Literature Search: Effectiveness of Speed Reduction Markings on Rural Curves

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Summary of Results

Overview

The following twenty-seven literature search results were collected to provide resources for determining if there is sufficient evidence that speed reduction markings (SPM) are effective safety countermeasures for reducing crashes and encouraging awareness of driving speed. The results focus on studies and reports as an aim to provide insight into speed limits, lighting conditions, adjacent land uses, and other applicable context. Some of the studies and reports collected may appear redundant as they are revisions to other included reports or studies or they may be publications on the same study in different journals. All variations were purposefully included in case a revision or alternate publication method may include pertinent information absent from the other.

Search Parameters

The results have been narrowed to focus on reports and studies evaluating SPM around curves on rural highways so guides and handbooks have largely been excluded in order to concentrate on effectiveness over standard practice. While no filters were placed on date range, the findings span from 2004 to 2025. As the focus is on curves along rural highways in the United States (US), any reports or studies outside of the US or discussing highway work zones, roundabouts, intersections, trail crossings, freeway exists and ramps, tunnel approach zones, and downhill sections of highways were excluded from the results list but do exist in the broader literature.

Arrangement of Results

The results are arranged according to relevance with the first section containing the most applicable publications in that they discuss studies of SPM on rural highway curves. The next section focuses on SPM through rural communities while the following section focuses on SPM through curves. The final section includes studies and reports on traffic calming measures for speed management where SPM at curves and/or on rural highways are part of the discussion but not the main focus of the discussion.

When available, links to the articles are included in the citations. If the link is not available or you are not able to access the full publication, please contact the ODOT Library to obtain a copy.

Speed Reduction Markings Annotated Bibliography

As the primary objective of this literature search concentrates on speed reduction markings intended to reduce speed around curves on rural highways, the first section of results include thirteen studies or reports on that topic. The next two sections provide ten results that discuss SPM in either rural communities or curves. The last section includes four results on traffic calming measures that includes discussion of SPM in curves on rural highways but is not the focus of the publication.

At Rural Curves

The following thirteen publications center on studies and reports over the previous twenty-two years that test the effectiveness of speed management around rural highway curves. There may be some redundancy in the results as two sets of reports appear to discuss the same study in different publications while another two results are a final and revised final copy of the same report. These results were intentionally retained in case one publication includes applicable information not found in the other.

Angioi, F., de Oña, J., Díaz-Piedra, C., de Oña, R., & Di Stasi, L. L. (2025). Effectiveness of smart horizontal markings on drivers' behavior along horizontal curves: A driving simulation study. *Accident Analysis & Prevention, 219,* 108086. https://doi.org/10.1016/j.aap.2025.108086

> Photoluminescent road markings (PRMs) are a potentially useful visual guidance technology for improving road safety in low-visibility conditions. However, the effectiveness of PRMs requires further research. Moreover, road infrastructure regulations lack guidelines for PRMs design. Here, we aimed at determining the effects of different PRMs colors and widths on transversal and longitudinal driving behavioral indices. We conducted a simulation-based 3x2x2 within-subjects experiment (PRM: unlit vs. smart green vs. smart red; marking width: conventional vs. wide; curve direction: left vs. right). We designed six two-lane rural highway scenarios with nighttime light conditions and no traffic. Each scenario included twenty-four horizontal curves with radii ranging from 120 to 440 m (recommended speed range 60–90 km/h). Thirty participants (age range 20–54 years) drove a semi-dynamic driving simulator for about one hour. Our results showed that the presence of PRMs affected the drivers' transversal behavior. The smart markings induced drivers to keep greater lateral distances from the road edge line than unlit ones along right curves. Smart green markings showed higher variability for vehicle positioning, indicating lower vehicle control. Wider-than-normal markings induced users to drive closer to the edge line at the Tangent-to-Spiral section. Overall, our study showed that smart markings - both green and red - induce the driver to "shy away" from the edge line, thus representing a potential tool for preventing roadway

departure events. Further studies are expected to confirm these results by focusing on different PRM layouts, traffic, and weather conditions.

Boodlal, L., et. al. (2015). *Factors Influencing Operating Speeds and Safety on Rural and Suburban Roads* (Report No. FHWA-HRT-15-030). Turner-Fairbank Highway Research Center, U.S. Federal Highway Administration. https://rosap.ntl.bts.gov/view/dot/35877

The objective of this project was to develop a technical report that describes treatments that result in driver self-selection of appropriate operational speeds on curve and tangent sections. The study was conducted in two phases. The first phase included a review of literature on design features and current practices associated with safer operating speeds and identification of treatments for field evaluations. The second phase involved evaluating treatments to determine their effectiveness in reducing speeds on two-lane horizontal curves in rural and suburban areas. High-friction surface treatment was evaluated at four treatment sites and three control sites in West Virginia. The speed and encroachment analyses found no consistent differences between the before and after time periods. The friction analysis, however, clearly demonstrated that the friction supply increased. Optical speed bars (OSB) were implemented and evaluated at seven sites in Massachusetts, four sites in Arizona, and eight sites in Alabama. Two different designs were tested as part of this research, and the results yielded inconsistent speed reductions at all the test sites. Based on the results, it can be concluded that the OSB designs used in this research were unsuccessful in reducing vehicle speeds. The safety effects of lane-width–shoulder-width combinations on rural two-lane, two-way road segments in Minnesota and Illinois were also estimated as part of this study. Parameters for lane width indicators showed that, with shoulder width ignored, the expected number of total (i.e., all types and severities) crashes increases as lane width decreases, but it is difficult to distinguish the performance of an 11-ft lane width from that of a 12-ft lane width. The main effect of shoulder width was a decrease in the expected number of crashes as shoulder width increased. In addition, the interaction of the lane width indicator and shoulder width showed that shoulder width has the greatest effect on safety when the lane width equals 10 ft. Shoulder width also has a greater effect on safety when the lane width is 11 ft than when the lane width is 12 ft.

Calvi, A. (2018). Investigating the effectiveness of perceptual treatments on a crest vertical curve: A driving simulator study. *Transportation Research Part F: Traffic Psychology and Behaviour,* **58,** 1074-1086. https://doi.org/10.1016/j.trf.2018.06.002

Rural roads are characterized by a high percentage of run-off-the-road accidents and head-on collisions, mainly caused by inappropriate speeds and failure to maintain a proper lateral position along the roadway alignment. Among several road safety

treatments, low-cost perceptual measures are considered an effective tool, as they generally increase the risk perceived by drivers, or even alter the drivers' speed perception, and consequently tempting them to decrease their speeds. Their effectiveness has been widely recognized in a number of studies, especially with respect to road intersections and curves. The overall aim of this study is to investigate the effects of different perceptual treatments on driving speed, along a crest vertical curve of an existing two-lane rural road, in order to identify the most effective measure to reduce speed and define its subsequent implementation in the field. Three perceptual treatments were tested using a driving simulator: white peripheral transverse bars, red peripheral transverse bars and optical speed bars, with each one being painted along the approaching tangent to the crest vertical curve. The effects of these speed-reducing measures were investigated using a sample of forty-four participants, by comparing the driving speeds with those recorded under a baseline condition (without a treatment); these were also used to validate the driving simulator's speed measurements with those found in the field. Moreover, subjective measures were collected, consisting of the driver's static evaluation of the desired speed, risk perception and markings comprehension, based on screen shot pictures that represented the simulated configurations of the treatments. The findings demonstrated an overall effectiveness of the perceptual treatments, although only the red peripheral transverse bars were found to significantly reduce the driving speeds (−6 km/h). The analysis of the questionnaire yielded interesting information and demonstrated the importance of performing driving simulation tests for evaluating the effectiveness of perceptual treatments. Finally, the results confirmed the enormous potential of using driving simulators to pinpoint a number of speed-reducing measures, and consequently select the most effective one that reduces cost and promotes safety before its actual implementation in the field.

Calvi, A., D'Amico, F., Bianchini Ciampoli, L., & Ferrante, C. (2019). Evaluating the effectiveness of perceptual treatments on sharp curves: a driving simulator study. *Traffic Injury Prevention, 20(sup2)*, S13–S19. https://doi.org/10.1080/15389588.2019.1669789

Objective: Speed has been identified as a key risk factor in road crashes, influencing the occurrence of a road crash and its severity. Excessive speeding is particularly dangerous on highway curves, and under critical traffic and environmental conditions. Various measures have been identified to be effective in managing and controlling vehicle speed. Among these, low-cost perceptual measures have been considered to be effective tools, as they generally increase the risks perceived by drivers, or alter speed perception, and consequently lead the drivers to reduce their speeds. The overall aim of this study is 1) to investigate the effectiveness of a set of perceptual treatments in reducing the driver's speed along a sharp curve of an existing rural road that is characterized by high crash

rates, and 2) to identify the most effective measure(s) to implement in the field to counteract the problem of speeding. Methods: A driving simulator study was developed and four speed-reducing measures (white and red peripheral transverse bars (PTB), optical speed bars (OSB) and chevrons) were tested on a sample of forty-two drivers. The driving speeds recorded using the treatments tests were compared to a baseline condition (treatments were not applied). Subjective measures were also collected; these included the driver's evaluation of the desired speed, risk perception, road legibility, and markings comprehension, as based on screenshot pictures that represented the simulated configurations of the treatments. Results: The outcomes demonstrated an overall effectiveness of the perceptual treatments. Particularly, red PTB were associated with a speed-reduction of up to 12 km/h along the curve under study. An analysis of the questionnaires revealed that drivers did not fully comprehend the relevant message of PTB. Despite that, the drivers did unconsciously reduce their speeds; this confirms the effectiveness of such perceptual treatments based on the optical illusion that entices drivers to reduce their speeds. Conclusions: The findings demonstrated the effectiveness of the perceptual treatments, especially red PTB, in enticing drivers to reduce their speeds whilst approaching the sharp curve under study or driving through the curve.

Donnell, E. T., et. al. (2019). *Reducing Roadway Departure Crashes at Horizontal Curve Sections on Two-lane Rural Highways* (Report No. FHWA-SA-19-005). U.S. Department of Transportation, Federal Highway Administration, Office of Safety. https://rosap.ntl.bts.gov/view/dot/55604

While several proven safety countermeasures and strategies exist to mitigate roadway departure crashes on horizontal curve sections of two-lane rural highways, there are several countermeasures or strategies that have yet to be proven via a rigorous safety evaluation. The purpose of this research was to identify several of these strategies or countermeasures, and to perform a statistical assessment of their safety effectiveness. This report details the following three evaluations: (1) observational before-after study of curve ahead warning pavement markings, (2) cross-sectional study of delineators on guiderail along horizontal curves, and (3) cross-sectional study of the safety effects of geometric design consistency. The findings from these evaluations indicate that the expected number of roadway departure crashes are associated with the horizontal curve radius, radii of adjacent horizontal curves, and the tangent lengths between curves. Further, the expected number of roadway departure crashes is associated with side friction demand on horizontal curves. Guiderail with delineators are expected to reduce total, fatal plus injury, run-off-road (ROR), and nighttime crashes along horizontal curves that are four degrees or sharper. Horizontal curve warning pavement markings are associated with fewer expected total, fatal plus injury, ROR, nighttime, nighttime ROR, and nighttime fatal plus injury crashes on two-lane rural highways.

Hallmark, S., Hawkins, Neal, & Smadi, O. (2012*). Toolbox of countermeasures for rural two-lane curves* (Report No. IHRB Project TR-579). Iowa Department of Transportation, Midwest Transportation Consortium. https://rosap.ntl.bts.gov/view/dot/26101

The Federal Highway Administration (FHWA) estimates that 58 percent of roadway fatalities are lane departures, while 40 percent of fatalities are single-vehicle run-off-road (SVROR) crashes. Addressing lane-departure crashes is therefore a priority for national, state, and local roadway agencies. Horizontal curves are of particular interest because they have been correlated with increased crash occurrence. This toolbox was developed to assist agencies address crashes at rural curves. The main objective of this toolbox is to summarize the effectiveness of various known curve countermeasures. While education, enforcement, and policy countermeasures should also be considered, they were not included given the toolbox focuses on roadway-based countermeasures. Furthermore, the toolbox is geared toward rural two-lane curves. The research team identified countermeasures based on their own research, through a survey of the literature, and through discussions with other professionals. Coverage of curve countermeasures in this toolbox is not necessarily comprehensive. For each countermeasure covered, this toolbox includes the following information: description, application, effectiveness, advantages, and disadvantages.

Hallmark, S., Hawkins, N., & Smadi, O. (2013). *Toolbox of countermeasures for rural two-lane curves* [revised] (Report No. IHRB Project TR-579). Iowa Department of Transportation, Midwest Transportation Consortium. https://rosap.ntl.bts.gov/view/dot/26672

The Federal Highway Administration (FHWA) estimates that 58 percent of roadway fatalities are lane departures, while 40 percent of fatalities are single-vehicle run-off-road (SVROR) crashes. Addressing lane-departure crashes is therefore a priority for national, state, and local roadway agencies. Horizontal curves are of particular interest because they have been correlated with increased crash occurrence. This toolbox was developed to assist agencies address crashes at rural curves. The main objective of this toolbox is to summarize the effectiveness of various known curve countermeasures. While education, enforcement, and policy countermeasures should also be considered, they were not included given the toolbox focuses on roadway-based countermeasures. Furthermore, the toolbox is geared toward rural two-lane curves. The research team identified countermeasures based on their own research, through a survey of the literature, and through discussions with other professionals. Coverage of curve countermeasures in this toolbox is not necessarily comprehensive. For each countermeasure covered, this toolbox includes the following information: description, application, effectiveness advantages, and disadvantages.

Iio, K., Nakai, H., & Usui, S. (2023). Effects of Speed Reduction Marking Patterns on Simulated Driving Speed and Lane Position. *Transportation Research Record: Journal of the Transportation Research Board*, *2677*(2), 880-897. https://doi.org/10.1177/03611981221108979

Speed reduction markings have been installed on highways as perceptual countermeasures for speeding. However, little is known about the effects of the shape and interval of road markings on driving speed and lane position. In this paper, a driving simulator experiment and questionnaires were performed to explore the effects of speed reduction marking patterns on driving speed and standard deviation of lane position (SDLP), as well as drivers' subjective feelings, mental workload, and visual attention. Thirty-nine participants drove on a simulated two-lane rural highway where speed reduction markings with different shapes and intervals were presented at horizontal curves. The pavement markings were associated with reduced throttle values and mean speed in advance of a horizontal curve. The marking shape did not affect participants? speed choice or SDLP. A cognitive alerting effect of the speed reduction markings was dominant because the participants did not drive more slowly with the markings with converging intervals toward the traveling direction compared to those with a constant interval. A questionnaire on drivers? attention reflected a potential use of road markings for drivers? lane-position maintenance. Since less than 18?% of the participants noticed the convergence in marking intervals, speed reduction markings may also induce the perceptual illusion of acceleration.

Latoski, S.P. (2009) Optical Speed Zone for Rural Two-Lane Highways. *ITE Journal, 79*(3), 30-35. Accessed 2026/05/11 at https://www.ite.org/pub/?id=E2555198-2354-D714-51A9-53F2E3442DC5

An optical speed zone on a two-lane rural highway tangent section, designed and installed by Mohave County Public Works (MCPW), is aimed to provide a significant reduction in mean speed down-stream of the zone. This is a low-tech tool for speed management using an agency's existing supply of road striping materials. An optical speed zone includes multiple speed bars, each represents a uniform transverse marking patterns, spaced variable to convey to road users a sensory perception of increasing speed during traveling through the zone. It targets a road user reaction of relaxing the accelerator or adjusting the cruise control causing the vehicle to reduce the speed at the down-stream end of the optical speed zone. The design and application of MCPW optical speed zone is expected to target road user's awareness about traveling speed.

Momeni, H., Russell, Sr., Eugene R., & Rys, M. J. (2015). *A study to mitigate rural high-speed horizontal curve crashes in Kansas* (Report No. K-TRAN: KSU-13-2). Kansas Department of

Transportation, Bureau of Materials & Research. https://rosap.ntl.bts.gov/view/dot/28824

Driving on horizontal curves is a more complicated task than on straight sections of a roadway, and poses more workload on drivers as well. While a small portion of roadways are made up of horizontal curve sections approximately a quarter of all fatal crashes on highways occur at horizontal curve sections. Thus, studying the crashes at horizontal curves and the safety improvement at these sections is one of the most interesting topics in the transportation safety field. Safety improvement of horizontal curve sections of rural transportation networks can effectively and considerably contribute to crash severity and frequency reduction. Low-cost countermeasures to improve traffic safety of horizontal curve sections and their effectiveness were discussed. A Kansas Department of Transportation (KDOT) crash database of nine years (from 2004 to 2012) was used and counties with high number of crashes were selected. Eleven counties with high number of horizontal curve related crashes were selected, and implemented countermeasures at the selected curves were investigated and discussed. K-5 highway is one of the highways with high number of crashes in which the speed limit of a long distance of the roadway, including the problematic curves, reduced in June 2009 from 55 miles per hour (mph) to 50 mph. The effect of this speed limit reduction on crash occurrences of seven years, including 3.5 years before and 3.5 years after the speed limit reduction, was investigated using a statistical t-test method. In addition, various countermeasures to improve the traffic safety of these horizontal curves were discussed.

Stamataidis, N., & Vest, A. (2004). Means to Reduce Operating Speeds on Curves. *Proceedings of the SIIV2004 II International Congress, Florence, Italy, Florence, Italy*. University of Kentucky. https://www.siiv.net/site/sites/default/files/Documenti/firenze/firenze11.pdf

Sharp horizontal curves can pose dangers to the driver when dealing with speed adjustment, vehicle placement, and judgment of the appropriate operating speed. Roadway designers use various warning methods to aid drivers in such situations. Two primary methods of achieving this are warning signs and pavement markings. There is a suspicion however that these devices are often misinterpreted or disregarded by drivers. Therefore, the effectiveness of signs and markings is reduced and often the intended reduction in operating speeds is not achieved. Safety concerns regarding the effectiveness of these devices arise which could be prevented by a proper and judicious placement of signs and markings. The objective of this study is to evaluate the use of several warning signs and pavement markings at problematic rural horizontal curves, and to evaluate their effectiveness in relation to speed reduction. Several types of warning signs and pavement markings were used to determine methods and combinations that could reduce operating speeds more effectively. All of the sites studied had an existing horizontal alignment sign with speed plaque in advance of the curve. The treatments

applied included one-direction large arrow signs, chevron alignment signs, the new sign that combines horizontal alignment and advisory speed, addition of flags to the existing sign, addition of flashing lights to the existing sign, post delineators, and transverse lines. All these treatments were applied to three curves and speed data were collected over a two-day period at four locations approaching and in the curve over a distance of approximately 350 m. The results indicate that the most promising treatments in reducing operating speeds are flashing lights and transverse lines. These treatments typically showed speed reductions ranging from 5% to 10%. An analysis of the over the 85th percentile speeds for these treatments showed also significant reductions ranging from 12% to 18%. This indicates that there was a greater impact for the higher operating speeds, which could be considered more important than the smaller overall reductions noted. Another treatment that also showed some potential for reducing speeds is the new combination sign.

Stamatiadis, N. & A. Vest (2008). Evaluation of warning signs and markings to reduce speeds on curves. *Efficient Transportation and Pavement Systems: Characterization, Mechanisms, Simulation, and Modeling* (pp. 315-324). CRC Press. https://www.taylorfrancis.com/chapters/edit/10.1201/9780203881200-35/evaluation-warning-signs-markings-reduce-speeds-curves-stamatiadis-vest

Sharp horizontal curves can pose dangers to the driver when dealing with speed adjustment, vehicle placement, and judgment of the appropriate operating speed. Roadway designers use various warning methods to aid drivers in such situations. Two primary methods of achieving this are warning signs and pavement markings. There is a suspicion however that these devices are often misinterpreted or disregarded by drivers. The objective of this study is to evaluate the use of several warning signs and pavement markings at problematic rural horizontal curves, and to evaluate their effectiveness in relation to speed reduction. Several types of warning signs and pavement markings were used to determine methods and combinations that could reduce operating speeds more effectively. The results indicate that the most promising treatments in reducing operating speeds are flashing lights and transverse lines. Another treatment that also showed some potential for reducing speeds is the new combination sign.

Wang, Z., et al. (2018). *Study on Motorcycle Safety in Negotiation with Horizontal Curves in Florida and Development of Crash Modification Factors* (Report No. BDV25-977-21). Florida Department of Transportation. https://rosap.ntl.bts.gov/view/dot/63608

Motorcycle crashes are overrepresented on horizontal curves, especially along rural two-lane roads. Most roadway design and traffic control strategies on horizontal curves include limited considerations for motorcycles. It is necessary to conduct a study to

investigate the factors contributing to motorcycle crash risk on horizontal curves and identify effective countermeasures to improve motorcycle safety. This project aimed to fill the gap by completing the following four tasks: 1. A comprehensive literature review to summarize current practices of preventing motorcycle crashes on horizontal curves; 2. A crash analysis to address relevant factors and how to influence motorcycle crash risk on horizontal curves, including crash occurrence, risk of fatalities and severe injuries, and motorcyclist-at-fault; 3. A field experiment to evaluate the effectiveness of Dynamic Speed Feedback Signs (DSFS) to reduce motorcycle speed and increase motorcyclist attention on curve risk; 4. A before-after crash analysis to address the effectiveness of DSFS in motorcycle crash reduction on horizontal curves; 5. Recommendations to address the identified curve-related safety issues for motorcycles in Florida and prevent motorcycle injury on horizontal curves. Advanced statistical models were used to analyze 11 years (2005–2015) of motorcycle crashes data collected on curves on Florida roadways. Crash Modification Factors (CMFs) of curve radius and curve type for single-motorcycle crashes on rural two-lane highways were developed. The CMFs can be used in Highway Safety Manual (HSM)-compatible motorcycle safety management. Significant factors contributing to motorcycle crash frequency, severity, and motorcyclist-at-fault on horizontal curves were also identified and quantified. A field behavior experiment collected speed profile data and eye tracking data from 10 participants with different DSFS operation modes ("OFF" – without DSFS, "STATIC" – continuously display speed limit, "DYNAMIC" – feedback scheme with flashing and "SLOW DOWN" display). The results indicate that DSFS in "DYNAMIC" mode can effectively increase motorcyclist attention on curves and intention to reduce speed. The before-after with comparison group study shows that the implementation of DSFS on rural two-lane undivided curves can reduce lane departure motorcycle crashes by 22%. Based on the analysis results, recommendations were developed for increasing awareness of curve risks, decreasing speed, roadside clearance, implementation of DSFS, and education/training.

Through Rural Communities

The following six publications include studies and reports from 2007 through 2021 that focus on the effects of pavement markings entering rural communities but are not specific to curves. There may be some redundancy in the results as two reports appear to discuss the same study in different publications while another three reference the same overarching project. These results were intentionally retained in case one publication includes additional information not found in the others.

Balde, A.D. (2010). *Speed Management in Rural Communities Using Optical Speed Bars* [Master thesis, Kansas State University]. K-State Electronic Theses, Dissertations, and Reports: 2004 - .

http://hdl.handle.net/2097/7026

Speed management has been a challenge, particularly in places where high-speed highways pass through. Due to high rate of fatalities and low budgets available, it is therefore necessary to identify low-cost effective approaches in reducing speeds. Optical Speed Bar (OSB) treatment is one such technique. This research makes an attempt to evaluate the effectiveness of OSBs in reducing approach speeds on two-lane, rural highways approaching small communities. Speed data were collected and analyzed "before" and "after" periods at five sites. Effectiveness of OSBs was evaluated using changes in mean and 85th percentile speeds under different categories by considering all vehicles, vehicle classification (two axles vs. more than two axles), day of the week (weekdays vs. weekends), and time of day (daytime vs. nighttime), as well as proportions exceeding posted speed limit, using t-test mean speeds, F-test for analysis of variance, and Z-test for proportions of vehicles exceeding posted speed limit between "before" and "after" datasets. Even though motorists were found to slow down on the approaches, in response to speed zones, speeding was noted. "Before" speed data indicated higher speeds than desired at the sites. The 85th percentile speeds were between 50 and 63 mph while the posted speed limits on the approaches were 45 mph at four sites, and the 85th percentile speed was about 42 mph at one site with an approach posted speed limit of 30 mph. The "before" degrees of noncompliance were up to 90 % of free-flowing vehicles at the sites. Speed data analysis showed significant reductions in speeds at ends of OSBs at four test sites. Mean and 85th percentile speeds and standard deviations were found reduced in the after periods. Percent reductions in mean speeds were between 1.2 and 8.2 %, with 85th percentile reductions between 3.2 and 8.9 %. At one site, no notable change in mean and 85th percentile speeds occurred at the end of OSBs, but significant increases in standard deviations were noted. Speed reductions were higher for two-axle vehicles, during the daytime and on weekdays with few exceptions. Results of the study showed, as other previous studies did, OSBs may have some minor effects on vehicle speeds. The study provides an indication that it may be possible to create safety improvements as result of using OSBs on the approach to a rural community. However, magnitude of speed reductions was generally small, though the reductions were statistically significant at the 95% confidence level. Because of the non-consistence of the magnitude of speed reductions at the test sites, no conclusion can be drawn as to how much OSB treatment reduced speeds. These results were based on "after" periods up to five months. Therefore, further study would be required to determine whether these safety improvements are sustained over an even longer time period. Even though minor speed reductions occurred, speeds observed at the sites were still higher than the posted speed limits, indicating OSBs were not effective enough in providing the desired speed limit compliance. Additional studies would be helpful to

identify combinations of countermeasures, for instance OSBs and other techniques, effective in providing speed limit compliance.

Balde, A. D., & Dissanayake, S. (2013). Effectiveness of Optical Speed Bars in Reducing Approach Speeds to Rural Communities. *Journal of Transportation Safety & Security*, *5*(3), 240–256. https://doi.org/10.1080/19439962.2012.756090

Speed management has been a challenge in rural communities due to low budgets, and it is necessary to identify effective, low-cost approaches to reduce speeds. Accordingly, this research attempted to evaluate the effectiveness of optical speed bars (OSB) in reducing approach speeds on two-lane, rural undivided highways approaching small communities. Speed data were collected and analyzed before and after installation of the OSBs at five such sites. Effectiveness of the OSBs was evaluated using changes in mean and 85th percentile speeds under different categories by considering all vehicles, vehicle classification, days of the week, and time of day. Significant reductions in mean speeds and speed variance were observed at the end of the OSBs at four of the five sites, and one site showed no statistically significant change in speeds. Speed reductions were higher during daytime and weekdays. Higher speed reductions for two-axle vehicles were observed, with the exception of the Belvue test site. Speed increased in the opposite direction and at data collection points ahead of OSBs in the treatment direction, whereas there were reductions in speeds at the end of OSBs, indicating that OSBs seem to be effective in reducing approach speeds.

Croshaw, K. J. (2014). *Application of meta-analysis to estimate the speed effects of highway treatments: A case study of optical speed bars on rural highways* [Master thesis, University of Utah]. The University of Utah ProQuest Dissertations & Theses. https://www.proquest.com/openview/748100e2b84f90d9dc252518f5839e5b/1?cbl=18750&pq-origsite=gscholar

Speeding-related crashes have contributed to a significant number of traffic-related fatalities throughout the United States. Previous analyses have indicated that small reductions in driver speed can significantly reduce the number of injury and fatal crashes. Many types of speed-reduction treatments have been tested and used. This study focuses on Optical Speed Bars (OSB). OSB are a low-cost speed treatment intended to cause drivers to reduce their speeds through alerting as well as perceptual cues. OSB have been tested using driving simulators and field applications. The results show statistically significant speed reductions. Although statistically significant, the magnitude of the reductions have generally been small in magnitude (with some exceptions). There are multiple field trials that have tested the speed reduction effects of OSB. Although many results have seen statistically significant speed reductions, it is difficult to compile,

interpret, and draw conclusions regarding overall OSB effectiveness based on the separate published studies. There is a need to quantitatively combine previous results so that more direct conclusions can be made about the expected speed reduction effects of OSB. Meta-analysis is a methodology that can be used to quantitatively combine the results from multiple published studies. A meta-analysis combines results from multiple treatments and gives one overall expected effect for the treatment. This thesis applies a meta-analysis to estimate the overall expected speed reduction effects of OSB using field studies published from 2000 – 2013. Both fixed effects and random effects models are used. The data consisted of five published studies, 17 treatment locations, and 34 individual data collection points within those treatment locations. The overall speed reduction effects were then estimated through six different analyses. Each analysis looked at different characteristics of OSB (e.g., line style, alerting and perception cues, and the location of data collection points). Overall, speed reductions were statistically significant but were small in magnitude. This conclusion parallels many previous studies; however, the meta-analysis provided an expected speed reduction for all applications of OSB. Meta-analysis proved to be an effective methodology to combine and represent multiple published studies and is recommended for other speed treatment applications.

Hallmark, S. , Hawkins, N. and Knickerbocker, S. (2021) Evaluation of Transverse Markings as a Speed Transition Zone Countermeasures in Small, Rural Communities. *Journal of Transportation Technologies*, *(11)*, 61-77. doi: 10.4236/jtts.2021.111004.

Small rural communities located along major state or county roadways typically find most of the traffic along their main thoroughfares is pass-through rather than local traffic. Unfortunately, drivers passing through these communities often enter at high rates of speeds, which are often significantly higher than the speed limit of the local segment. Speed management in rural areas requires different considerations compared to urban areas and, within the US, rural speed management is not as advanced with little experience or guidance for agencies to draw on. This paper summarizes the results of a study that evaluated, in part, several different types of transverse pavement markings within the speed transition zones in small rural communities. Three different countermeasures were evaluated: converging chevrons, transverse lane markings, and optical speed bars.

Hallmark, S. L., Peterson, E., Fitzsimmons, E., Hawkins, N., Resler, J., & Welch, T. (2007). *Evaluation of Gateway and Low-Cost Traffic-Calming Treatments for Major Routes in Small Rural Communities* (Report N. CTRE Project 06-185, IHRB Project TR-523). Iowa Highway Research Board, Iowa Department of Transportation. https://www.intrans.iastate.edu/research/completed/traffic-calming-techniques-for-small-rural-

communities/

Many rural communities have developed around highways or major county roads; as a result, the main street through small rural communities is often part of a high-speed rural highway. Highways and county roads are characterized by high speeds outside the city limits; they then transition into a reduced speed section through the rural community. Consequently, drivers passing through the community often enter at high speeds and maintain those speeds as they travel through the community. Traffic calming in small rural communities along major roadways is common in Europe, but the U.S. does not have experience with applying traffic-calming measures outside of major urban areas. The purpose of the project was to evaluate traffic-calming treatments on the major road through small Iowa communities using either single-measure low-cost or gateway treatments. The project was partially funded by the Iowa Highway Research Board (IHRB). The focus of the IHRB portion was to evaluate single-measure, low-cost, traffic-calming measures that are appropriate to major roads through small rural communities. Seven different low-cost traffic treatments were implemented and evaluated in five rural Iowa communities. The research evaluated the use of two gateway treatments in Union and Roland; five single-measure treatments (speed table, on-pavement "SLOW" markings, a driver speed feedback sign, tubular markers, and on-pavement entrance treatments) were evaluated in Gilbert, Slater, and Dexter.

Hallmark, S., Knickerbocker, S., & Hawkins, N. (2013). *Evaluation of Low Cost Traffic Calming for Rural Communities: Phase II* (Report No. IHRB Project TR-630). Iowa Department of Transportation, Midwest Transportation Consortium**.** https://rosap.ntl.bts.gov/view/dot/26102

The main goal of the research described in this report was to evaluate countermeasures that agencies can use to reduce speeds as drivers enter rural communities located on high-speed roadways. The objectives of this study were as follows: Identify and summarize countermeasures used to manage speeds in transition zones; Demonstrate the effectiveness of countermeasures that are practical for high- to low-speed transition zones; Acquire additional information about countermeasures that may show promise but lack sufficient evidence of effectiveness; and Develop an application toolbox to assist small communities in selecting appropriate transition zones and effective countermeasures for entrances to small rural communities. The team solicited small communities that were interested in participating in the Phase II study and several communities were also recommended. The treatments evaluated were selected by carefully considering traffic-calming treatments that have been used effectively in other countries for small rural communities, as well as the information gained from the first phase of the project. The treatments evaluated are as follows: Transverse speed bars; Colored entrance treatment; Temporary island; Radar-activated speed limit sign; and

Speed feedback sign. The toolbox publication and four focused tech briefs also cover the results of this work.

At Curves

The following four publications encompass studies and reports from 2005 through 2025 that focus on the effects of pavement markings entering curves but not specific to rural highways.

Calvi, A., D'Amico, F., Ferrante, C., Bianchini Ciampoli, L., & Tosti, F. (2020). Applying Perceptual Treatments for Reducing Operating Speeds on Curves: A Driving Simulator Study for Investigating Driver's Speed Behavior. In: Stanton, N. (Eds.), *Advances in Human Factors of Transportation. AHFE 2019. Advances in Intelligent Systems and Computing: Vol 964*. Springer, Cham. https://doi.org/10.1007/978-3-030-20503-4_31

The aim of this driving simulator study is to investigate the effectiveness of different speed-reducing measures on a sharp curve of an existing road. Specifically, three perceptual treatments (white peripheral transverse bars, red peripheral transverse bars and optical speed bars) and chevrons are tested by means of a driving simulator over a randomly selected sample of forty-four drivers. The observed driving speeds are finally compared to those recorded under a baseline condition (with no treatment). Results confirmed the enormous potential of driving simulators in assessing the viability and design of several speed-reducing measures, especially those related to drivers' perceptions that are strongly based on human factors issues, thereby allowing the selection of the most effective one in terms of cost reduction and safety promotion, in view of its actual implementation on the field.

Calvo-Poyo, F., Garach, L., & de Oña, J. (2025). Do wider longitudinal road markings influence driving speed perception? *Traffic Injury Prevention*, *26*(8), 915–923. https://doi.org/10.1080/15389588.2025.2465822

Excessive speed is one of the factors most frequently associated with traffic accidents and noncompliance with traffic regulations. Road markings serve as a fundamental aid for drivers, with their design playing a critical role in road safety. Wider longitudinal markings create a visual narrowing effect on the driving lane, potentially increasing the perception of speed and encouraging drivers to reduce their speed, thereby enhancing traffic safety. However, this phenomenon has received limited attention in prior studies, which have predominantly relied on field experiments with small sample sizes and have often overlooked important variables such as night driving conditions. Given these considerations, the objective of the present study is to examine whether the perception of speed while driving on curves increases with the use of wider longitudinal markings compared to those established by traffic regulations. To address this objective, video

recordings were made of vehicles navigating 6 curves under 2 conditions: With standard longitudinal markings and with modified, wider markings. Subsequently, a survey was conducted with 2,419 participants. The participants were shown the videos and asked to identify in which segments they perceived greater vehicle speed. The findings revealed that the likelihood of perceiving greater speed on curves with wider markings was significantly higher in the following cases: Female participants, drivers who had not caused an accident or received a traffic ticket in the past 5 years, those with greater driving experience, higher vehicle speeds, viewing standard markings prior to the wider ones, navigating right-oriented curves, and nighttime driving conditions. These results demonstrate that the application of wider longitudinal road markings can, in general, enhance the perception of speed on curves. This effect has the potential to improve road safety by promoting slower driving behavior.

Vest, A., Stamatiadis, N., Clayton, A., & Pigman, J. G. (2005). *Effect of warning devices on curve operating speeds* (Report No. KTC-05-20/SPR-259-03-1F). University of Kentucky Transportation Center. https://rosap.ntl.bts.gov/view/dot/21621

The objective of this study is to evaluate the use of several warning signs and warning methods to identify those that have the greatest impact on reducing vehicle speeds when traversing a horizontal curve. Three sites were selected from a list of proposed sites for the testing of the various warning methods. Each warning treatment was installed and a five-day waiting period was allowed before operating speeds for the treatments were measured. The results of the various warning methods were mixed; however, some warning treatments were able to reduce operating speeds on a consistent basis. The most effective of these treatments were the transverse lines, the new combination Horizontal Alignment/Advisory Speed sign, and flashing lights on both the existing warning signs and new combination warning sign. It should also be noted here that for all three sites, a reduction in the average of the speeds over the 85th percentile speed was observed, indicating that most of the treatments have a reducing effect on the most unsafe driving, those traveling above the 85th percentile speed.

Yotsutsuji, H., Otazawa, T., & Kita, H. (2020). A simulation study on the pattern of speed reduction markings affecting driver's speed choice before curve entry. *Transportation Research Procedia*, *48*, 1296–1305. https://doi-org.slo.idm.oclc.org/10.1016/j.trpro.2020.08.154

Speed reduction markings (SRMs) on road surface consist of transverse marking lines with decreasing spacing in the direction of vehicle movement. SRMs installed on a straight lane adjacent to a transition curve section contribute to deceleration of the vehicle toward the curve. A leading vehicle's driver on SRM-installed lane may be exposed to accident risks due to shortage of deceleration and rear-end collision of a

following vehicle. To avoid such risks, a layout of spacing intervals among the marking lines of SRMs is required to be optimized according to a speed trajectory of the leading vehicle approaching the curve. The aim of our study is to examine the optimal layout pattern by use of numerical simulation of both the vehicle speed trajectory and the rear-end collision. We construct an optimal control model of driving behavior with speed perception, and we combine it with a car-following model. In the case of SRMs before a sharp bend, our numerical examples showed the results as follows: 1) The layout pattern in which a decreasing rate between the spacing intervals is greater in the end section on SRM-installed lane than in the remaining sections may produce a high risk of the rear-end collision, although the leading vehicle safely enters the curve. 2) The pattern in which the decreasing rate is zero in all sections on SRM-installed lane may produce an accident with which the leading driver meets within the curve, although the rear-end collision risk is very few. These results indicate that the layout pattern of SRMs affecting speed choice of the leading driver toward the curve must consider not only the vehicle speed trajectory of the leading vehicle but also the rear-end collision risk of the following vehicle.

Traffic Calming Measures for Speed Management

The following four publications from 2007 through 2021 do not have a primary focus of SPM at curves in rural communities but they do include discussion of these topics so are added as supplemental materials.

Albin, R., et al. (2016). *Low-cost treatments for horizontal curve safety 2016* (Report No. FHWA-SA-15-084), Pennsylvania Transportation Institute.
https://rosap.ntl.bts.gov/view/dot/50421/dot_50421_DS1.pdf

FHWA created the Low-Cost Treatments for Horizontal Curve Safety in 2006 (McGee and Hanscom, 2006). There have been many advances in highway safety since that initial 2006 guide. The purpose of this publication is to serve as an update to the 2006 Low-Cost Treatments for Horizontal Curve Safety. The primary audience for this publication is local transportation agencies. This publication provides information specifically relating to lower volume two-lane roads and the agencies that manage them. It will help transportation agencies and their construction crews understand the available countermeasures and how to select and apply them.

Finley, M. D., et al. (2021). *Traffic Control Device Analysis, Testing, and Evaluation Program: FY2020 Activities* (Report No. FHWA/TX-21/0-6969-R3). Texas A&M Transportation Institute.
https://rosap.ntl.bts.gov/view/dot/60219

This project provides the Texas Department of Transportation with a mechanism to

conduct high-priority, limited-scope evaluations of traffic control devices. Work conducted and concluded during the 2020 fiscal year included: (1) review of retroreflective raised pavement marker practices; (2) review of optical speed bar practices in horizontal curves; (3) review of traffic signal head backplate practices; (4) review of intersection conflict warning system practices; (5) development of guidance for the application of 6-inch pavement markings; (6) assessment of the effectiveness of work zone signing; and (7) assessment of the effectiveness of pedestrian crossing treatments at night.

Hallmark, S. L., Hawkins, N., & Knickerbocker, S. (2013). *Speed management toolbox for rural communities* (Report No. IHRB Project TR-630). Iowa Department of Transportation, Midwest Transportation Consortium. https://rosap.ntl.bts.gov/view/dot/26312

The primary objective of this toolbox is to summarize various known traffic-calming treatments and their effectiveness. This toolbox focuses on roadway-based treatments for speed management, particularly for rural communities with transition zones. Education, enforcement, and policy strategies should also be considered, but are not the focus of this toolbox. The research team identified treatments based on their own research, a review of the literature, and discussion with other professionals. This toolbox describes each treatment and summarizes placement, advantages, disadvantages, effectiveness, appropriateness, and cost for each treatment. The categories of treatments covered in this toolbox are as follows: horizontal physical displacement, vertical physical displacement, narrowing, surroundings, pavement markings, traffic control signs, and other strategies.

Katz, B. J. (2007). *Peripheral Transverse Pavement Markings for Speed Control* [Doctoral dissertation, Virginia Tech University]. ETDs: Virginia Tech Electronic Theses and Dissertations. http://hdl.handle.net/10919/27759

In the United States, speeding is considered to be a contributing factor in about 30 percent of fatal crashes (US DOT, 2000). In an attempt to reduce speeds on roadway segments where speed is considered to be a safety concern, various low cost countermeasures have been investigated. Such countermeasures include pavement markings that give a psychological appearance of narrowing and/or increasing speed have been considered as a relatively low-cost treatment. Perceptual cues are one potential method of influencing motorists to slow down, and ultimately, to save lives. These perceptual techniques might be useful at lowering speeds in a variety of driving situations such as work zones, curves, roundabouts, and toll plazas. Evaluations are required in order to determine the effectiveness of these various treatments at reducing speeds. This research project explored several possible perceptual countermeasures to

try on the approaches to curves for reducing speeds. It was ultimately decided to evaluate the effects of peripheral transverse lines in reducing speeds. Although there have been some limited evaluations of peripheral transverse markings in previous studies, no significant field evaluation has been performed and a recommended design for the markings has not been discussed. The projected results of the research effort is to determine pavement marking treatments with a high probability of success at reducing speeds, develop and design peripheral transverse markings based on site considerations, determine the effectiveness of the markings in the field, determine optimal pavement marking design using a driving simulator, and use a controlled research environment to finalize the design. This dissertation contributes to the body of knowledge on speed reduction research through the development of low cost speed reduction strategies, the design of peripheral transverse lines for varying geometric conditions, evaluation of these treatments in the field, in the simulator, and on a controlled roadway, and to finally compare the benefits of each of the evaluation approaches. In the field, peripheral transverse lines spaced at a frequency of 4 bars per second were evaluated in New York, Mississippi, and Texas. The markings were applied on approaches to curves in both rural and urban environments on both multi-lane and two-lane roadways. The authors concluded that overall, the pavement markings reduced speeds up to 59% compared to the baseline in the short term and 24% in the long term on overall vehicle speeds. When evaluating design alternatives of peripheral transverse markings, a follow-up study was performed and compared baseline conditions to markings spaced at a constant interval, exponentially closer, at two bars per second, and at four bars per second. The peripheral transverse lines were effective in reducing centerline encroachment; however, the results were inconclusive as to which particular marking spacing pattern was most effective. There was a large amount of variability in driving speeds using the driving simulator which made it ineffective at comparing designs. The third evaluation was performed at the Virginia Tech Smart Road in which reductions in speed were compared to the baseline at two locations. While one curve had large preview distances and no effect due to the treatments, speed reductions on a freeway ramp type of curve resulted in a speed reduction 42% greater than the reduction in the baseline condition. There are several advantages and disadvantages to evaluations in the field, simulator, and at a controlled research setting which are summarized in this dissertation. Overall, all three have potential of looking at different elements, but it was determined that variability when measuring speed in the driving simulator makes it more challenging as a tool for measuring speed reductions.

Questions?

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