimental site, the location and number of lane changes and erratic maneuvers were recorded for several days. An erratic maneuver was defined where a motorist changed lanes through the gore; changed two or more lanes; swerved between lanes and the shoulder; or drove over the solid white line. Before-and-after traffic counts showed no discrepancies in the before-and-after traffic volumes at the locations. The Texas Department of Transportation provided information to verify that there was no nearby construction or nonrecurring congestion that could skew the data.

Overall, the results of the study showed that there was a significant decrease (from 6 to 31 percent decrease) in the number of lane changes at all locations. In addition, two of the locations had a larger percentage of the motorists in the after condition exiting the dropped lane further upstream than in the before condition. The decrease in erratic maneuvers was even more statistically significant, with a decrease in the number of erratic maneuvers ranging from 18 to 40 percent. In the 300 feet closest to the gore, the results were even more conclusive. The percentage decrease in the number of lane changes was from 42 to 64 percent, and the drop in erratic maneuvers was 29 to 50 percent decrease. These decreases can be critical to driver safety because the motorist is no longer having to perform complex maneuvers (i.e., speed and/or lane changes) while the demand on the mental workload is high. If used consistently, lane drop markings and left-turn arrows may be able to perform even better once a driver expectancy is established.

PEDESTRIAN CROSSWALKS

Retting, et al. reported that nearly 100,000 pedestrians are injured every year in motor vehicle crashes in the United States (*8*). Pedestrians are encouraged to cross streets at intersections, which are often equipped with crosswalk markings and/or traffic signals (*8*). Despite this, intersections account for about 39 percent of nonfatal pedestrian injuries and 18 percent of fatalities (*8*). The best method to increase intersection safety is to physically separate the pedestrian and motorist (i.e., pedestrian tunnels or pedestrian bridges), but these alternatives are expensive to construct and may not be used by the pedestrians (*8*).

Retting et al. (*8*) reported that the use of messages painted in the crosswalks ("EXTEND HAND TO CROSS") increased the percentage of pedestrians signaling to motorists that they intend to cross the street. Because of this, Retting et al. (*8*) experimented with the use of special signs and pavement markings to alert pedestrians to turning vehicles. The experimental signs had the message "LOOK FOR TURNING VEHICLES" and the message painted in the crosswalk was "WATCH TURNING VEHICLES".

The experiment was conducted at three intersections that had a large number of pedestrians and a high daily traffic volume. At the first site, the signs were installed first and the pavement markings were added later. The second site had the pavement markings placed first with the signs added at a later time. The third site had both the signs and pavement markings installed at the same time.

As evident in Table 3, all three methods decreased the average number of conflicts for every 100 pedestrians. At the site where the messages were installed first followed by the signs, there was a slight increase in the average number of conflicts after the signs were installed. Yet, this was still a 61 percent reduction in the number of conflicts than in the before condition. Similarly, the number of pedestrians looking for turning vehicles increased for all three experiments (See Table 4). In the follow-up studies, both the average number of conflicts and the percentage of pedestrians looking for turning vehicles were as good as or had slightly decreased when compared to the results immediately following installation. In either case, the follow-up study showed a significant safety benefit over the before condition.

Table 3: Conflicts per 100 Pedestrians (*8*)

Description	Before Study	Sign Only	Paint Only	Sign and Paint	Follow-Up Study
Signs followed by Painted Messages	2.7	0.6	---- NA ----	0	0
Painted Messages followed by Signs	3.1	---- NA ----	0.7	1.2	0
Both Added at the Same Time	2.5	---- NA ----	---- NA ----	0	0

Retting, et al. were unable to observe actual crash data to determine the effectiveness of the pavement markings and signs installed, but one can determine that the reduced number of conflicts and increased pedestrian awareness should result in reduced number of accidents over time (*8*). As discussed in the section PAVEMENT MARKING LIMITATIONS, this method to increase the pedestrian safety may prove to be especially effective when used at locations that are known to a high accident rate

Table 4: Percentage of Pedestrians Looking for Turning Vehicles (*8*)

Description	Before Study	Sign Only	Paint Only	Sign and Paint	Follow-Up Study
Signs followed by Painted Messages	82	92	---- NA ----	97	97
Painted Messages followed by Signs	85	---- NA ----	95	97	95
Both Added at the Same Time	85	---- NA ----	---- NA ----	96	93

SUMMARY

Pavement markings may not be applicable at all locations that are known to be hazardous, but their use may help increase the safety of locations. At sharp horizontal curves, experimental pavement marking patterns have been shown to decrease the entrance speed of vehicles and reduce the number of accidents at these locations. At freeway lane drops, pavement markings have been shown to decrease the number of erratic maneuvers and lane changes while at the same time reducing the mental workload for the motorists. Pavement markings were also shown to increase the awareness of motorists to turning vehicles and to increase the number of pedestrians looking for turning vehicles while crossing the street. Both of these experiments resulted in fewer conflicts, which could mean fewer crashes in the future.

When evaluating the use of pavement markings, one should remember that crashes are random occurrences and thereby may result in mixed results. The key to cost effective use of pavement markings is to first identify high crash locations and then determine if pavement markings may prove beneficial. This methodology should produce better results than systematically using pavement markings in all hazardous locations.

REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. FHWA, U.S. Department of Transportation, 1988.

2. Retting, R.A., and C.M. Farmer. Use of Pavement Markings to Reduce excessive Traffic Speeds on Hazardous Curves. ITE Journal, Vol. 68, No. 9, September 1998, pp. 30-36.

3. Agent, K.R. Transverse Pavement Markings for Speed Control and Accident Reduction (Abridgment). In Transportation Research Record 773, TRB, National Research Council, Washington, D.C., 1980, pp. 11-14.

4. Al-Masaeid, H.R., and K.C. Sinha. Pavement Markings. Journal of Transportation Engineering, Vol. 120. No. 5, September/October 1995, pp. 723-736.

5. Retting, R.A., M.A. Greene, and J. Van Houten. Use of Pavement Markings to Reduce Rear-End Conflicts at Commercial Driveway Locations. In Transportation Research Record 1605, TRB, National Research Council, Washington, D.C., 1997, pp. 106-110.

6. Fitzpatrick, K., M. Lance, and T. Lienau. Effects of Pavement Markings on Driver Behavior at Freeway Lane Drop Exits. In Transportation Research Record 1495, TRB, National Research Council, Washington, D.C., 1995, pp. 17-27.

7. A Policy on Geometric Design of Highways and Streets 1994. American Association of State Highway and Transportation Officials, Washington, D.C., 1995.

8. Retting, R.A., R. Van Houten, L. Malenfant, J. Van Houten, C.M. Farmer. Special Signs and Pavement Markings Improve Pedestrian Safety. ITE Journal, Vol. 66, No. 12. December 1996, pp. 28-35.