A Review of Two Innovative Pavement Marking Patterns that have been Developed to Reduce Traffic Speeds and Crashes

Prepared for the AAA Foundation for Traffic Safety
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Abstract

Regardless of whether we consider fatal crashes recorded throughout the United States or total crashes recorded in one state, it is clear that speeding is a serious threat to the motoring public. In 1993, for example, some 53,343 drivers were involved in fatal traffic crashes in the United States. Of these 53,343 drivers,

11,019 (20.7%) were reported to have been speeding. In the same year, 716,589 drivers were involved in crashes (including fatal, injury- producing, and property-damage-only crashes) in Texas. Of these 716,589 drivers, 114,552 (15.6%) were reported to have been speeding.

The reasons why drivers speed are many: their judgement is impaired by alcohol or other drugs, they are in a hurry, or they intend to maintain a speed in excess of the posted limit but below a level at which they believe they will be cited. But in addition to these reasons, some drivers speed inadvertently. That is to say, drivers sometimes fail to realize that the speeds at which they are traveling are too fast for the existing highway environment, such as intersections, traffic circles, bridges, horizontal curves, and construction zones. Further aggravating and adding to the inadvertent speeding phenomenon is the fact that drivers who have been traveling at a relatively high rate of speed for an extended time may habituate to that speed and underestimate the degree to which they are lowering their speed upon approaching an intersection, traffic circle, bridge, horizontal curve or construction zone.

This report reviews the available literature on two illusionary pavement marking patterns that have been developed and fielded in the last twenty years to reduce traffic speeds and traffic crashes that result from driver inattention and habituation to high-speed driving:

- The converging chevron pavement marking pattern
- The transverse bar pavement parking pattern

The Converging Chevron Pavement Marking Pattern

The AAA Foundation for Traffic Safety's initial interest in the use of illusionary pavement markings to reduce traffic speeds and crashes arose in response to early reports that the converging chevron pavement marking pattern applied to the Yodogawa Bridge in Osaka, Japan, was effective in reducing crashes:

> A painted bridge deck surface that creates an optical illusion motivating motorists to curb their speed has totally eliminated accidents on Yodogawa Bridge over the past six months. Osaka traffic police painted geometric arrows along the 2,461 ft. bridge spanning the Shin Yodogawa River last November, giving drivers an illusion of speed. No accidents resulting in injury have occurred on the bridge since the pattern was painted, whereas two people died and nine were injured in 10 bridge accidents last year prior to the painting initiative. (Cited in *Public Innovation Abroad*, published by the International Center, Academy for State and Local Government, Volume 17, Number 6, June 1993.)

Further investigation of the effectiveness of the pavement markings used in Japan suggests that although the converging chevron patterns that have been employed to date hold promise for reducing traffic crashes, they may not be the panacea that the previous quote would lead one to believe. Published reports of crash frequencies recorded before and after the application of the chevron pattern suggest that crashes may be reduced by 25 to 50 percent through the use of this pavement marking pattern.

Although the reported estimates of the crash-reduction effectiveness of the converging chevron pattern are quite high perhaps unrealistically high the costs of applying this pattern are relatively low ($15,000 to $90,000) and the service lives of these patterns (4 to 6 years) are of sufficient duration to make them an attractive investment even if only small reductions in traffic crashes were realized through the use of this treatment.

The Transverse Bar Pavement Marking Pattern

Of the several innovative pavement marking patterns that have been developed to reduce traffic speeds and crashes, the pattern that has been most often employed and evaluated is the transverse bar pattern first promoted by Denton (1971, 1980). This pattern has been most often used at the approaches to traffic circles that are preceded by long stretches of highway on which drivers could maintain, and habituate to, higher speeds. Other applications of this pattern have been located at the approaches to intersections, horizontal curves, construction areas, and freeway off ramps.

In this report, 10 different studies of the effects of transverse bar patterns on traffic speeds were reviewed. The pavement marking studies differed in the number of lanes included in the pattern; the material from which the bars were constructed; the number, color, and width of individual bars; the length of the pattern; the spacing between adjacent bars; the feature involved (e.g., traffic circle or intersection); and the gap between the pattern and the feature.

Given all these variations in patterns, wide variations in outcomes across these studies are, perhaps, not too surprising.

- Most of the studies that were reviewed indicated that traffic speeds could be reduced by the application of transverse bar markings (e.g., Denton 1973). Reductions in average (mean) speed were typically less dramatic than reductions in 85th percentile speed or "percent of drivers exceeding the speed limit" (e.g., Backus 1976).

- Some studies show reductions in speed variability associated with transverse bars (e.g., Denton 1973); others show no appreciable effect on speed variability (e.g., Enustun 1972).

- Some studies suggested that the speed-reduction effectiveness of these patterns can be maintained for many months (e.g., Havell 1983); others suggest the benefits of the markings are transitory and fade within a matter of days or weeks (e.g., Maroney and DeWar 1987).

- When transverse bars were used in conjunction with pavement discontinuities (i.e., rumble strips), speed reduction was enhanced (e.g., Zaidel et al.), but speed variability tended to increase (e.g., Enustun 1972). Indeed, Zaidel et al. suggest that the kinesthetic and/or auditory feedback provided by some transverse pavement bar applications may play a role in their speed-reduction effectiveness.

- Speed reductions associated with transverse bar markings may be more pronounced during the day than at night (Denton 1973; Agent 1975).
- Finally, it should be noted that transverse bar markings may reduce traffic speeds, but for reasons not originally proposed. Rather than creating the illusion in drivers that they are travelling too fast, the patterns may simply function as warning signals indicating that the drivers should reduce their speeds (e.g., Zaidel et al. 1984; Jarvis and Jordan 1990).

The most extensive study of the crash-reduction effectiveness of the transverse bar pattern was conducted by Helliar-Symons (1981). The markings were found to reduce "relevant" crashes by 35 to 70 percent. Further consideration of the Helliar-Symons data suggests that the transverse bar pattern may reduce total crashes by about five percent. Nevertheless, given the low cost ($3,000 to $4,000) and long service life (5 years) of transverse bar patterns, this countermeasure is also deserving of further research.

Introduction

The standard traffic engineering countermeasures that are used to reduce traffic speeds and crashes include signs, signals, delineators, pavement discontinuities (e.g., rumble strips), and pavement markings. This report reviews the available literature on two illusionary pavement marking patterns that have been developed and fielded in the last 20 years. It summarizes what is known about the patterns' effectiveness of these patterns in reducing speeds and crashes and about their cost and service lives.

The first, and more recently developed, pattern reviewed in this report comes from Japan and is referred to as the "converging chevron" pattern. This pattern is characterized by a series of chevrons on the pavement surface that are placed progressively closer together. The first chevrons encountered by a driver passing through the pattern are widely spaced; those later in the pattern are closer together. The intent of this pattern is to create the illusion that drivers are travelling faster than they really are and to foster the impression that the traffic lanes are narrowing.

The second pattern will be referred to as the "transverse bar" pattern. This pattern has been applied in many different forms and guises and in many different contexts and countries (e.g., Great Britain, Israel, South Africa, Australia, United States, and Canada) going back to the mid-1970s. This pattern consists of a series of stripes or bars placed across the roadway perpendicular to the path of traffic. The first bars encountered in the pattern are widely spaced; subsequent bars in the pattern are placed closer and closer together. When this pattern works as intended, drivers perceive that they are failing to reduce their speed as rapidly as they should as they proceed through the pattern.

Regardless of whether we consider fatal crashes recorded throughout the United States or total crashes recorded in one state, it is clear that speeding is a serious threat to the motoring public. In 1993, for example, some 53,343 drivers were involved in fatal traffic crashes in the United States. Of these 53,343 drivers, 11,019 (20.7%) were reported to have been speeding.[1] In the same year, 716,589 drivers were involved in crashes (including fatal, injury- producing, and property-damage-only crashes) in Texas. Of these 716,589 drivers, 114,552 (15.6%) were reported to have been speeding (TTI, 1994).

The reasons why drivers speed are many: their judgment is impaired by alcohol or other drugs, they are in a hurry, or that they intend to maintain a speed in excess of the posted limit but below a level at which they believe they will be cited. In addition to these reasons, some drivers speed inadvertently. That is to say, drivers sometimes fail to realize that the speeds at which they are traveling are too fast for the existing highway environment, e.g., intersections, traffic circles, bridges, horizontal curves, and construction zones. Further aggravating inadvertent speeding is the fact that drivers who have been traveling at a relatively high rate of speed for an extended time may habituate to that speed and underestimate the degree to which they are lowering their speed when they approach an intersection, traffic circle, bridge, horizontal curve, or construction zone.

All drivers have experienced the phenomenon of leaving a freeway at 65 mi/hr (105 km/hr), reducing their speed to, say, 40 mi/hr (64 km/hr) and feeling as if they were traveling at 20 mi/hr (32 km/hr). If, immediately upon leaving the freeway, they approach an intersection on a road that is posted at 30 mi/hr (48 km/hr), they are traveling 10 mi/hr (16 km/hr) in excess of the speed limit but feel as if it is 10 mi/hr (16 km/hr) below the limit.

Both the transverse bar pavement marking pattern and converging chevron pattern seek to redress the problem of inadvertent speeding and the crashes that may result from them.

Discussion and Research Recommendations

The AAA Foundation for Traffic Safety's initial interest in innovative pavement markings to reduce traffic speeds and crashes arose in response to early reports of the effectiveness of the converging chevron pavement marking pattern applied on the Yodogawa Bridge in Osaka, Japan:

> A painted bridge deck surface that creates an optical illusion motivating motorists to curb their speed has totally eliminated accidents on Yodogawa Bridge over the past six months. Osaka traffic police painted geometric arrows along the 2,461 ft. bridge spanning the Shin Yodogawa River last November, giving drivers an illusion of speed. No accidents resulting in injury have occurred on the bridge since the pattern was painted, whereas two people died and nine were injured in 10 bridge accidents last year prior to the painting initiative.[2]

Further investigation of the effectiveness of the pavement markings used in Japan suggests that although the converging chevron patterns that have been employed to date hold promise for reducing traffic crashes, they may not be the panacea that the previous quote would lead one to believe. Many questions remain to be answered. How effective are converging chevrons in reducing different types of crashes, at different times of day, and under different traffic and environmental conditions? Will this pattern continue to produce beneficial results over protracted periods of time? Or will the novelty of this pattern wane and the benefits of the pattern evaporate? To the extent that this pavement marking is reducing traffic crashes, what is the mechanism responsible for that reduction?

It should be noted that the costs associated with the converging chevron patterns are relatively low ($15,000 to $90,000) and the service lives of these patterns (4 to 6 years) of sufficient duration to make these patterns an attractive investment even if only small reductions in traffic crashes are realized through the use of this treatment.

Given the limited information currently available on the converging chevron patterns, the more extensive literature on transverse bars was reviewed in an attempt indirectly to shed some light on the benefits that might accrue to this chevron pattern over time and to discover what we know and do not know about illusory pavement markings in general.

Comments on the Transverse Bar Literature

In reflecting on the findings from the transverse bar literature, the first thing to recognize is that these studies employed many different kinds and types of transverse pavement markings. Table 16 shows how the 10 speed studies and one crash study differed in terms of the number of lanes included in the pattern; the material from which the bars were constructed; the number, color, and widths of individual bars; the length of the pattern; spacing between adjacent bars; the feature involved; and the gap between the pattern and the feature.

The pattern used by Havell, for example, contained 94 bars and was almost 400 m (1,312 ft) in length. One of the two patterns used by Agent in 1979 contained 21 bars and was 378 m (1,240 ft) long. Clearly, the visual patterns presented to drivers traversing the five patterns are quite different.

Of the five patterns, those employed by Havell (1983) and Helliar-Symons (1981) appear most comparable. However, even these two patterns are quite different in the rates at which spacing is reduced between adjacent bars and, potentially, quite different in terms of the impressions they create in drivers.[3]

Given all of these variations in patterns, not to mention differences in traffic, geography, and climate, great variations in outcomes across these studies are, perhaps, not too surprising.

With regard to the speed studies:

- Most of the studies that were reviewed indicated that traffic speeds could be reduced by the application of transverse bar markings (e.g., Denton 1973). Reductions in average (mean) speed were typically less dramatic than reductions in 85th percentile speed or "percent of drivers exceeding the speed limit" (e.g., Backus 1976).
- Some studies show reductions in speed variability associated with transverse bars (e.g., Denton 1973); others show no appreciable effect on speed variability (e.g., Enustun 1972).
- Some studies suggested that the speed-reduction effectiveness of these patterns can be maintained for many months (e.g., Havell 1983); others suggest the benefits of the markings are quite transitory and fade within a matter of days or weeks (e.g., Maroney and DeWar 1987).
- When transverse bars were used in conjunction with pavement discontinuities (rumble strips), speed reduction was enhanced (e.g., Zaidel et al.), but speed variability tended to increase (e.g., Enustun 1972). Indeed, Zaidel et al. suggest that the kinesthetic and/or auditory feedback provided by some transverse pavement bar applications may play a role in their speed-reduction effectiveness.
- Speed reductions associated with transverse bar markings may be more pronounced during the day than at night (Denton 1973; Agent 1975).
- Finally, it should be noted that transverse bar markings may reduce traffic speeds, but for reasons not originally proposed. Rather than creating the illusion in drivers that they are travelling too fast, the patterns may simply function as warning signals indicating the drivers should reduce their speeds (e.g., Zaidel et al. 1984; Jarvis and Jordan 1990).

With regard to crash studies: the literature is quite sparse. Havell (1983) concluded, as previously stated, that "[t]here was no evidence to indicate that the. . .[transverse]. . .markings were themselves causing accidents." Helliar-Symons (1981), on the other hand, estimates that relevant (i.e., potentially impactable) injury crashes on the approaches to traffic circles might be reduced by 57 percent. If Helliar-Symons' data are reanalyzed to estimate the reduction in "total crashes" attributable to transverse markings, rather than "relevant injury crashes" the estimated 57 percent reduction might be lowered to about 5 percent.

Research Recommendations

Although the literature on transverse bars is fairly extensive, the findings of that literature are highly variable and, at times, contradictory. Nevertheless, the potential benefits associated with transverse bar and converging chevron pavement marking patterns and the relatively low cost of these patterns suggest that more research is justified.

Experimental studies such as driving simulation studies and full-scale experiments in traffic and proving grounds facilities and evaluative studies should be pursued to address the questions that were raised by this literature review. Specific research topics that might be addressed through experimental and evaluative studies are outlined below.

Experimental Studies

Much progress has been made in driving simulators since Denton (1971) first used a driving simulator to assess the potential speed reduction effectiveness of two experimental transverse bar patterns. Today's simulators could be used to address several of the issues that have been raised in this discussion.

1. There are at least two mechanisms through which the transverse bar pavement marking pattern might serve to reduce traffic speeds and crashes: by warning or altering drivers to an upcoming situation and by deluding drivers into perceiving that they are travelling too fast. Jarvis and Jordan (1990) and Zaidel et al. (1984) suggest that the benefits of the transverse bar pattern result from alerting or warning drivers of an upcoming situation, not from deluding them into perceiving that they are travelling too fast.

   To determine which of these two mechanisms is at work in the transverse bar pattern, a driving simulator might be used to compare the performance of subjects travelling over transverse bar patterns with uniform spacings and transverse bar patterns with reduced spacing between the bars. If the transverse bar pattern serves only to alert the driver to upcoming conditions, then the two patterns should produce comparable results. If the hypothesized illusional properties of the transverse bar pattern are the causal mechanism for this treatment, then the reduced spacing pattern should be more effective than the uniform spacing pattern.

2. The literature review showed that many different transverse bar patterns have been employed in real-world applications. The various patterns that have been used to date are highly variable in terms of length, number of bars, and the rate at which inter-bar spacings are reduced. Parametric studies should be conducted to better define those patterns that provide

good illusionary qualities as a function of pattern length, number of bars, and bar spacing.

3. The literature also suggested that those transfer bar patterns that were purposely designed to provide drivers with auditory and kinesthetic feedback (through the use of rumble strips), as well as those patterns that may have unintentionally been designed to provide auditory and kinesthetic feedback (through the use of thermoplastic bars rather than painted bars), may be more effective in reducing speeds than installations that do not provide auditory and kinesthetic feed back. Modern driving simulators that are capable of providing auditory and kinesthetic feedback, as well as visual feedback, could be used to evaluate the worth of various transverse bar patterns with and without auditory and kinesthetic feedback.

4. Driving simulators could also be used to compare the responses of experimental subjects to transverse bar patterns and converging chevron patterns. The cost of installing a converging chevron pattern is substantially higher than the cost of installing a transverse bar pattern. If the converging chevron pattern cannot be shown to produce more beneficial responses in experimental subjects, then the added cost associated with the converging chevron pattern may not be justified.

5. The converging chevron pattern, as it has been applied in Japan, includes a dashed 30 cm (1 ft) wide edge line. This edge line may promote the perception in drivers that the traffic lane is narrower than it really is. If this impression is created, driver workload may be increased, speeds reduced, and attention enhanced. On the other hand, these dashed edge lines may have little to do with the reported effectiveness of the converging chevron pattern. Simulations with and without these edge lines would serve to resolve this issue.

   If the dashed edge lines are of little consequence in promoting the illusion, they should be removed. Their removal would reduce the cost of the application and eliminate a potential source of crashes resulting from differential friction, particularly in wet weather.

6. Other issues pertaining to the effectiveness of illusory pavement markings that might be investigated through the use of driving simulators include (a) the effectiveness of these patterns in simulated daylight and darkness situations; (b) the effects of simulated traffic on the saliency of the illusions; (c) the effects of roadway geometry; and (d) the effectiveness of the illusions as a function of repeated exposures, i.e., does the effectiveness of the illusory dissipate when the novelty wears off?

7. Finally, the possibility should be considered that various pavement marking patterns, such as the transverse bar pattern and the converging chevron pattern, may show relatively little effect on vehicle speeds but still

serve to reduce the probability of traffic crashes. That is to say, even if innovative or illusionary pavement marking patterns do not dramatically reduce vehicle speeds, they may nonetheless alert or rouse drivers into a heightened sense of awareness in which they are better prepared to avoid a crash. To assess this possibility, experimentation in driving simulators should monitor various physiological correlates of driver attention, as well as operational variables such as speed, brake applications, etc.

Many of the driving simulation studies that have just been proposed could be carried out more traditionally by applying pavement marking patterns in the real-world highway environment (or, in some cases, at a proving grounds facility) and then conducting the same basic experiments discussed above with human subjects operating instrumented vehicles. The advantages of using driving simulators include safety (the study is not being conducted in traffic), good control over the experimental conditions (there are no problems associated with weather, sun angle, traffic conditions, etc. with simulators), and ease of changing experimental conditions such as pattern geometry and lighting conditions. Final decisions regarding the use of driving simulators or more traditional experimental methods will involve the availability and costs of high-fidelity driving simulators, instrumented vehicles, and proving grounds facilities.

Evaluative Studies

Based on the available literature and information gleaned from studies such as those discussed above, several (say, 10) optimized pavement marking patterns should be fielded.[4] Candidate locations for the treatment patterns would include sites where drivers are obliged to reduce speed after having maintained (and become habituated to) a higher speed, such as a stop-controlled intersection, sharp horizontal curve, or traffic circle located subsequent to long, straight, and level expanses of highway.

At five of the 10 treatment sites, speed data should be recorded for extended periods before and after the application of the pavement marking pattern, and at several locations within the pattern and upstream from the pattern. Each recorded speed should be characterized by: location within (or upstream from) the pattern, date, time of day, vehicle type, and weather conditions.

By collecting a large volume of detailed information on vehicle speeds, several questions regarding the speed reduction effectiveness of innovative pavement marking patterns can be addressed:

Are traffic speeds reduced following the application of the pavement marking pattern?

In answering this question, particular attention should be paid to the effects that the pattern may be having on high-speed drivers. Rather than looking at changes in average (mean) speed from before to after, which may be a fairly insensitive measure of the effectiveness of our treatment, instead the study should consider the effects that treatment may have on the right tail of the speed distribution, e.g., 85th or 95th percentile speeds, or the percent of drivers exceeding the posted speed or the advisory speed.

How is the speed reduction effectiveness of innovative pavement markings influenced by lighting, weather, and traffic conditions?

Do pavement marking patterns have more influence over the speeds of passenger cars or trucks?

Does the speed reduction effectiveness of innovative pavement markings dissipate over time as the novelty of the treatment pales?

In addition to monitoring traffic speeds at five of the treated sites, measurements of the durability and frictional properties of the pavement marking materials used at all 10 treatment sites should be taken to determine the rate at which these materials deteriorate over time. To determine the ultimate worth of the treatments imposed, statistical estimates of the crash reduction effectiveness of the patterns should be conducted. These estimates should be made by comparing the crashes sustained at the 10 treatment sites and the 40 comparison sites for a period three years before and three years after the pavement markings are applied. In conducting this evaluation of the crash reduction effectiveness of innovative pavement markings, particular attention should be paid to the statistical power of the evaluation that is proposed. Based on the crash reduction effectiveness figures provided by Helliar-Symons (1981), it may be concluded that transverse bar pavement marking patterns may be able to reduce total crashes by about 5 percent. If that figure is "in the ball park," then it is known that a substantial sample of crashes at the treatment and comparison sites will be necessary to demonstrate the efficacy of the treatment. Before this evaluation is initiated, and before the treatments are applied, a power analysis should be conducted to ensure that the projected samples sizes are reasonable for purposes of this analysis.

Sub-analyses of the crash reduction effectiveness of the innovative pavement marking patterns might also ask (if sufficient quantities of crash data are available):

When are the markings most effective, e.g., night or day, good weather or bad, time of day, etc.?

What kinds and types of crashes are most affected, e.g., front-to-rear or angular crashes, minor or severe injury crashes?

Footnotes

[1] Data derived from the Fatal Accident Reporting System (FARS), the National

Highway Traffic Safety Administration, U.S. Department of Transportation.

[2] *Public Innovation Abroad,* published by the International Center, Academy for State and Local Government, Volume 17, Number 6 (June 1993).

[3] It should be noted that the pattern spacing employed by Helliar-Symons is the standard pattern in Britain: *Departmental Standard TD 6/79, Transverse Yellow Bar Markings at Roundabouts* (Reprinted August 1986). This standard is reproduced in the appendix to this report.

[4] The 10 treatment sites would be randomly selected from a candidate list of 50 potential treatment sites. The 40 sites not selected for treatment would be saved for purposes of comparison.