

Synthesis of Traffic Calming Techniques in Work Zones



Final Report
January 2009

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| 16. Abstract Nationwide, over 1,000 fatalities and 40,000 injuries occur annually in work zones, which include both construction zones and areas where maintenance is performed. The majority (85%) of work zone accidents result from unsafe driver behavior, and vehicle speed is often a factor in work zone crashes. In order to address speed and driver behavior near work zones, roadway agencies have developed different traffic calming measures. The objective of this research is to summarize the effectiveness of different traffic calming treatments for reducing speeds in work zones. This project <ol style="list-style-type: none"> 1. identified work zone traffic calming treatments for which information has not been well summarized, 2. identified state of the art and new technologies for work zone traffic calming, and 3. synthesized research related to items 1 and 2 | | | | | |
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**Final Report
January 2009**

Principal Investigator

Shauna Hallmark
Associate Professor
Center for Transportation Research and Education, Iowa State University

Co-Principal Investigators

Neal Hawkins
Associate Director of Traffic Operations

Tom Maze

Professor

Center for Transportation Research and Education, Iowa State University

Research Assistants

Eric Fitzsimmons, Nicole Oneyear

Authors

Eric Fitzsimmons, Nicole Oneyear, Shauna Hallmark, Neal Hawkins, Tom Maze

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the Iowa Department of Transportation

A report from
The Center for Transportation Research and Education

Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103
Fax: 515-294-0467
www.ctre.iastate.edu

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1. BACKGROUND

1.1. Scope of Problem

Over 1,000 fatalities (National Work Zone Safety Information Clearinghouse 2007) and 40,000 injuries (FHWA 2007) occur annually in work zones nationwide. Work zones include both construction zones and areas where maintenance is performed. Speed is often a factor in work zone crashes and is a serious concern for roadway agencies. In order to address speed and, more generally, driver behavior, different traffic calming measures have been developed for use in work zones.

Although it is commonly believed that the victims of work zone crashes are construction workers, a nationwide study found that 84% of victims between 1994 and 1998 were vehicle occupants. In 1998, 58% of fatal crashes in construction zones occurred after dark. That is 8% more than the 50% of all fatal crashes that occur at night (Schmitz 2000). Recent statistics reported by the Federal Highway Administration indicate that over 40,000 people are injured each year from vehicle crashes in work zones and that 15% of the reported fatalities in work zones were non-motorists, including pedestrians, workers, and bicyclists. Furthermore 1,010 fatalities were reported in 2006, up 45% over the previous 10 years (FHWA 2008). The *2006 Fatality Analysis Reporting System* similarly reports that over 1,000 people were killed in construction or maintenance zones (Transportation Development Foundation 2008). A study conducted for the Georgia Department of Transportation found that 53% of fatal crashes occurred in work zones that were idle, and 34% occurred in work zones that were in progress (Dixon and Wang 2002).

Work zone crashes are caused by a variety of factors, such as driver error, distracting activities, inadequate visibility, poor road surface condition, roadway obstructions, inadequate traffic control, and improper management of material, equipment, and personnel in work zones. The majority (85%) of work zone accidents, however, are the result of unsafe behavior, such as traveling at unsafe speeds (Lindly et al. 2002).

The speed of a vehicle traveling through the work is determined by the driver's judgment of the environment. A posted speed limit in a work zone is determined in much the same way as a posted regulatory speed limit on a road, in that a traffic study, traffic control plan, and engineering judgment must be used to determine an appropriate speed at which the driver feels safe and is not tempted to push an unsafe speed through the work zone. When an engineer decides to reduce the work zone speed limit from the posted speed limit, two items must be taken into consideration: the number and severity of work zone crashes and the potential for crashes where speed related hazards exist (Garber and Patel 1994). Garber and Patel (1994) explain that these hazards could include hidden or unobvious work zone features, reduced work zone design speed, or unprotected work space where a misdirected vehicle could encounter danger.

A study conducted in 1964 found that crash rates are lowest for vehicles traveling near the mean speed of traffic (Stuster et al. 1998). Various other studies have concluded that vehicles traveling at low speeds are more likely to be involved in a crash than those traveling at high speeds (Solomon 1964; Cirillo 1968). Research completed by Lave and Garber and Gadiraju found speed variance to be a contributing factor to fatal crashes (Lindly et al. 2002). As a result, speed variance in work zones should also be a consideration.

Several measures have been well researched, resulting in varying degrees of effectiveness. Maze (2000) summarized a number of speed control measures, which have been implemented by different agencies, and conducted a survey of states to determine the state of the practice. The study found that flagging and police enforcement are effective in reducing work zone speeds, but these measures are expensive and sometimes impractical. The author also summarized studies on the use of additional regulatory signs; these were found to be ineffective by themselves, but the use of regulatory signs with flashing beacons did have some traffic calming effect. The study also evaluated reduction in lane width and drone radar and found mixed results. Other studies on speed feedback signs (Texas Transportation Researcher 2006a) and the use of temporary transverse rumble strips indicated that these measures were effective.

Other measures are not as well understood or not as widely applied. Decoy police vehicles, pavement markings, radar speed indicators, uniformed police officers, transverse speed bars, supplemental flagging devices, fluorescent orange sheeting (Dixon and Wang 2002), and marketing campaigns have been used. In some cases, little research has been done to evaluate their effectiveness, and in other cases studies have not been well summarized. Additionally, this information is often not summarized in a manner that agencies can easily use.

1.2. Overview of Project

The objective of the present research is to summarize the effectiveness of different traffic calming treatments for reducing speeds in work zones.

To accomplish this, the research

1. identified work zone traffic calming treatments for which information has not been well summarized,
2. identified state of the art and new technologies for work zone traffic calming, and
3. synthesized research related to items 1 and 2.

This work builds on earlier research by Maze (2000). The author conducted a literature review, summarized known information about strategies for reducing speed in work zones, and identified and described technologies that had been used to control speeds. The study found that flagging and the use of police enforcement strategies had the most positive impact but that these were expensive. The study also found that while many strategies had some success in slowing motorists down in work zones, none of the techniques were capable of reducing speeds to the levels desired in a work zone. Finally, the study included a survey to determine state policies regarding work zone speed reduction and management. The survey indicated that most of the

states that responded reduced speeds to 10 mph below the regular posted speed, while a few reduced the speed limit by 20 mph. Regulatory speed limit signs and police enforcement were the most common strategies reported to reduce speeds. When asked about the effectiveness of the different strategies, 7% of respondents indicated that they thought regulatory signs were effective in reducing speeds, and 70% felt that police enforcement was effective. Maze (2000) also reported that 18 of the 34 agencies had used changeable message signs, some used radar to detect and indicate speed along with the signs. The study also summarized agencies in the Midwest that have studied the effects of speed reduction strategies in work zones.

1.3. Summary of Information in Report

All available literature and information on traffic calming in work zones was reviewed and summarized. Vendors were also contacted to determine the state of the art in traffic calming practices. This report summarizes the available information in the following format:

- Section 2 discusses static signing practices in work zones.
- Section 3 discusses dynamic signing, such as changeable message signs or speed feedback signs.
- Section 4 discusses automated flaggers.
- Section 5 discusses public awareness campaigns.
- Section 6 discusses policy and enforcement.
- Section 7 discusses pavement marking treatments such as transverse bars, rumble strips, and wider pavement markings.
- Section 8 discusses intelligent transportation system (ITS) technologies.
- Section 9 summarizes the most current vendor technologies available.

Table 1-1 summarizes the information about the various technologies.

Table 1-1. Summary of work zone treatments

| Treatment | Speed reduction | Other benefits |
|--------------------------------------|--|----------------|
| Advance warning | 74% of drivers reduced speed at first sign or near work zone (Benekohal et al. 1992) | |
| Variable speed limit | <ul style="list-style-type: none"> ■ Mixed results, may have reduced speeds for vehicles at higher speeds (Lyles et al. 2004) ■ Nighttime decrease of 3-10 mph (Riffkin et al. 2008) | |
| Changeable or variable message signs | <ul style="list-style-type: none"> ■ 66% of survey respondents indicated they slowed with presence of signs (King et al. 2003) ■ Reduced speeds near sign by 6-7 mph but not sustained (Dixon and Wang 2002) ■ Reduction in 85th percentile speed of 2-9 mph (Sorrell et al. 2007) ■ 7 mph decrease in mean speed (Thompson 2002) ■ 2 mph reduction in 85th percentile speed (Brewer et al. 2006) | |

Table 1-1. Summary of work zone treatments (continued)

| Treatment | Speed reduction | Other benefits |
|------------------------------|---|--|
| Speed feedback signs | <ul style="list-style-type: none"> ■ 4 to 5 mph reduction mean speed (McCoy et al. 1995) ■ 5 mph decrease in 85th percentile speeds (Maze 2000) ■ 3.7 mph reduction mean speed (Meyer 2003) | |
| Drone radar | <ul style="list-style-type: none"> ■ 6 to 33% reduction in vehicles traveling above speed limit (MDSHA 2005a) ■ Decrease in % of vehicles traveling 15 mph over the posted speed limit (Pigman et al. 1989) ■ Reduced number of vehicles traveling more than 10 mph over the speed limit ■ 1 to 2 mph reduction (Fontaine and Hawkins 2001) ■ 3–6 mph decrease in mean speed (Benekohal et al. 1993) | |
| Automated flagger | No effect on approach speeds (Booker et al. 1987) | <ul style="list-style-type: none"> ■ Drivers know where and when to stop (Booker et al. 1987) ■ Can replace flaggers in some instances (MN/DOT 2000) |
| Public awareness campaigns | 0.2 to 1.8 mph speed reduction during daytime (Wang et al. 2003) | |
| Double fine | Found both increases and decreases in mean speeds (Ullman et al. 2002) | |
| Enforcement | 85% of responding states report reduction in speeds (Kamyab et al. 2003) | |
| Automated enforcement | No information | |
| Transverse pavement markings | <ul style="list-style-type: none"> ■ Decrease in 85th percentile speeds (Meyer 1999) ■ Up to 4 kph decrease (Hildebrand et al. 2003) | Increased safety to due to retro reflectivity |
| Temporary rumble strips | <ul style="list-style-type: none"> ■ Reduction in 85th percentile speeds (Meyer 2003) ■ Around 1 mph reduction in mean speed (Horowitz and Notbohm 2002) ■ Reduction of 2 mph in mean speed (Richards et al. 1985) | |
| Wider pavement marking | No information available | Better visibility of lane lines |
| Dynamic lane merger | No information available | <ul style="list-style-type: none"> ■ Found reduction in aggressive behavior (FHWA 2007) ■ Improved travel speeds (FHWA 2007) |
| Automated work zone system | | Felt rear-end crashes and congestion were reduced (FHWA 2007) |

2. STATIC SIGNING

This section summarizes signing strategies that notify drivers about an upcoming work zone or remind drivers about their speed.

2.1. Advance Warning

Posting regulatory and work zone speed reductions signs are common in most work zones and are specified in the *Manual for Uniform Traffic Control Devices (MUTCD)*. Advance warning typically takes the form of bright orange signs with black text indicating the distance to or length of roadwork areas.

Benekohal et al. (1992) investigated a four mile-long construction work zone, which mainly consisted of bridge repair, on a two-lane divided highway in Illinois to determine where different classes of vehicles slowed down. This labor-intensive study was conducted in the field using two video cameras. The researchers found that about 63% of all drivers reduced their speeds shortly after the first work zone speed limit sign, 11% of drivers reduced their speeds when they were close to the actual work zone activity, 11% of drivers remained at a constant speed, and the remaining drivers could not be classified. The researchers also found that, although speeds were generally lower, more than 70% of automobiles and 55% of trucks exceeded the work zone posted speed limit of 45 mph. The researchers recommended examining placement of work zone speed limit signs and suggested potentially placing more signs to slow vehicles down further upstream of the work zone (Benekohal et al. 1992).

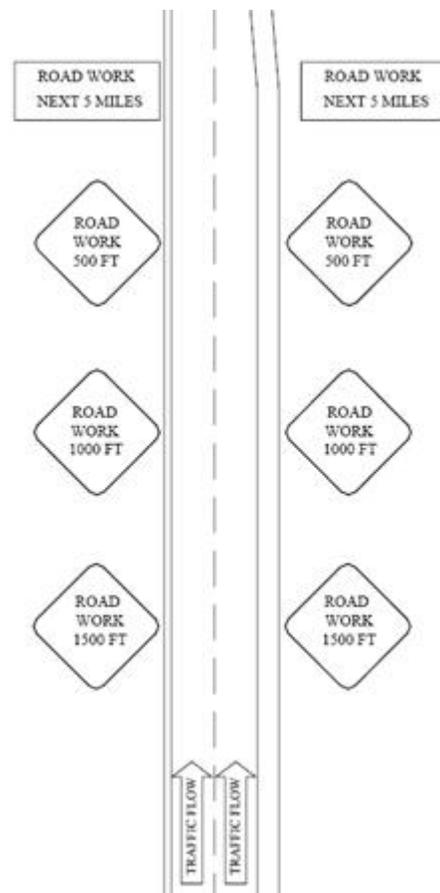


Figure 2-1. Typical advanced warning configuration (Texas Transportation Researcher 2006b)

3. DYNAMIC SIGNING AND RADAR UNITS

This section describes various dynamic and interactive devices that can reduce speeds through work zones and make drivers more aware of their behaviors.

3.1. Variable Speed Limit

Variable speed limits (VSLs) change as roadway conditions change. The VSLs are used to reflect current road and environmental conditions. They have been used during congestion, in inclement weather, and in active work zones. The intent is to keep drivers at a constant safe speed that reflects current conditions. The hypothesis is that motorists will better comply with realistic speed limits that reflect existing conditions. A study conducted in Michigan through a 19 mile work zone (Lyles et al. 2004) investigated the effectiveness of variable speed limit units deployed for four short duration times. Six to seven monitoring and display trailers were installed at 0.5 to 1 miles spacing, and vehicle speeds were recorded based on the nature of the road work. The measures of effectiveness included vehicle speeds and the location of the display trailer. The researchers report mixed results based on equipment issues. However, they concluded that the average speed of vehicles increased through the work zone and travel time increased, and limited data showed that the percentage of vehicles traveling at high speeds decreased while the system was operating (Figure 3-1).

Riffkin et al. (2008) studied the effectiveness of VSL signs in reducing driver speed. VSL signs were placed on I-80 in Utah during a pavement crack and seal project where both eastbound and westbound travel was restricted to one lane. Two variable speed limit signs were used in this study, one placed immediately before the construction zone and the other located about half-way into the construction zone. Speed was collected at five points, one before the construction zone and the other four within. Two different test setups were used. The first setup involved the VSL sign posting a speed limit of 65 mph at all times; the other setup set the speed at 55 mph during the day and 65 mph at night. Results showed statistically significant decreases in speed (3–10 mph) during nighttime with the use of a VSL sign as opposed to a standard static sign. Daily speeds were also reduced,



Figure 3-1. VSL in Michigan (FHWA 2004)

but the effect of the variable speed limit sign alone could not be determined due to the effects of congestion. The sign also resulted in a 1.5–5 mph decrease in speed variance during the nighttime (Riffkin et al. 2008).

3.2. Changeable or Variable Message Signs

Changeable message signs (CMS) or variable message signs (VMS) are traffic control devices that can display different messages to drivers to alert them to unusual driving conditions (Figure 3.2). A CMS relays information that is difficult to relay with static signing and is used to supplement other required signing (Opiela 2003). Researchers at the Texas Transportation Institute have studied the format of CMS using laboratory simulations. It was found that drivers strongly preferred alphanumeric formats (83%) to numeric formats (17%). Recognition levels were also 20% higher for alphanumeric formats. Drivers could best comprehend and remember information from two screens and four units. A unit is a piece of information that answers a simple question (Texas Transportation Researcher 2006a).

King et al. (2003) investigated user acceptance and understanding of VMS. The study used interviews and mail-in surveys to gather data from drivers at several locations downstream from the work zone. The study found that although almost all drivers could understand the message, only 78% were able to read the entire message. The researchers suggested that either traffic in adjacent lanes partially blocked the sign or the sign did not change quickly enough. The survey results were used to examine the influence of age and other demographic characteristics on driver response to VMS. A total of 66% of respondents said that the signs caused them to slow down. It was found that respondents under the age of 25 included the lowest percentage of people who slowed down. However, driver age did not seem to affect the perception of danger (King et al. 2003).



Figure 3-2. Changeable message sign displaying speed message (FHWA 2008)

Some CMS units are changeable message signs with radar (CMR), which display warning messages when a vehicle is traveling at an unsafe speed. The standard message on the CMS unit changes when a vehicle is traveling faster than the programmed speed, typically 3 mph above the speed limit. A study conducted in Virginia tested this speed reduction strategy using four separate messages at seven work zones on two interstate highways. The messages used included: “YOU ARE SPEEDING, SLOW DOWN,” “HIGH SPEED, SLOW DOWN,” “REDUCE SPEED IN WORK

ZONE,” and “EXCESSIVE SPEED, SLOW DOWN.” All four were found to effectively lower the number of vehicles speeding. A similar study conducted in Georgia found an average

reduction in speed of 6–7 mph immediately adjacent to the unit. However, the reduction in speed did not extend into the work area itself, potentially due to the physical site and distance between the CMR unit and the active worksite. The study concluded that although CMR units lack the novelty factor of other devices and appear to provide long-term speed reductions, there is no quantitative speed reduction observed in the active work area (Dixon and Wang 2002).

A study conducted by Sorrell et al. (2006) at four work zones in South Carolina tried to determine the effectiveness of a CMR unit and the most effective of four message sequences. For the message sequence testing, there was a default message followed by four other messages that were tested. The default message was “STAY ALERT/WORK ZONE.” Sequence 1 displayed “YOU ARE SPEEDING/SLOW DOWN,” and sequence 2 displayed “YOUR SPEED IS ___ MPH/SLOW DOWN.” Sequence 3 displayed “YOUR SPEED ___ MPH,” and if the driver was not speeding the sequence then displayed “THANKS FOR NOT SPEEDING,” while if the driver was speeding the sequence displayed “SLOW DOWN.” The fourth sequence read “YOU ARE SPEEDING/MINIMUM FINE \$200.” Data were collected at three locations: the first was between 1,000 ft and half a mile upstream of the CMS, the second was within 300 ft downstream of the CMS, and the third was 1,200 ft downstream of the CMS. To gather the speed data, a laser gun was used at the first location and radar guns were used at the other two locations. Collections were done in two phases: phase 1 involved all message sequences and phase 2 involved further testing of sequences 3 and 4.

Results for phase 1 indicated that 85th percentile speeds decreased from 2–9 mph, varying greatly between locations, for all four signs. Mean speed decreased between stations 1 and 2 at all locations and then either stayed constant or decreased again between stations 2 and 3. Results for phase 2 concluded that the average 85th percentile speed dropped about 10 mph between stations 1 and 2 and about 4–5 mph between stations 1 and 3 for both messages (sequences 3 and 4). Between stations 1 and 2, mean speed was found to be reduced between 8 and 11 mph, and between stations 1 and 3 mean speed was reduced by about 3 mph. It was also found that the percentage of drivers speeding decreased by about one-half between stations 1 and 3, from a little over 10% at station 1 to approximately 5% at station 3.

The Maryland State Highway Administration (MDSHA 2005b) evaluated the effectiveness of two portable changeable messaging signs (PCMS) capable of speed display in advance of a work zone along the Baltimore Beltway (I-695). The signs were placed 4,165 and 1,200 ft upstream of the work zone. The PCMS at both sites displayed the messages “Entering Work Area” and then “Stay Alert” for vehicles traveling between 20 and 52 mph. For vehicles traveling 57 to 85 mph, the PCMS displayed the messages “YOUR SPEED ___ MPH” and “OBEY SPEED LIMIT 50 MPH.” The researchers evaluated non-congested speed data before implementation of the signs; one week, three weeks, five weeks, and seven weeks after implementation; and one week after the signs were removed. The results indicated that average speeds were reduced by 4.5 to 7.8 mph one week after the signs were installed, and then speeds increased over time. The study also found a large decrease in the percentage of vehicle exceeding the posted speed limit by 10 mph one week after implementation, with a 45% reduction at the first site and a 59% reduction at the second. The reduction also decreased over time, but at seven weeks a 21% reduction was still noted.

Thompson (2002) also studied the effectiveness of using a CMS to reduce driver speeds in work zones. A radar-activated CMS on a trailer, which included a solar-powered backup that can be controlled via a hand-held controller or a laptop computer, was placed at the end of taper where the left lane was closed. The site was a southbound lane on an I-95 bridge located near Waterville, Maine. The CMS, when active, would display either the speed limit when the vehicle was not speeding or the phrase “YOU ARE SPEEDING!!!” when the vehicle was speeding. Data were collected using a time vs. distance method for determining speed. The “before” data were collected with the sign in place but not active, data were then collected again right after installation, and data were finally collected several weeks later to measure the sign’s long-term effect.

Results from this study indicated that when the sign was active, the percentage of speeding vehicles decreased about 11%, from 65% to 54%, with the average speed decreasing 7 mph, from 55 mph to 48 mph. Data also showed that the sign was just as effective, if not more so, during the second data collection period. The mean speed during the first data collection was 54.5 mph, and during the second data collection it was 41.9 mph. This change may have been due to an increase in police patrol in the work zone, which was unrelated to this study (Thompson 2002).

A study conducted by Brewer et al. (2006) investigated the use of CMS and work zone speed limit signs surrounded by orange reflective tape. Two sites were selected: one site was a rural highway and the second was on a U.S. highway within a small community. Field testing involved a three-day before and a three-day after treatment speed study at six data collection locations using piezometric counters. A PCMS with radar either displayed “GIVE US A BRAKE” if the driver was not speeding or “SLOW DOWN” and “YOUR SPEED ___” if the driver was speeding. The sign was first placed at the merge taper, then removed, and then placed at the merge taper and near the midpoint, then removed. Then, posted speed limit signs with reflective tape were installed. Data were analyzed using a statistical model. The researchers found that the posted speed limit sign with a reflective orange board was less effective than the CMS in reducing vehicle speeds, and the CMS showed greater effectiveness when two signs were present in the work zone. Having two signs reduced the 85th percentile speed of passenger cars by 2 mph and trucks by 1 mph, and both speeds were statistically significant at the 95% confidence level (Brewer et al. 2006).

3.3. Speed Feedback Signs

Speed feedback signs are interactive signs that measure and display an individual vehicle’s speed. Speeds are usually measured using radar. These signs typically differ from CMS in that speed feedback signs can only display speed, but several have the capability of displaying other text, such as “Slow Down.” These signs also differ from CMS in that a speed feedback sign always has a mechanism to measure speed, while a CMS may or may not have that capability.

McCoy et al. (1995) investigated the effects of work zone approach speeds using two speed monitoring displays on a four-lane divided highway in South Dakota. The site was between an on-ramp and an off-ramp. The two speed monitoring displays were placed just over 300 ft prior to the work zone taper facing oncoming traffic. Along with the lane closure, the researchers

included the effects of a highway on-ramp, which crossed the work zone area and entered into the travel lane. Video detection was set up to monitor the on-ramp to determine whether entering vehicles affected the vehicles in the travel lane traveling through the work zone. Three sites were established to study the approach speeds using tape switches: 4,000 ft prior to the taper, at the beginning of the taper, and at the end of the taper, which was 672 ft after the second site. Speed data were collected before and after the speed monitoring displays were installed. Data were collected for one day for each period. Using a general linear analysis, researchers found that when the speed monitoring displays were present, the mean speed was reduced 4 to 5 mph and the percent of vehicles traveling at excessive speeds were reduced by 20% to 40% (McCoy et al. 1995). Field tests completed by the Texas Transportation Institute found that the presence of devices displaying a driver's speed increased compliance rates by 10% to 27% (Texas Transportation Researcher 2006a).

Maze (2000) evaluated how speed control devices impacted vehicle speeds and speed uniformity through a work zone on I-35 in Iowa. This site consisted of a left lane closure with a crossover leading into two-way traffic. The device tested, according to the report, was a "large white box which used K-band radar and two 18 in. LED characters, which are visible in direct sunlight from up to 1,000 ft away." The device was placed 2,250 ft upstream of the taper, and two traffic data collection trailers were placed at 1,500 and 500 ft upstream of the taper. Speed data were collected for two days before and four days after the speed display was installed. Speed data for the last four days (the "after" study) were collected under two modes. One of these modes was just having the radar active without the sign displaying the vehicles' speeds, and the other was to have the radar active and show the speeds. The radar-only mode was used to evaluate the radar's effect on individuals using radar detectors. From the data, it was determined that mean speeds decreased about 3 mph, which was not statistically significant at the 0.05 level of significance, and 85th percentile speeds decreased by 5 mph. The study also indicated that the number of vehicles complying with the speed limit increased (Maze 2000).

Meyer (2003) studied the long-term effectiveness of a speed display on the northbound lane of a US 40 interchange in Kansas. The device was placed on a rural two-lane highway on Kansas Route 10, located west of Lawrence, Kansas. Figure 3-3 shows the device, which consists of a trailer mount containing a stalker radar speed sensor, backlit display, and strobe flash. The device works such that when the threshold speed is attained, the strobes are activated. Data were collected for one hour each weekday (between 6:30 a.m. and 8:30 a.m.) from July 16th to September 6th 2002, except for August 6th. The speed display was placed in the same place each day. An observer (or sometimes two) was located so that data were taken either 100 ft upstream or 400 ft downstream of the speed display. A radar-detector detector was used to pinpoint vehicles that used a radar detector. Data from these vehicles were compared to data from vehicles



Figure 3-3. Speed display (Meyer 2003)

without radar detectors to see whether radar detection or displaying vehicle speeds affects a driver's response more.

Results indicated that decreases in mean speed, 85th percentile speed, and percentage speeding were all found to be statistically significant at a confidence level of 95%. The mean speed decreased by 3.7 mph. It was found that, with the display in place and active, compliance with the speed limit increased up to nearly 30%. The comparison of the effectiveness of the display from the first week to the end of the third week indicated that there was no statistically significant difference in any speed parameter. Finally, it was found that the presence of a radar detector in a vehicle, when compared to vehicles without radar detectors, produced no statistically significant difference in mean speed, 85th percentile speed, or the percentage of vehicles speeding. While not conducted in a work zone, this study shows the effectiveness of the long-term use of speed feedback signs, which could be applicable to a work zone (Meyer 2003).

McCoy and Pesti (2002) investigated the effectiveness of a condition-responsive work zone traffic control system on I-80 between Lincoln and Omaha, Nebraska. This study included three CMS located 1.13, 3.13, and 7.83 miles ahead of the work zone. These signs detected slow moving or stopped traffic at the approach to the work zone and provided a two-phase message for drivers upstream. The two signs farthest away from the work zone were blank if traffic conditions did not warrant their use, and the sign closest to work zone warned of a lane closure ahead. When traffic conditions warranted the use of the two upstream signs, they were turned on and displayed the road work advisory followed by the actual reduced speed ahead. Vehicle speeds and volume were collected using cameras on overhead bridges. A multiple regression analysis showed that when traffic density was low, the signs showed little effectiveness. However, when traffic density was higher and the signs came on more frequently, a speed reduction resulted. The two signs closest to the work zone were effective under these conditions, while the sign farthest away from the work zone showed no effectiveness (McCoy and Pesti 2002).

3.4. Mobile Speed Enforcement

Mobile speed enforcement refers to portable devices, such as video or static image cameras, that can identify and record vehicles that exceed the posted speed limit or that are driving recklessly. A study conducted by Benekohl et al. (2006) evaluated the effectiveness of mobile automated speed enforcement in a work zone located in St. Clair County, Illinois. A speed camera van was located prior to the work zone, and the researchers investigated whether and how the system reduced vehicle speeds at the van and 1.5 miles after the van using video cameras downstream to investigate spatial effect. The speeds of 100 vehicles were recorded and reduced for the following categories: free flowing vehicles, platooned vehicles, and heavy vehicles in shoulder and median lanes. The researchers found that, generally, vehicles did not exceed the posted 55 mph by more than 10 mph around the speed camera van, and the reduction of the mean speed was between 3.2 to 7.3 mph for all vehicle categories. The study also indicated that the free flowing vehicles and heavy vehicles showed a statistically significant decrease, from 40% to 8% of vehicles exceeding the posted speed limit, close to the speed camera van. The researchers concluded mixed results for the ability of the automated enforcement to determine spatial effects because the speeds were not significant.

3.5. Drone Radar

Another technology used to interact with drivers is a drone radar system (Figure 3-4), which is a small, lightweight, weatherproof device that emits a short-range radio signal that activates commercially available radar detectors. The assumption is that when a vehicle's portable radar detector is triggered, signaling possible police enforcement, the driver will slow to or below the posted speed limit (Fontaine and Hawkins 2001). The Maryland State Highway Administration reported that drone radar systems were very effective in reducing the number of vehicles traveling at excessive speeds. The number of vehicles traveling above the speed limit was reduced by 6% to 33%. However, a disadvantage is that only the small percentage of drivers, those with a radar detector system, are targeted (MDSHA 2005a). Drone radar can also become ineffective when drivers realize no police enforcement is present.



Figure 3-4. K-band drone radar (Fontaine and Hawkins 2001)

Pigman et al. (1989) studied the use of drone radars as a speed reduction device on I-75 in northern Kentucky, without the presence of a work zone. The study area has historically had high crash rates, and it was assumed that drivers traveling at excessive speeds would slow down because of onboard radar detectors. Speed was collected at two locations by use of embedded loops connected to automated traffic recorders and throughout the study area using a time-distance method. This study was conducted over a 70 day period, in which the drone radar would operate for specified days, and increased police enforcement would operate while the drone radar was operating on specified dates. Pigman et al. found that drone radar was statistically effective in reducing the number of vehicles traveling in excess of 15 mph over the posted speed limit of 55 mph. It was also found that increased enforcement along the study corridor statistically reduced the mean speed when the drone radar was operating as well (Pigman et al. 1989).

At highway work zones, Freedman et al. (1994) studied the effects of drone radar in reducing crash risk by encouraging a uniform speed. The study also investigated the use of drone radar at high-crash rate sights identified by the Missouri State Highway Patrol. Speeds were recorded at 12 long- and short-term work zone sites in Missouri, where the posted speed limits ranged from 65 mph to 45 mph, in both urban and rural settings where geometry was level and straight. Speeds at each site were collected at two points. The first data collection and drone radar point was located at the speed reduction point typically 0.4 miles upstream of the work zone and lane closure point. The second point was well within the work zone (0.2 to 0.8 miles within long zones), or 0.8 downstream of the high-crash location. Speed data were collected for eight hours for a single day at each site using a commercially manufactured laser speed measurement system. A before and after study of vehicle speeds found that mean speeds were moderately lower but statistically significant, and in some locations the decrease was greater for trucks. The researchers also noted that although moderate reductions in mean vehicles speeds were observed, the number of vehicles speeding, especially heavy vehicles traveling more than 10 miles per hour over the posted speed limit, was found to be reduced (Freedman et al. 1994).

A one-mile radius K-band drone radar system was tested by Fontaine and Hawkins (2001) on both two-lane and four-lane rural short term work zone projects. Results found that the system provided small reductions in the average speed, ranging from -2 mph before the taper and -1 mph through the work zone (Fontaine and Hawkins 2001).

Research into the number of drone radars needed in a work zone to slow vehicles' speeds was conducted in rural Illinois by Benekohal et al. (1993). This study consisted of three experiments on a four-lane divided highway, in which one lane in each direction was closed. The three experiments included recording speed with no radar device present, recording speed with one radar gun present, and recording speeds with two radar guns present. Conversations between truckers were also monitored using a CB radio. Data were collected for the control experiment (no device present) during the hours of 10:00 a.m. to noon, and data for the two experiments with radars were collected from 1:40 to 4:25 p.m. The researchers found that the drone radars caused a 3–6 mph decrease without police presence. It was also found that when truckers discussed the possibility of police presence in a work zone, the increased level of communication led to an increase in awareness of speeds. The researchers concluded that drone radars worked well for short distances, but found that communication that related to the possibility of police presence played a more important role in decreasing speeds (Benekohal et al. 1993).

4. AUTOMATED FLAGGER ASSISTANCE DEVICE

Although not technically speed reduction devices, automated flaggers are described here because they can calm traffic that is required to stop. Booker et al. (1987) evaluated two devices that were simultaneously intended to improve the safety of the flagger when lane closure occurred due to work zone activity. The first device tested was a 12 in. wide by 100 ft long temporary rubber stop bar located where a traditional flagger would hold cars before entering the work zone. Traditionally, stop bars are found at major and minor intersections where a traffic control device can be found, and stop bars give the driver a visual cue about where to stop the vehicle. The second device studied included an oversized sign paddle. This device consisted of two signs mounted back-to-back on a freestanding wooden structure (Figure 4-1), which could be rotated depending on vehicle motion.

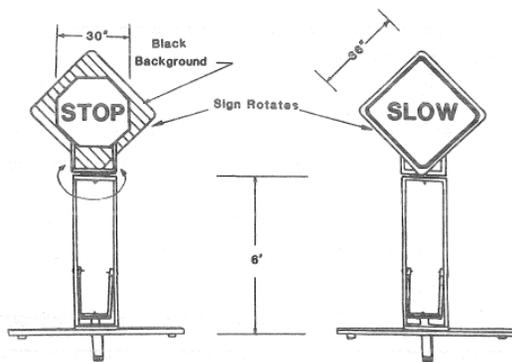


Figure 4-1. Stop/slow paddle device (Booker et al. 1987)

Both devices were evaluated in Port Arthur, Texas, on a two-lane, two-way rural highway that averaged 7,000 vehicles per day. Appropriate advance warning devices were deployed prior to the flagging devices. The advance warning included Road Construction Ahead, Be Prepared to Stop, One Way Traffic Ahead, and Flagman Ahead. Three types of data were collected over a two-day period for two hours: vehicle stopping points at work zone approaches, vehicle through speeds at work zone approaches, and vehicle approach speeds to the work zone. The results indicated that the temporary stop bar and oversized paddle sign helped drivers know when and

where to stop, although it was found that the vehicle approach speeds were not affected. The researchers believed that the drivers approached the work zone at a speed they felt comfortable with, no matter the device in place (Booker et al. 1987).

In a study conducted by the Minnesota Department of Transportation (Mn/DOT 2000), the effectiveness of the autoflagger as a substitute for traditional flagging methods was determined. The device was tested at five different sites throughout Minnesota from 1996 to 1997. The sites included the Winona Bridge, Wabasha Bridge, MNTH 96 west of Stillwater, the St. Louis River Bridge, and the Jackson Street Bridge, all of which are two-lane roadways. At each site, an AUTOFLAGGER device was placed at each end of the work zone, with a flagger in close proximity to each device. The flaggers used hand signals to make the drivers aware the AUTOFLAGGERS were more than just stop signs. An AUTOFLAGGER, shown in Figure 4-2, consists of a Stop/Slow sign with a flashing red beacon attached to the top. The portion that says “Stop” in Figure 4-2 then rotates into a sign that reads “Slow” (Figure 4-3).



Figure 4-2. AUTOFLAGGER (Mn/DOT 2000)



Figure 4-3. AUTOFLAGGER rotating (Mn/DOT 2000)

At each site, a motorist survey card was handed out to the first driver stopped in each queue. This survey asked questions about the driver's perception and recommendations for the use of the sign. Also, an observer from the Mn/DOT Office of Traffic Engineering took data about the motorists' response, operation of equipment, and actions of the flaggers. A vehicle count sheet was also handed out to workers that asked about the operation of equipment and for a count of the vehicles passing through the work zone. The results of the survey, observer data, and vehicle count sheet all recommended that the AUTOFLAGGER was a useful tool that, when used correctly, helps make the work zone safer for flaggers. In addition, the observers came to the conclusion that the AUTOFLAGGER caused no additional confusion to the work zone (Mn/DOT 2000).

5. PUBLIC AWARENESS CAMPAIGNS

In a 1998 report that suggested measures for improving safety in work zone projects, the Federal Highway Administration (FHWA) recommended innovative signs. The report stated that an attention-getting sign would further enhance safety by getting drivers' attention and reducing their speeds (FHWA 1998).

5.1. Various Agencies

In an effort to slow drivers down in work zones, the City of Sacramento, California, setup "The Tony Pontiliana Work Zone Safety Awareness Campaign," which included radio and television advertisements along with special signs that are deployed in work zones (Figure 5-1). The funding needed to launch this program was privately raised, and the city in 2007 declared the month of April "Work Zone Safety Awareness Month" (City of Sacramento 2007). Similar signs were used in Pennsylvania starting in 2000. Other techniques used in Pennsylvania include a series of billboards and television and radio public service announcements. Another technique involves including work zone safety training in high school driver's education courses (Schmitz 2000).



Figure 5-1. Innovative work zone speed signs (City of Sacramento 2007)

A study conducted by Wang et al. (2003) evaluated multiple work zone speed countermeasures, including an innovative message sign that displayed "My Daddy Works Here, Drive Slowly." The research team selected three research sites in Georgia to study, and the innovative sign was placed at two sites. Speed data were collected using Numetrics Hi-Star devices before, immediately after, and two or three weeks after implementation of the sign. The research team used a two-sample t-test and Turkey's HSD test to evaluate the immediate influence. The sign resulted in 0.2 to 1.8 mph speed reduction at one site during daylight hours, and little effect at the second sight. It was also concluded that the innovative message sign had no effect during nighttime conditions (Wang et al. 2003).

The National Work Zone Safety Information Clearinghouse (http://www.workzonesafety.org/public_awareness) provides a list of campaign programs that have been developed at various federal, state, local, and private agencies, as shown in Figure 5-2.

| <u>State Agency</u> | <u>Campaign Name</u> |
|--|--|
| Alaska | <u>"Pay Attention. Listen to the Signs. Don't Pay Double Fines."</u> |
| Alaska | <u>"Safety Check"</u> |
| American Society of Safety Engineers | <u>North American Occupational Safety and Health Week</u> |
| American Traffic Safety Services Association | <u>National Work Zone Memorial</u> |
| American Traffic Safety Services Association | <u>Work Zone Traffic Violator Awareness Program</u> |
| Arizona | <u>"Highway Hawk"</u> |
| California | <u>"Slow for the Cone Zone"</u> |
| Colorado | <u>Chill: Changing the Way We Drive</u> |
| Connecticut | <u>Operation Big Orange</u> |
| Connecticut | <u>Work Zone Safety Awareness Campaign</u> |
| Delaware | <u>Vesting of Delaware Kicks off 2008 WZS Campaign</u> |
| Georgia | <u>"Slow Down. It Won't Kill You"</u> |
| Illinois | <u>Work Zone Safety Calendar Contest</u> |
| Kansas | <u>"Give 'em a Brake"</u> |
| Kansas | <u>"Safer Driving, Safer Roads"</u> |
| Kentucky | <u>"Drive Smart"</u> |
| Louisiana | <u>TIMED 2 Drive Safe</u> |
| Louisiana | <u>"Geaux Orange: Drive Safe on the Huey"</u> |
| Maine | <u>"Backseat Driver"</u> |
| Michigan | <u>"Give 'em a Brake"</u> |
| Minnesota | <u>"Stay Back. Stay Alive"</u> |
| Minnesota | <u>Work Zones. Pay Attention or Pay the Price.</u> |
| Missouri | <u>MoDOT Drive Smart Campaign</u> |
| Montana | <u>Transportation Awareness Program</u> |
| Nebraska | <u>"When You're in the Driver's Seat, You Make the Difference!"</u> |
| Nevada | <u>"Give 'em a Brake"</u> |
| Nevada | <u>"The Flagger Moms of Orange Cone Hell"</u> |
| North Carolina | <u>NCDOT Work Zone Safety Program</u> |
| Oklahoma | <u>Work Zone Awareness Week</u> |
| Oregon | <u>Work Zone Public Service Campaigns</u> |

Figure 5-2. Public awareness campaigns (Source: National Work Zone Safety Information Clearinghouse 2007)

| <u>State Agency</u> | <u>Campaign Name</u> |
|---------------------|--|
| Pennsylvania | <u>"Slow Down - My Mommy Works Here" and "Slow Down, My Daddy Works Here."</u> |
| South Carolina | <u>"Let 'em Work, Let 'em Live"</u> |
| South Carolina | <u>"Take the Pledge - Wear the Pin"</u> |
| South Carolina | <u>"The Children"</u> |
| South Carolina | <u>Work Zone Safety High Visibility Enforcement Campaign</u> |
| Tennessee | <u>Get in the Zone</u> |
| Texas | <u>Give Us a Brake</u> |
| Texas | <u>Know Your Vital Signs</u> |
| Virginia | <u>Teaching Teens About Work Zones</u> |
| Washington | <u>Give 'em a Brake</u> |
| Washington | <u>Give 'em a Brake</u> |
| West Virginia | <u>Work Zone Safety</u> |
| Wisconsin | <u>"Trooper Talk"</u> |
| Wisconsin | <u>Impact / Zone</u> |

Figure 5-2. Public awareness campaigns (continued)

5.2. Iowa Department of Transportation

In 2007 the Iowa Department of Transportation (Iowa DOT) developed a public service work zone outreach program called "Sweet Ride on the Safe Side." The program was sponsored by the Iowa DOT, central Iowa television station KDSM Fox 17 (<http://www.kdsm.com>), Charles Gabus Ford (<http://www.gabusford.com>), and others. The outreach program provided a website that featured information about the program and about work zone safety, as shown in Figures 5-3 and 5-4. A target audience that included young drivers 14 to 24 years of age could view a work zone safety video or other information on the website: <http://sweetridecontest.com>. After viewing the video or reading the other information, site visitors could take a short quiz. If they scored 100% on the quiz, visitors were entered in a contest to win a 2008 Ford Fusion. Visitors could take the quiz as often as they liked but were only entered in the contest once. The prize was awarded by a random drawing at the end of the contest.

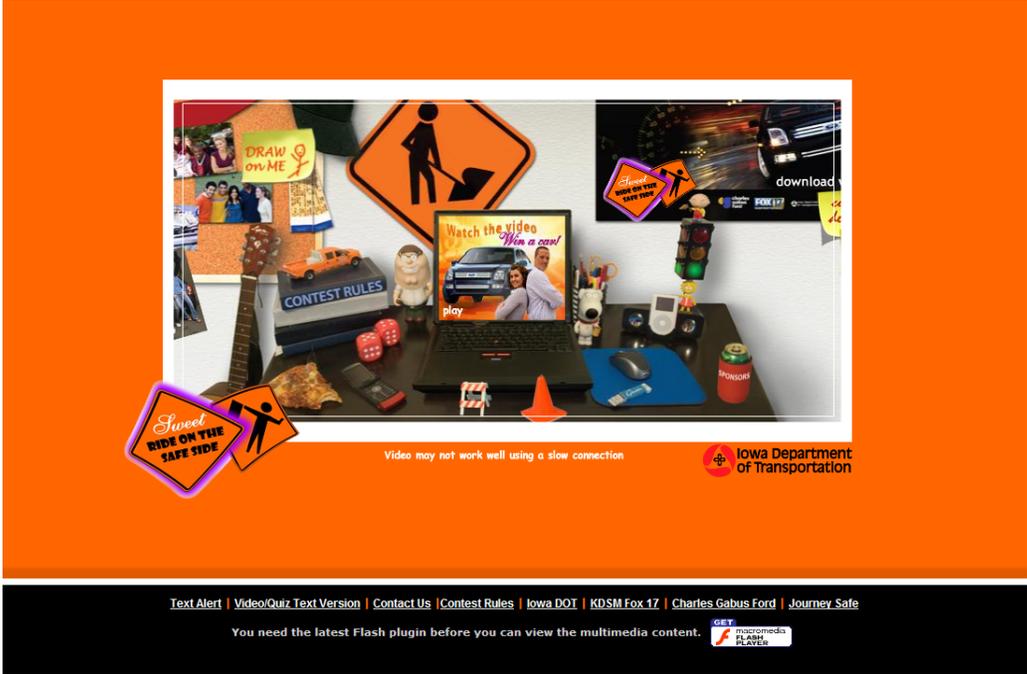


Figure 5-3. Sweet Ride on the Safe Side website

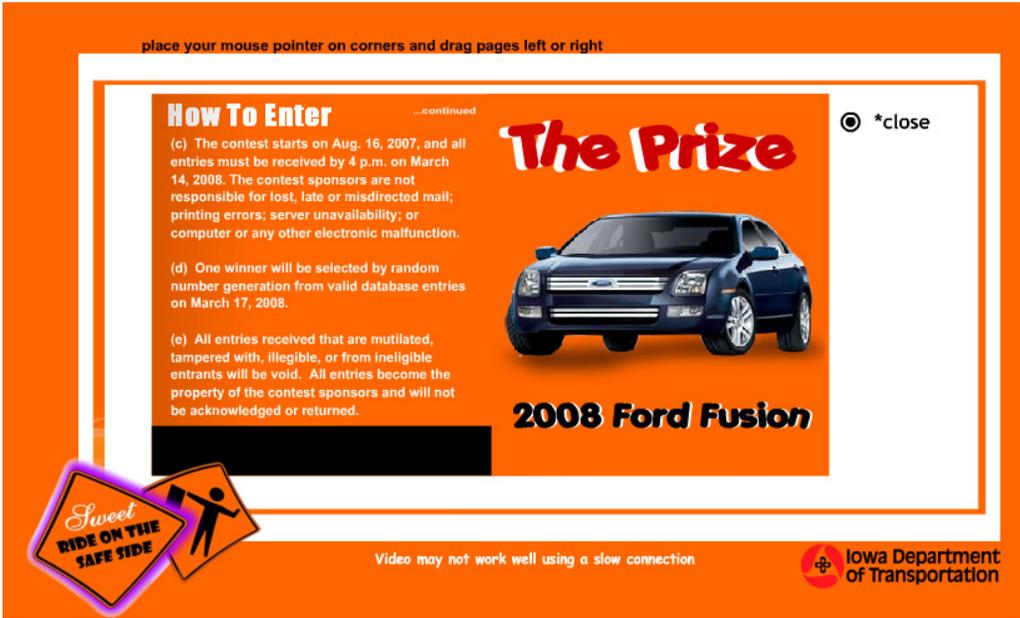


Figure 5-4. Program rules for Sweet Ride on the Safe Side

6. POLICY AND ENFORCEMENT

This section describes strategies, policies, and devices that help enforce posted speed limits and other traffic laws in work zones.

6.1. Double Fine Law

In 1998, the Texas congress implemented a double-fine law, which doubles the fines for all traffic violations in work zones. Ullman et al. (2000) investigated the effectiveness of the double-fine law in reducing work zone speeds. A before and after study in ten Texas work zones between November 1997 and May 1998 investigated whether vehicle speeds decreased in the work zones when the new law was implemented. Data were collected for 125 free flowing vehicles at each site during off- and on-peak hours in both traffic directions. The researchers found that the average speed at two sites decreased 4 mph and at two sites increased by 6 mph. Additionally, the average speeds at six of the ten sites were statistically unchanged, with similar trends resulting from an investigation of the 85th percentile speeds.

6.2. Regular Enforcement

Stationary or mobile police enforcement has been shown to be an effective measure for reducing vehicle speeds through work zones. A stationary officer usually located at the beginning or end of the work zone enforces a small targeted area. A mobile or circulating police officer covers larger area but has shown to be less effective in reducing work zones speeds (Richards et al. 1985).

Kamyab et al. (2003) studied the effectiveness of police presence on increasing safety in work zones. First, a survey of state departments of transportation's (DOTs') use of law enforcement in work zones was conducted. Surveys were sent out to all 50 DOTs and 7 turnpike agencies, with 28 DOTs responding. Results showed that 85% of responding states saw a reduction in speeds when enforcement was used, and 69% believed that safety was improved with the enforcement presence. Only five states had quantifiable results showing that police presence increased safety. The second part of the study examined construction projects on I-35/80 in Iowa. Multiple improvements were performed on a section of the interstate during two different periods, approximately a year apart. During the first period of construction, no extra law enforcement was used. During the second period, law enforcement was presented in 4–9 hour shifts. A decrease of 26 crashes was observed between the two periods (Kamyab et al. 2003).

6.3. Automated Enforcement

Automated law enforcement usually uses a traffic camera to capture pictures of vehicles and drivers who do not obey speed limits, signs, or traffic signals. Automated law enforcement devices for recording speed limit violations have a threshold speed: when a vehicle exceeds that

speed, the device snaps a picture of the speeding vehicle. The picture captures the license plate number, which is then used to identify the owner, who is sent a ticket. Automated speed enforcement is similar to red light running cameras. The Washington State Department of Transportation (WSDOT 2008) reported that it had started a pilot project using automated speed enforcement in construction zones on I-5. Automated enforcement has also been used in a work zone in Chicago (Agnew 2007).

7. IN-LANE TREATMENTS

This section describes pavement markings and other treatments that can help reduce speeds in work zones.

7.1. Transverse Pavement Marking Bars

Transverse pavement marking bars, sometime referred to as peripheral transverse bars, transverse strips, or optical bars, are pavement markings placed perpendicular to the flow of traffic. They are of varying sizes and patterns. Meyer (1999), for example, evaluated transverse markings 24 to 42 inches wide that stretch across the roadway. (This research will be described below.) Hallmark et al. (2007) evaluated transverse bars as entrance treatments to rural communities. These lines were 12 in. (parallel to lane line) by 18 in. (perpendicular to lane line), as shown in Figure 7-1. The bars for this type of marking are often either placed in sets or in a pattern in which the bars converge, giving drivers the perception that are traveling faster than they are or that they are accelerating (Hancock and Riessman 2004). Several studies have been conducted that investigate using peripheral transverse bars to reduce vehicle speed on highway exits and sharp curves (Katz et al. 2006).



Figure 7-1. Transverse bars

Meyer (1999) studied the effectiveness of optical pavement marking bars as a means to alert drivers of an approaching work zone, reduce the approaching vehicle speeds, and maintain a lower speed over a several-kilometer work zone. A divided highway segment west of Topeka, Kansas, was selected that had an annual average daily traffic (AADT) of 18,000 vehicles per day, 20.5% of which were estimated to be heavy vehicles. The work zone selected was a reconstruction project where both directions of traffic were to be carried on either the eastbound or westbound lanes. Traffic was separated by tubular channelizers and reflective bricks. Three patterns were used in this study, including a leading pattern, primary pattern, and work zone pattern. Leading up to the deceleration area (primary pattern), the leading pattern bars had consistent dimensions of 9 ft wide by 3.5 ft wide and a consistent spacing of 20 ft between bars. The primary pattern consisted of 29 bars that ranged from 42 in. to 24 in. wide (longitudinal) and converged at an estimated deceleration rate of 1 mph per second. The work zone pattern consisted of four sets of six bars that were spaced 500 ft between sets. All three patterns used in this study are illustrated in Figure 7-2.

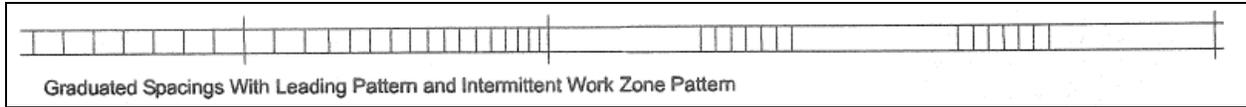


Figure 7-2. Leading, primary, and work zone bar pattern (Meyer 1999)

Data were collected using pneumatic road tubes at 10 specified locations within the treatment. Effectiveness was determined by a change in 85th percentile speed. The researchers found that the optical bars reduced speeds and speed variations in situations that require drivers to decelerate from highway speeds to accommodate a highway work zone project (Meyer 1999).

Work zone traffic calming research using transverse bars was also investigated by Hildebrand et al. (2002) at a rural highway site in New Brunswick, Canada. A simple before and after speed study was conducted over two days during the daytime and nighttime hours, and data sets were comprised of around 100 vehicles in the day and 50 vehicles during the night. Speed measurement locations were upstream, immediately upstream, and downstream of the treatment, and speeds were recorded for two days, one of which was close to the treatment installation. A test of comparison of two sample means and two sample variances were selected as the analysis methodology, which included a test at the 5% significance level. The authors did not specify the design characteristics of their study, but Figure 7-3 shows the results.

Table 4 – Summary of Speed Bar Effect on Speed, Pace and Standard Deviation

| Site | Mean (km/h) | 85 th Percentile (km/h) | Percent in Pace (%) | Standard Deviation (km/h) |
|--------------------------|-------------------|---------------------------------------|------------------------|---------------------------------|
| Rte 1 - Musquash Day#1 | -2.4 | -3.2 | -5.0% | -0.24* |
| Rte 1 - Musquash Day#2 | +0.6 | -0.5 | +3.0% | -1.55* |
| Rte 1 - Musquash Night#1 | -7.7* | -7.4 | +9.0% | -1.44* |
| Rte 1 - Musquash Night#2 | -4.0 | -3.9 | +3.5% | -0.53* |
| Average | -3.4 km/h* | -3.8 km/h* | +2.6% | -0.94 km/h* |

* Statistically significant at 5% significance level

Figure 7-3. Speed bar results (Hildebrand et al. 2002)

Hildebrand et al. concluded that the mean and 85th percentile speeds were reduced (statistically significant) by 3.4 km/h (2.1 mph) and 3.8 km/h (2.4 mph), and the greatest reduction in speed occurred during the nighttime observations. Furthermore, it was also concluded that the transverse bars provided an increased level of safety during the night conditions due to the high retro-reflective capabilities of the pavement markings (Hildebrand et al. 2002).

7.2. Temporary Transverse Rumble Strips

This section discusses the use of temporary transverse rumble strips to alert drivers. It should be noted that the Iowa Department of Transportation discourages the use of transverse rumble strips except as advance warning for rural stop signs.

Temporary rumble strips serve to supplement driver attention toward work zone warning signs prior to and within a freeway work zone involving lane restrictions, reductions, and sharp detour transitions (Harwood 1993). Rumble strips provide both a tactile and audible warning to reduce speed. The use of rumble strips is not consistent. They are used as advance treatments to rural stop-controlled intersection approaches, toll plazas, horizontal curves, and work zones. Rumble strips warn drivers, but because they do not have a single standard use, drivers do not know what action they are supposed to take. As a result, drivers need additional information to let them

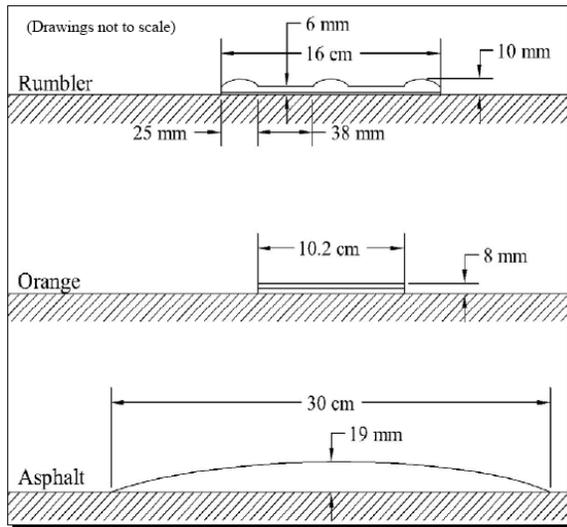


Figure 7-4. Rumble strip cross sections (Meyer 2003)

know what the desired action is (Ray et al. 2008). Rumble strips can either be temporary, semi-permanent, or permanent and can be constructed from an array of products, including formed asphalt, exposed aggregate, plastic, or rubber (Harwood 1993; Meyer 2003). The width of rumble strips, as shown in Figure 7-4, ranges from 5 to 31 cm (2 to 12 in.), with a typical dimension of 10 to 20 cm (3.9 to 7.9 in.). Heights are typically 0.32 to 3.8 cm (0.13 to 1.5 in.) (Meyer 2003).

Meyer (2003) investigated the noise level, speed reduction, vehicle vibration, and durability of two types of temporary rumble strips, as compared to asphalt rumble strips. Two sites, located in Horton and Perry Lake, Kansas, were selected, and rumble strips were placed in two eastbound and two westbound sites, as illustrated in Figures 7-5 and 7-6. Both

sites selected consisted of a rural two-lane highway where one through travel lane was open and opposing-direction vehicles were required to stop. Figure 7-7 shows the typical rumble strip dimensions and spacing, along with an experimental placement the research team tried. Each site consisted of both an asphalt rumble strip work zone and a second work zone with both asphalt and temporary rumble strips.

The research team used a sound/vibration analyzer, accelerometer, microphone, and pneumatic road tubes to test the sites. The road tubes were deployed at the work zone approaches before the stop point (no data was collected downstream of the rumble strips) for an average of 19 days, and the effects of vehicles platooned were removed.

Meyer found that all three treatments showed a decrease in speed while the temporary rumble strip that was painted orange had the greatest effectiveness (Figure 7-8).

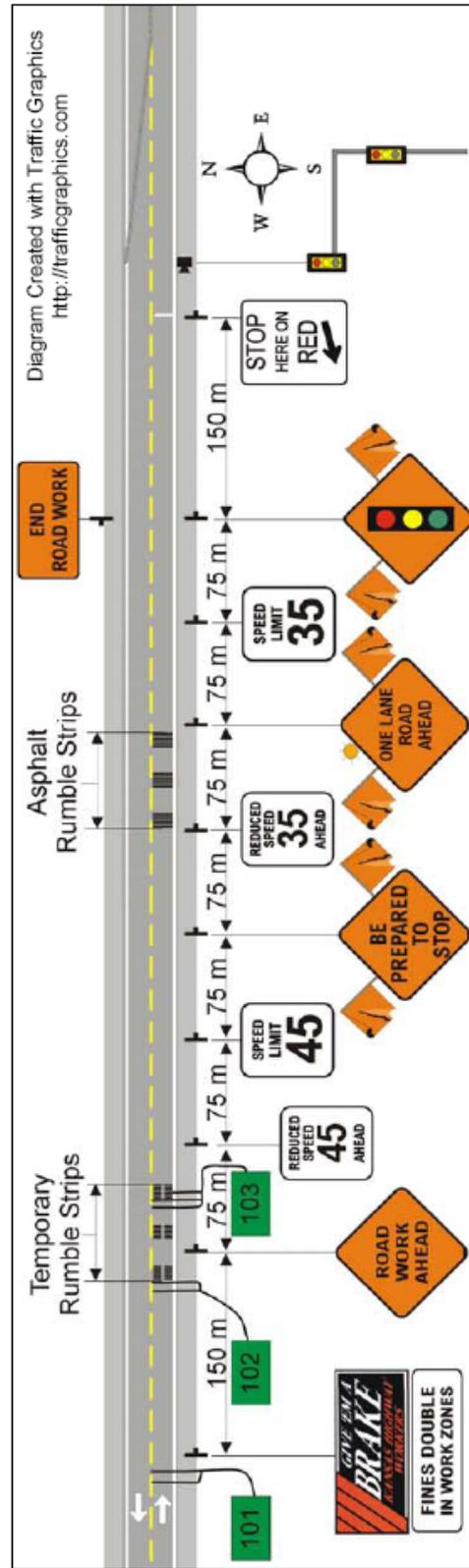
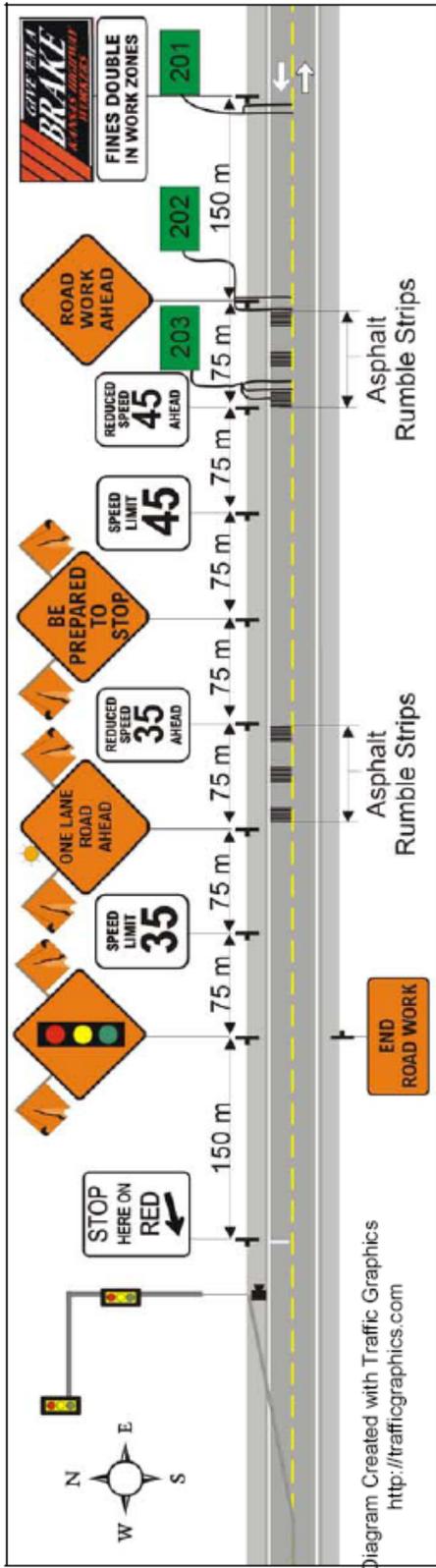


Figure 7-5. Rumble strip specified in work zone traffic control plan at the first site (Meyer 2003)

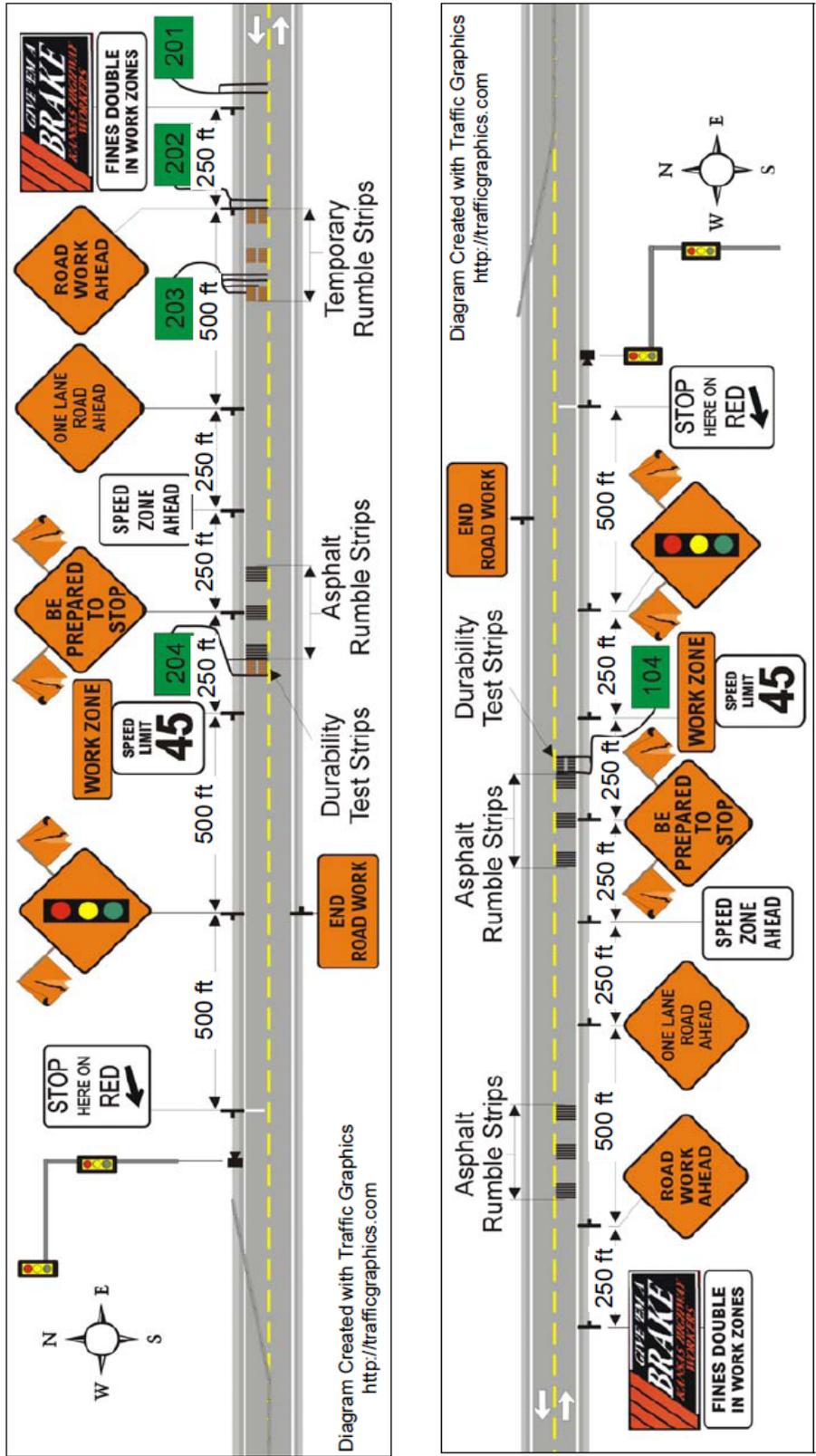


Figure 7-6. Rumble strip specified in work zone traffic control plan at the second site (Meyer 2003)

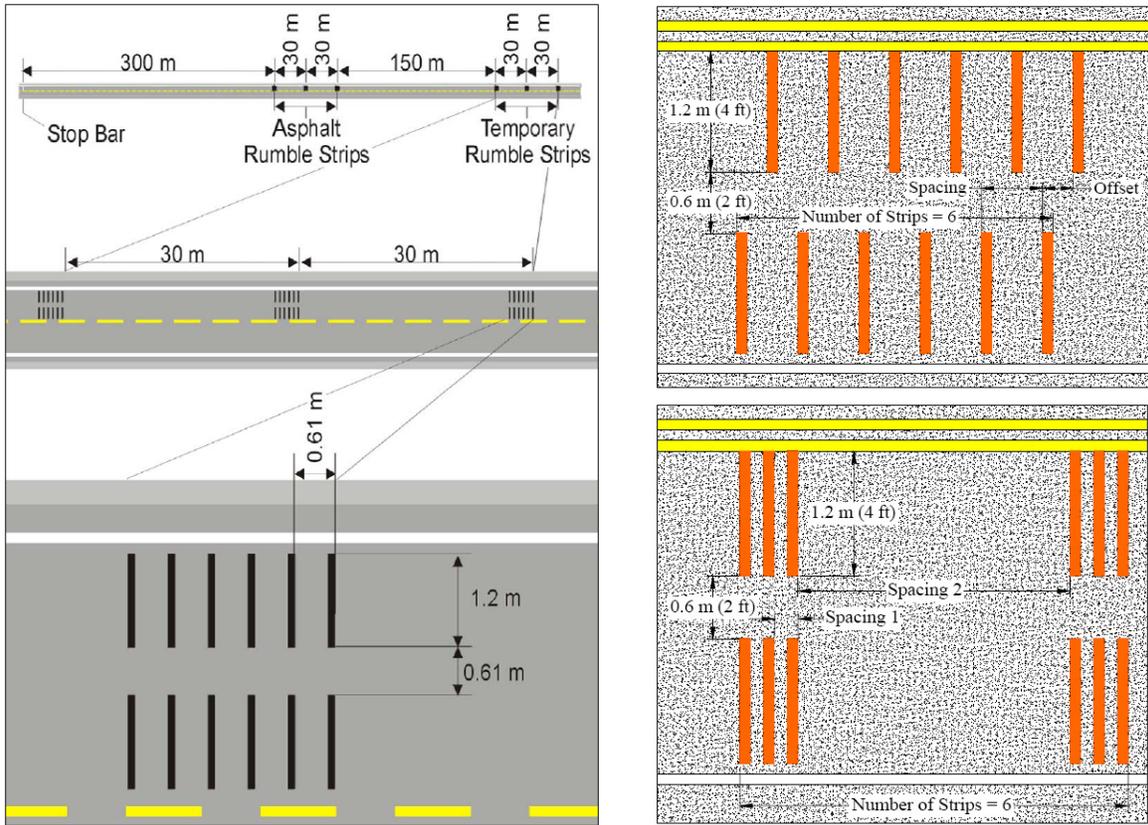


Figure 7-7. Temporary rumble strip specifications (Meyer 2003)

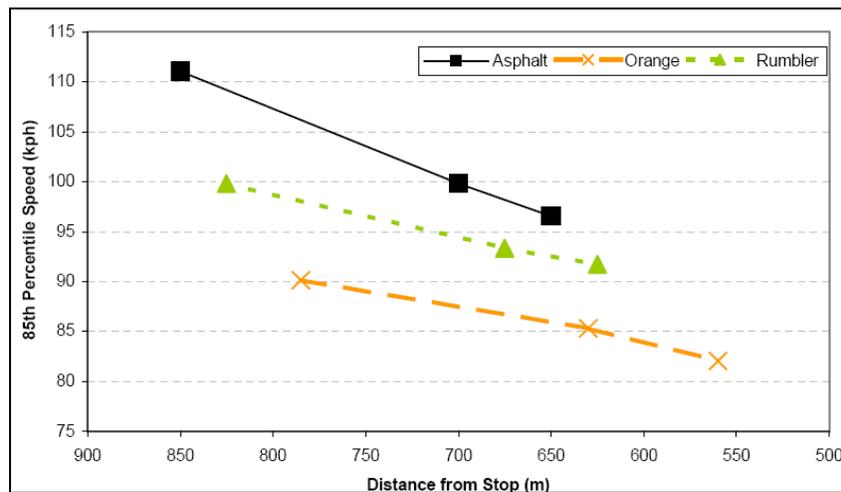


Figure 7-8. 85th percentile speed comparison for passenger cars (Meyer 2003)

Horowitz and Notbohm (2002) investigated the use of temporary rumble strips for reducing work zone approach speeds prior to a temporary traffic signal. The strips were installed at the intersection of State Trunk Highway 26 and County Trunk Highway E in Dodge County, Wisconsin. The 12 set rumble strip was placed 1,106 ft away from the temporary stop bar in an

area free of road cracks. Each rubber strip measured 4 ft wide by 0.25 in. high and can be seen in Figure 7-9.



Figure 7-9. Temporary Rumble Strip (Horowitz and Notbohm 2002)

Three separate sets of data were collected, including vehicular speed, interior noise levels, and vibrations. Using a laser gun, speed data were collected prior to the intersection before and after installation for one day in three locations. The three checkpoints used were 554, 881, and 1,215 ft from the intersection. At 500 ft, average speeds were reduced from 42.9 to 41.8 mph (1.1 mph change, statistically significant at 0.05 level); at 800 ft, the average speed was reduced from 47.8 to 46.5 mph (1.3 mph change, statistically significant at 0.05 level); and at 1,106 ft the average speed was reduced from 49.9 to 48.6 mph (1.1 mph change, not statistically significant at 0.05 level). The researchers concluded that the temporary

rumble strips did not contribute to a substantial change in speed.

Similar conclusions were made by Richards et al. (1985) using temporary 1/2 in. high polycarbonate rumble strips to reduce approaching work zone vehicle speeds on a rural two-lane, two-way highway in Texas. The investigators planned on installing the rumble strips at two sites, but due to the strips' inability to adhere to the pavement, only one site could be studied. The study evaluated the rumble strips in three different patterns, as shown in Figure 7-10. These include clusters of eight rumble strips with equal spacing; clusters of eight rumble strips with logarithmic spacing; and individual rumble strips spaced 52 to 66 ft at both sites, as described in a FHWA report by Noel et al. (1989).

Speeds were collected at three locations for 125 vehicles (prior to, at, and in the work zone) using a digital stopwatch and 200 ft of observed roadway. Richards et al. (1985) reported that the mean speed only decreased by 2 mph, indicating that the rumble strips were not an effective device.

In 2004, temporary transverse rumble strips were studied on a Maryland highway to alert drivers of unusual or unexpected road conditions. Research has found that while driver awareness increased, the reduction in average speed was minor, and workers believed drivers were more aware of the activity in the work zone (Lessner 2005).

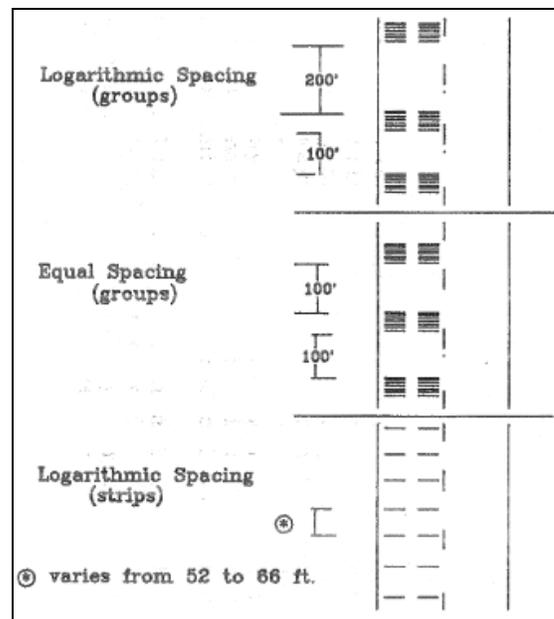


Figure 7-10. Temporary rumble strip placement (Noel et al. 1989; Richards et al. 1985)

7.3. Wider Pavement Markings

Wider pavement markings have been used to improve the visibility of centerline, lane line, or edgeline stripping to improve visibility (Ray et al. 2008). Wider lane lines were used in a work zone in Maryland along I-695, as shown in Figure 7-11. Wider lane lines give the perception that the lanes are narrower and provide a sense of constraint that, ideally, slows drivers down. Research on I-695 has shown that the number of lane changes was reduced, but the reduction in average speed was minor (Lessner 2005). No other information was available about whether speed reductions have been achieved using wider markings.



5-inch paint lane lines



10-inch paint lane lines

Figure 7-11. Use of wider lane lines

8. INTELLIGENT TRANSPORTATION SYSTEMS TECHNOLOGY

Several ITS technologies can help reduce traffic flow disruptions. While not specifically designed to reduce speeds, ITS can smooth and calm traffic flow. Note that ITS strategies can include technologies listed in previous sections, such as variable speed limits and dynamic message signs.

8.1. Dynamic Lane Merger

Dynamic lane merger systems help reduce flow disruptions at the taper from two lanes to one lane by starting no passing zones before the taper based on traffic volumes and queue (Bushman and Klashinsky 2004). These systems use electronics and communications equipment to monitor traffic flow, and, when queuing increases, the system regulates the merge by requiring either an early merge or a late merge (FHWA 2007). Signs that read “LEFT LANE DO NOT PASS WHEN FLASHING” and that have flashing lights and traffic monitoring devices that measure the speed, vehicle volume, and occupancy are placed upstream of the work zone. If the traffic monitoring device detects congestion, a signal is sent to the next sign upstream, which causes the lights on that sign to start flashing, which then forces vehicles to merge prior to the congestion. A typical device is shown in Figure 8-1 (Bushman and Klashinsky 2004).



Figure 8-1. Typical dynamic lane merger device (Bushman and Klashinsky 2004)

The Michigan Department of Transportation deployed an early merge system in 2003. At a present threshold of traffic volume, vehicle speed, and detector occupancy, the system activated a “Do Not Pass” message. A study found that average travel speed increased by 6 mph and crashes were reduced. Mn/DOT also studied the benefits of a dynamic lane merge system using a late merge system and found that aggressive driver behavior was eliminated, queue lengths decreased, and both lanes were nearly equally utilized (FHWA 2007).

8.2. Automated Work Zone Information System

An automated work zone information system (AWIS) alerts travelers to work zone conditions before they enter the work zone so they can take appropriate actions. During reconstruction of a 40-mile section of I-55 in Illinois, the state implemented an automated portable real-time traffic control system consisting of a dynamic message sign, portable electronically linked traffic sensors, and portable closed circuit video cameras. The system provided real-time traveler information about delays and lane closures. The system also displayed the number of citations issued. A study of this system found that only two crashes occurred in 16 months, and there was

a downward trend in violations. California has also used an AWIS to provide information to travelers in advance of a work zone so they can choose alternate routes. When this system was implemented, traffic volume and peak delay decreased. Arkansas has used an AWIS that consisted of a central system controller, two highway advisory radio systems, five traffic radar sensors, five dynamic message signs, and two speed stations. The state believed that rear end crashes and congestion were both reduced (FHWA 2007).

9. RECENT VENDOR TECHNOLOGIES

As part of this research, the team attempted to locate new technologies or techniques that may be available for reducing speeds in work zones. The team made a list of 25 vendors that were known to sell or manufacture products for work zones or for traffic calming. The website of each vendor was searched to determine whether any innovative products or services were available to reduce speeds in work zones. A number of products were found, but most have been in use and thus the team did not consider them to be innovative. The team also attempted to contact each company. The vendors that either feature innovative products or were available for contact are discussed in this section.

One system that the team considered innovative is a radar detection system from Image Sensing Systems Canada, Ltd. The system uses remote traffic microwave sensors (RTMS) placed on the sides of roads. According to the website, it is the “only multi-zone traffic detector unaffected by any type of weather.” The company’s website claims, “In many tests performed by traffic professionals worldwide, this presence radar technology has been recognized as the best for almost all traffic management applications.” The website also contains links to studies or tests using the product. One of these test summaries describes the use of the RTMS in Florida to display travel times to specific areas in Tampa Bay on a total of eight dynamic message signs. It was found that the accuracy of the times posted against actual travel times (which were traveled by a test vehicle in free flow conditions) was “right on target.” The information listed here was found at the manufacturer’s website, http://www.eistraffic.com/rtms_features.html.



Figure 9-1. FG300 Interstate-grade Curb System

Another product that has recently become available from vendors is the FG300 Interstate-grade Curb System by Davidson Traffic Control Products. This product, according to the manufacturer’s website, is “a median separation system that provides efficient and cost-effective channelization of traffic.” It involves a single-piece FHWA-approved curb system to provide safe channelization, as shown in Figure 9-1 (http://www.filtronaextrusion.com/SiteCollectionDocuments/Traffic/FG_300_Curb_Overview__201-0406.pdf).

A third product is the Sequential Work Zone Lamp or the SynchroGUIDE, by Dorman VariText. This product involves a set of high-intensity super-bright single-LED devices, which are placed along barricades. These devices have intelligent wireless technology that can provide directional guidance via lighting along a barricade as a driver travels past, as shown in Figure 9-2.



Figure 9-2. SynchroGUIDE

Other companies replied to an e-mail that the team sent. Wanco noted that it offers additional sizes and options for its products. North American Traffic offers products that can be customized. For example, an “intrusion siren” can be put on autoflaggers to sound when a car drives through the barricades and into the work zone. Horizon Signal Technologies reported that it had no additional products, while Synergy sent information about its Automated Flagger System. The last company to respond was Swarco, which sent more information on its version of removable rumble strips, the Rumbler.

For the companies already listed above, Dorman VariText sent information about its Posted Speed Limit Dual Diagram VATACS, which is listed on the company’s website. Davidson Traffic Control Products also sent more information about its temporary rumble strips.

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