Research Report
KTC-05-20/SPR-259-03-1F

KENTUCKY TRANSPORTATION CENTER

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EFFECT OF WARNING SIGNS ON CURVE OPERATING SPEEDS

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Effect of Warning Devices on Curve Operating Speeds

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16. Abstract

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 sign 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.

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EXECUTIVE SUMMARY

Horizontal curves are among the most hazardous situations for drivers. Drivers are frequently either unaware of impending changes in roadway geometry or do not adequately reduce their operating speed when negotiating these geometric changes. Currently, the standard treatment of the traditional warning sign with advisory speed plaque seems to have no effect in reducing speeds on the most dangerous of curves. It is the focus of this study 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.

A literature review yielded the following conclusions:

1. Pavement markings effectively reduce vehicle speeds while not diverting drivers' attention from the roadway.
2. Warning signs are most effective when used in conjunction with additional supplementary warning signs and devices (i.e., combination Horizontal Alignment/Advisory Speed sign, flashing lights, flags, etc.).
3. Speed reductions attributed to warning signs and pavement markings vary from site to site depending on the roadway geometry, operating speed, etc.
4. Flashing lights are useful in reducing speeds regardless of the accompanying sign or degree of danger in a horizontal curve.

Three sites were selected from a list of proposed sites for the testing of the various warning methods. These sites met a series of criteria which included a sharp rural curve, a problematic history of speed related incidents, a long tangent section, no vertical grade, and no intersections, driveways, or commercial activity that could adversely affect the speed data. Each warning treatment was installed and a five-day waiting period was allowed before operating speeds for the treatments were measured. This waiting period was implemented so that local traffic could become more familiar with the treatment and in turn, not give false speed-readings due to potential novelty effects. Speeds were first measured for the existing conditions, and then the following warning treatments were tested:

1. Bright orange flags placed on the existing warning sign.
2. A large arrow placed so that it could be seen from the tangent section of the roadway.
3. A new combination Horizontal Alignment/Advisory Speed sign located at the point of curvature, after the existing warning sign as a supplementary sign.
4. Post delineators placed throughout the curve at 50-foot intervals.
5. Transverse lines beginning at the point of curvature extending back into the tangent section.
6. Rumble strips placed on 12 of the transverse lines beginning at the point of curvature extending back into the tangent section.
7. The new combination Horizontal Alignment/Advisory Speed sign supplemented the existing warning sign. Two 6-inch flashing lights were mounted on the upper portion of the sign and they were visible to drivers only at night. Post delineators were placed on the inside of the curve at 50-foot intervals from the point of

curvature to the end of the curve. The rumble strips placed during the previous trial remained in place during this measurement as well.

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 sign and new combination warning sign. It is important to note that the combination of treatments also reduced speeds at all three locations. This indicates that the most substantial impact is created when warning treatments are used in combination, especially with rumble strips which convey both physical and audible stimuli to the driver to reduce their operating speed. 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.

1 INTRODUCTION

The basic premise for geometric design of roadways is to provide a safe and efficient facility. However, there are other constraints, such as financial and geographic, which forbid the ideal roadway design from being materialized. These less than ideal situations can lead to the use of geometric conditions that may require sharper curves, limited sight distances, steeper grades, and other issues that could affect the driver's ability to follow the intended design. The prevalent problem with such designs is that they do not provide any information or clues to the driver as to the appropriate operating speed. Sharp horizontal curves can pose dangers to the driver when dealing with speed adjustment, vehicle placement, and judgment of the appropriate operating speed. Traffic engineers have introduced many warning methods to aid drivers in realizing and using the appropriate operating speed at hazardous roadway locations. Therefore, a prime location to test some of these warning methods is at horizontal curves that have some of these undesirable characteristics.

Two primary methods of conveying roadway information to the driver are warning signs and pavement markings. According to the Manual on Uniform Traffic Control Devices (MUTCD), "warning signs call attention to unexpected conditions … to situations that might not be readily apparent to road users" and "alert road users to conditions that might call for a reduction of speed or an action in interest of safety and efficient traffic operations" (MUTCD, 2000). Also according to the MUTCD, "markings on highways have important functions in providing guidance and information for the road user" and can be "used to supplement other traffic control devices". The MUTCD notes that an important characteristic of the pavement markings as opposed to the warning sign is that they allow the driver to focus on the roadway but still acknowledge the warning.

There is a suspicion however that warning signs are often not properly noted by drivers. In these cases, the effectiveness of signs and markings is reduced and often the intended reduction in operating speeds is not achieved. Moreover, the absence of adjusting the operating speeds may lead to a crash. Thus, 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. The specific tasks undertaken to complete this study are to evaluate the standard warning signs and pavement markings, determine which warning signs and pavement markings are the most effective methods of speed reduction at horizontal curves, and to recommend the most effective method(s) for the reduction of operating speeds.

2 LITERATURE REVIEW

A literature review was completed to gain a better understanding of the effectiveness of warning signs and pavement markings at reducing operating speeds. There have been many innovative approaches in the implementation of warning signs and pavement markings, which assisted in determining what the best measures to apply in this study were.

2.1 Pavement Markings

The MUTCD states that the two most common types of pavement markings are longitudinal (i.e., center and edgeline markings) and transverse markings (i.e., crosswalk lines, intersection stop lines, etc.). Pavement markings come in many shapes, sizes, and functionalities. Regardless of their immediate purpose, pavement markings are used to inform and warn drivers, pedestrians, and bicyclists of local and federal regulations and potentially hazardous locations. The MUTCD states that the most inherent function of pavement markings is that they allow motorists to focus on the roadway where the danger is located, as opposed to signs or lights located off the roadway (MUTCD, 2000). Typical pavement markings are placed in advance of the impending roadway hazard to allow motorists to react accordingly and provide them with a sufficient amount of time to determine their proper reaction. Normally, the redesign and reconstruction of the roadway is the most efficient means of addressing potential hazards, but when redesign and reconstruction are not feasible, pavement markings can be used to alleviate or moderate these situations (Storm, 2000).

Transverse pavement markings, or optical speed bars, are stripes located at horizontal curve tangents, roundabout approaches, intersection approaches, construction areas, and freeway off ramps (Meyers, 1999). The goal of transverse markings is to reduce speed and improve safety at potentially hazardous locations. The markings are placed in advance of the location in question and perpendicularly to the path of traffic to decrease vehicle speed before the location is reached. The spacing between stripes is reduced and they decrease in thickness as they get closer to the location (Griffin and Reinhardt, 1996). The purpose of these markings is to create an optical illusion, which would force drivers to slow down. The line spacing and size is intended to give the driver a sense of acceleration, regardless of whether or not the vehicle is actually accelerating. This impression of acceleration gives drivers the indication they are traveling faster than intended, which in turn forces them to decrease their operating speed.

A set of three applications of transverse pavement markings conducted by Enuston (1972) examined their effectiveness on operating speeds. Each application was at a different type of facility and included an approach to a construction zone at an Interstate facility, a curve approach at a two-lane rural highway, and an approach to an overpass. A different roadway length and number of lines was used in each application to address the specifics of each site. Speed measurements were taken at the approach and along the treatment, and comparisons were made before and after the installation. Mixed results were obtained for each site regarding the effectiveness of the transverse lines in reducing operating speeds. For the work zone approach, the results indicated a minimal speed reduction which decreased with time and was attributed to a novelty effect. The second site, which utilized rumble strips in combination with transverse lines, had a larger initial speed reduction, but eventually the average speed began to return to the initial average speed. Moreover, the rumble strips reduced speeds dramatically, and the average speed increased considerably when the rumble strips were removed. In the third study, the average speeds were reduced following the treatment installation without any change in speed variation.

In studies where transverse markings were placed at a roundabout approach, significant speed reductions were noted. Denton (1971) described a situation where yellow transverse markings were inserted at the approach of a traffic roundabout in Scotland. After monitoring speed for approximately three weeks before and after the installation of the markings, it was concluded that the average speed decreased considerably with the biggest decrease coming during morning hours (9-11 am). Havell (1983) implemented white transverse pavement markings prior to a traffic circle in South Africa. The results indicated a 10 percent speed reduction approximately 100 m from the roundabout entry. Speed measurements taken eight months later showed that the speed reductions still held, and it was concluded that this reduction would continue to be observed in the future.

Backus (1976) implemented transverse pavement markings across two-lanes of traffic on a four-lane highway approaching a horizontal curve and the speed was measured 100 feet from the point of curvature. It was determined that before the insertion of the pavement markings, the 35 mph speed limit was exceeded 60 percent of the time, and 18 percent of the traffic exceeded 40 mph. After the installation of the markings, the percentage of traffic exceeding 35 mph decreased by 35 percent, and the percentage of traffic exceeding 40 mph decreased by 10 percent. The experiment also yielded a decrease in average mean speed of 2.5 mph, which Backus concluded was statistically significant.

Other studies on applications of transverse lines in situations other than curve approaches showed similar results. Jarvis (1989) completed a study that experimented with transverse markings at the approaches of 5 separate intersections. The markings resulted in small speed reductions at the intersection approach but speeds increased as soon as the drivers left the marked area. The study determined that the markings acted merely as a hazard warning rather than a tool for affecting driver operating speeds. Liebel and Bowron (1984) studied the use of transverse markings on a freeway off ramp that ended at a signalized intersection. The researchers concluded that while speed reduction on vehicles traveling at or below the suggested safe speed was minimal, the speed reduction was particularly promising with drivers exceeding the safe speed. Agent (1975) used transverse markings on a rural Kentucky curve that had experienced many speed related crashes. The results indicated small speed reductions but began retracting back to normal. However, in a follow up evaluation 6 months later, there was still a noticeable change. The study concluded that the transverse markings did reduce speeds and that they have the ability to alert drivers of the upcoming hazard more effectively than the use of warning signs.

2.2 Warning Signs

The MUTCD states "warning signs call attention to unexpected conditions on or adjacent to a highway or street and to situations that might not be readily apparent to road users." A main objective of warning signs is that they give a sufficient amount of time for drivers to react to forthcoming roadway hazards (MUTCD, 2000). The application of warning signs can be based on an engineering study or engineering judgment. If the warning sign placement is performed from an engineering study, then the required time for a proper reaction needs to be considered. This time is the total time needed to react to a warning sign based on Perception, Identification (understanding), Emotion (decision making), and Volition (execution of decision) (PIEV). The PIEV times can vary accordingly, based on the dimensions of the roadway, posted or 85th percentile speed, and the hazards associated with the roadway.

The most common type of warning sign in advance of a curve is the Horizontal Alignment sign. This sign is often accompanied by an Advisory Speed plaque, which is located below the Horizontal Alignment sign. The common function of this warning sign is to alert drivers of the impending change in the horizontal curvature of the roadway. The Advisory Speed plaque suggests a safe speed that should be used to safely negotiate the curve. The excessive use and commonality of the Horizontal Alignment sign is probably the reason that the sign is often ignored. It has been noted that the overuse of this and other signs in general "tends to breed disrespect for all signs" (MUTCD, 2000). Therefore, drivers will pay less attention to warning signs if they are used too frequently, thus creating an unsafe environment.

The combination Horizontal Alignment/Advisory Speed sign is a relatively new sign that combines the Horizontal Alignment sign with the Advisory Speed plaque onto a single sign. This sign is used to supplement the Horizontal Alignment sign with Advisory Speed plaque and is installed at the point of curvature, after the Horizontal Alignment sign. This signing reiterates the warning conveyed from the Horizontal Alignment sign as the driver approaches the curve. The sign duplication (2 warning signs) is envisioned to work as a stronger indication of the potential hazard.

The one-direction Large Arrow sign is most commonly used to demarcate an upcoming change in the horizontal alignment of the roadway. The sign should be placed at a location that allows the sign to be seen for a sufficient distance from the tangent of the curve. The ample distance will provide drivers an adequate amount of time to make a decision based on the change in alignment.

Common devices located on warning signs are flags, flashing lights, and spotlights. The goal of these types of warnings is to give the driver a different warning perspective. For instance, bright, orange flags on a Horizontal Alignment sign are definitely not a usual occurrence. The attention paid to a sign could typically be increased if something atypical was attached to the sign. Such an addition could possibly alert drivers in an uncharacteristic manner forcing them to slow down or alter their driving behavior. Several studies have been performed to determine the effectiveness of warning signs accompanied by flashing lights. Lyles (1981) used flashing lights with the existing warning signs that warned drivers of construction zones on rural highways. The flashing lights resulted in a 3 to 4 mph speed reduction for short work zones and a 7.5 mph speed reduction for long work zones. Zegeer (1975) studied a situation where flashing lights are used with school zone speed restriction signs. The flashing lights reduced average speeds by 3.6 mph, and on roads with speed limits of 55 mph, the average speed was reduced by 10 mph. Hanscome (1976) studied a situation where flashing lights were used to warn of the possibility of skidding due to wet weather. The flashing lights reduced average speeds by 9 percent for wet conditions.

2.3 Delineators

According to the MUTCD, "delineators are particularly beneficial at locations where the alignment might be confusing or unexpected, such as … curves" (MUTCD, 2000). Delineators are good methods of guidance[1] especially at night, because they are reflective and are at a comparable height to the headlights of vehicles. It is essential that delineators be spaced at a constant distance with several delineators visible at all times, when used at locations of changing horizontal alignment. A study by Zador et al (1986) found that speeds increased by approximately 1.5 mph at horizontal curves after the installation of post delineators. The study also found that vehicles tend to move towards the centerline of the roadway after the installation of post delineators on right horizontal curves, and have no placement effect for left horizontal curves. The authors concluded that an argument could be made that the speed increases found in the post delineator cases, reflect the adaptation of the drivers to an increased level of information about the upcoming roadway conditions, giving them an advantage in maneuvering through the curves.

2.4 Literature Review Summary

Operating speeds can effectively be reduced if warning signs and pavement markings are installed at hazardous roadway locations. The literature review showed the following.

1. Pavement markings can reduce operating speeds effectively. These markings act as a visual warning, they alter human perception, and they enable drivers to pay attention to the roadway without having to look off to the side of the roadway to see a warning sign.
2. Warning signs have also been found to reduce operating speeds at hazardous roadway sections and thus affect safety. They seem to be even more beneficial if coupled with other warning signs or devices. Typical warning signs (i.e., curve warning signs, speed plaques, chevrons, etc.) are often overlooked due to their frequent use, but if additional warning signs or devices (i.e., combination Horizontal Alignment/Advisory Speed sign, flashing lights, flags, etc.) are used with the commonly used warning sign, drivers will often acknowledge the warning sign when they normally would not, or they may react quicker to the warning.

[1] The MUTCD claims that delineators are guidance devices and not warning devices.

3. Speed reductions attributed to warning signs and pavement markings vary from site to site, so it is very difficult to accurately predict what kind of results will occur.
4. The literature dealing with warning signs and flashing lights explained that where flashing lights are used and the hazard is not obvious, regardless of the type of accompanying sign, a speed reduction of 2 to 3 mph can be expected; where the hazard is more clearly explained by the sign, the speed reduction is likely to be greater and the driver will probably be more attentive.

3 METHODOLOGY

The research plan focused on identifying potential sites where different treatments were to be introduced and speed measurements would be taken to estimate the effectiveness of each treatment. A request for candidate sites was made to each Kentucky Transportation Cabinet District office and a list of potential sites was developed. Each site proposed was evaluated through a site visit where the alignment was examined and documented. The existing warning signs and pavement markings were noted and any particular elements of the sites were recorded. A list of sites was then proposed to the Study Advisory Committee. The list was reduced to appropriate sites based on a variety of criteria (Table 1). This report presents the findings for 3 of these sites.

TABLE 1 Proposed sites

County	Road and Milepoint	ADT	Urban/Rural	Applicable	Crashes 2000-2003
Greenup	KY 1/5.7	2,010	Rural	Yes	4
Henry	KY 146/5.5	3,500	Rural	Yes	10
Lee	KY 52/19.5	1,750	Rural	Yes	1
Breathitt	KY 15/2.5	5,590	Rural	Yes	
Lee	KY 52/22.6	1,550	Rural	Yes	
Morgan	Mt. Pkwy./63.04	5,140	Rural	Yes	
Muhlenberg	US 431/6.3	2,850	Rural	Yes	
Pike	US 460/6.2	11,300	Rural	Yes	
Powell	Mt. Pkwy./35.6	8,000	Rural	Yes	
Wolfe	Mt. Pkwy./38.2	8,000	Rural	Yes	
Johnson	KY 302/5.6	1,190	Urban	Maybe	
Meade	KY 144/21.7	1,160	Rural	Maybe	
Floyd	KY 122/18.7	6,480	Urban	No	
Floyd	KY 1428/5.6	3,730	Urban	No	
Morgan	KY 705/4.8	439	Rural	No	

The speeds were measured for existing and newly treated conditions at 4 locations throughout the curve approach. The devices were placed throughout the tangent and curve section on the curve approach, and a time and speed for each vehicle that passed over them were measured. This allowed for the tracking of individual vehicles throughout the curve approach and the observation of their speed reduction as they progressed through the study area. The location for the speed measurement devices differed for each site because of the existing geometry and traffic control. A factor considered was the distance from the existing warning sign to the point of curvature.

All treatments were given a five-day waiting period before speeds were measured. This waiting period was implemented so that local traffic could become more familiar with the treatment and in turn, not give false speed-readings due to potential novelty effects. For instance, if a local driver navigates the same road every day, and then sees something different, then this driver is likely to slow down more than usual. If the drivers are given a few days to become familiar with the new situation, the recorded speeds will be more accurate and will allow for a better evaluation of the effectiveness of the treatment.

3.1 Site Selection

The initial stages of this project dealt with the selection of curves throughout Kentucky. Each of the 12 districts in Kentucky was asked to locate curves within their district that had problems with excessive speeds and speed related crashes. The districts proposed a total of 15 sites that could be used in this study (Table 1). These locations were then visited to evaluate the existing characteristics and to determine their potential for further inclusion. It was also necessary to select sites in a way that their characteristics would be most beneficial to this study. For instance, the ideal site would have a sharp rural curve, a problematic history of speed related incidents, a long tangent section, no vertical grade, and no intersections, driveways, or commercial activity that could adversely affect speed data. Moreover, the willingness of the district to assist in sign placement and removal was considered a very crucial factor in selecting the sites. The 15 sites were then narrowed down to 10 sites that were considered suitable. The three sites eliminated from the database were not applicable to this study because the curves were located at intersections or congested areas. Two sites noted as "maybe" in Table 1 were classified as such because they were located close to intersections, but not near as close as the non-applicable sites.

3.2 Curve Warning Treatments

Several types of warning signs and pavement markings were considered for use in this study to determine which methods and combinations are those that could reduce operating speeds most effectively. All of the sites that were studied had an existing Horizontal Alignment sign with an Advisory Speed plaque in advance of the curve. Other signs, warnings, and pavement markings that were used were:

- the one-direction Large Arrow sign (one site),
- the Chevron Alignment sign (one site),
- the Combination Horizontal Alignment/Advisory Speed sign,
- the existing warning sign with flags,
- the existing warning sign, and
- the new combination sign with flashing lights, post delineators, and transverse lines.

Approximately one year after these warning treatments were tested, two more curve warning treatments were evaluated. These treatments included:

- rumble strips, and

- the combined use of rumble strips, 48-inch combination Horizontal Alignment/Advisory Speed sign, flashing lights, and post delineators.

In order to ensure that the results obtained in the latest treatments were comparable to those obtained earlier, new measurements were taken for the transverse lines (which were currently present). A comparison between the old and new speeds for the transverse lines would allow for determining whether any change had occurred and whether there were any lasting effects from the use of the transverse lines.

The existing Horizontal Alignment sign with speed plaque was already in place at all sites; therefore, it was not changed (Figures 1 and 2).

Figure 1. Lee Co. – Existing conditions

Figure 2. Greenup Co. – Existing conditions

The Large Arrow sign was used on the outside of the curve in 2 locations (Lee County and Greenup County) at a right angle to the oncoming traffic (Figures 3 and 4).

Figure 3. Greenup Co. – Large Arrow

Figure 4. Lee Co. – Large Arrow

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Three existing chevron alignment signs were in place on the outside of the curve at the Henry County site, but three more were added in advance of the existing chevrons to accentuate the curve. Additional chevron signs were used because the MUTCD recommends that at least two signs should be visible to the driver at all times and the availability of sufficient distance to provide the driver with adequate reaction time. Neither of these two stipulations was followed so the situation was corrected with the additional signs. The existing chevron signs at the Lee and Greenup County sites were satisfactorily placed to allow at least two chevrons to always be visible; therefore, no additional chevrons were used (Figures 5 and 6).

Figure 5. Lee Co. – Chevrons

Figure 6. Henry Co. – Chevrons

The combinational Horizontal Alignment/Advisory Speed sign was used at all three sites (Figures 7 and 8). The MUTCD states that this sign should supplement other warning signs and should be placed at the point of curvature. Therefore, this sign was located after the existing curve warning sign with speed plaque at the point of curvature for all sites.

Figure 7. Lee Co. – New combination sign

Figure 8. Greenup Co. – New combination sign

The existing warning sign with flags was used at all three study sites. Two flags were attached to the top portion of each sign (Figures 9 and 10).

Figure 9. Greenup Co. – Warning sign with flags

Figure 10. Henry Co.-Warning sign with flags

Flashing lights were attached first to the existing warning sign (Figure 11). The following week, the new combination sign was installed again and flashing lights were used on the sign as well as the existing new combination sign (Figure 12). The flashing lights were 6-inch lights that flashed only at night.

Figure 11. Henry Co. – Existing warning sign with flashing lights

Figure 12. Henry Co. – New combination sign with flashing lights

Post delineators were used at all three study sites (Figures 13 and 14).

Figure 13. Greenup Co. – Post delineators

Figure 14. Lee Co. – Post delineators

Transverse lines were used at all three site locations (Figures 15 and 16). However, the number of lines and spacing between lines differed from site to site because of the different degree of curvature and available approach tangent. In the Lee County site, 15 transverse lines were applied because of a short approach tangent. In the other two sites 24 lines were used. The lines were used only in the tangent sections leading up to the curve to avoid the potential of reduced friction while in the curve, particularly during wet conditions.

Figure 15. Lee Co. – Transverse lines

Figure 16. Greenup Co. – Transverse lines

One year later, the transverse lines were tested again at all three sites to determine their effect over an extended period of time and provide a current basis for comparisons for the new treatments. Then rumble strips were placed on top of the transverse lines to enhance their visibility and simultaneously produce a rumbling sound and vibration to the drivers. The rumble strips consisted of 3 or 4 strips of thermoplastic placed across either the entire lane or the portion of the lane which would be crossed by a vehicle's wheels (Figures 17 and 18).

Figure 17. Lee Co. – Rumble strips

Figure 18. Henry Co. – Rumble strips

The final treatment tested was a combination of the reinstallation of the new combination sign, flashing lights on both signs, post delineators in conjunction with the rumble strips overlaid on the transverse lines. The results of the research conducted in the previous year identified each of the treatments noted above as having a significant or a promising impact in affecting operating speeds. It was thus assumed that there may be a collective or additive effect if all treatments were used simultaneously. Therefore all treatments were combined and tested at all 3 locations (Figures 19 and 20). The rumble strips were applied only to 12 stripes starting at the point of curvature and proceeding backward on the tangent. The underlying expectation here was that all these treatments applied together would have a greater effect in alerting the driver to reduce their speeds than the use of any one method by itself. The new sign, flashing lights and post delineators were all placed in the same manner as they had been in the previous treatments.

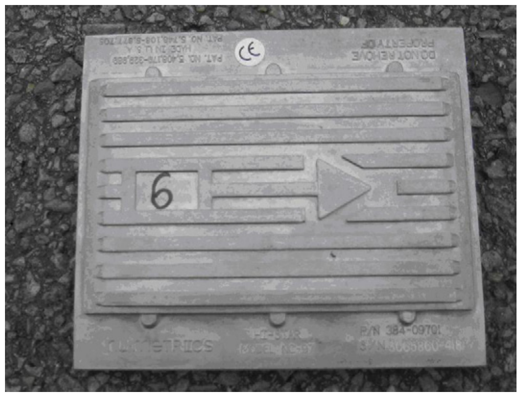
Figure 19. Lee Co. – Combination

Figure 20. Henry Co. – Combination

3.3 Speed Measurement

The speeds for this project were measured with HI-STAR Vehicle Magnetic Imaging Traffic Analyzers (Model NC-97). The HI-STAR devices are small sensors that are installed in the center of a travel lane and require no physical contact from vehicles to measure and record speeds (Figure 21). HI-STAR counters use vehicle magnetic imaging (VMI) to detect vehicles as they move through the earth's magnetic field. The metal from cars interferes with the magnetic field and this disturbance creates electrical signal changes in the HI-STAR sensors. This process allows the HI-STAR devices to accurately measure vehicle speeds and volumes.

Figure 21. HI-STAR unit.



The HI-STAR devices also came equipped with a computer analysis program, Highway Data Management (HDM). One of the primary functions of this software was to program the devices before each data collection exercise. HDM allows the user to set up a starting and ending time for the devices. The software also had many graphical and analytical assets, which could be used to evaluate the data. Another unique function of the HDM software is that it had the capability to track individual vehicles throughout a system of several in-line counters.

A potential problem for speed measurements is that not all vehicles pass over the devices. As noted above, four devices were used in each site and it was possible that some vehicles may only pass over some of the devices, thus hindering the data collection process. A common area that seemed to generate the most missed opportunities was the fourth device, which was placed in the curve and frequently produced a smaller number of observations than the other counters. The missed recordings can be attributed to vehicles actually using some of the paved shoulder to navigate the curve. Observations during site visits indicated that drivers often position their vehicle in a way that avoids the device or they actually drive over it.

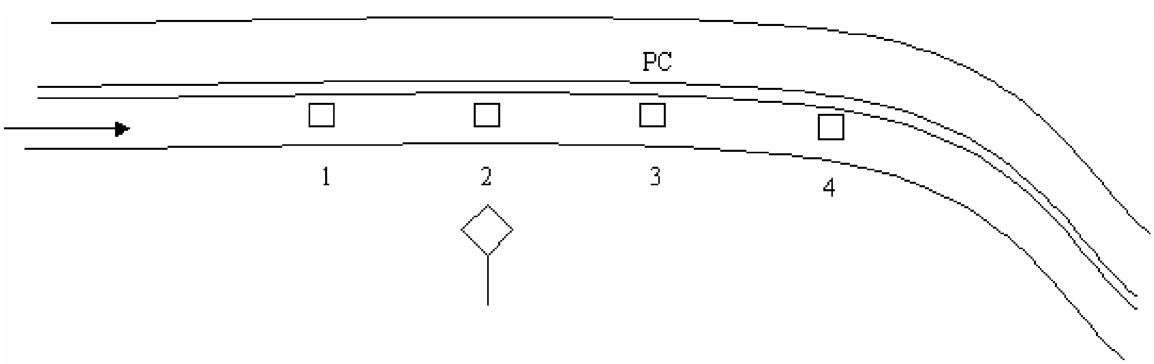
The problem with unmeasured speeds was solved with a program written in Microsoft Visual Basic. The program would evaluate the data of the four devices and delete the information associated with erroneous data, i.e. vehicles that could not be traced throughout the entire curve. Another concern with automated speed measurements is the ability to identify free flowing vehicles, i.e. vehicles that can determine their speeds based on the geometry of the roadway as opposed to the speed of a leading vehicle. Drivers following another driver do not represent the operating speed they would normally be traveling under free flow conditions and therefore the true response of these drivers to the warning treatment cannot be properly evaluated. To ensure that only the leading vehicles of platoons were used here, the software used minimum headways to determine whether vehicles were closely following other vehicles. This headway was then used to determine whether the next vehicle that passed over each device was a free flowing or a closely-following vehicle.

Figure 22 shows the typical layout for the location of the speed measuring devices. Device 2 was placed at the existing warning sign and it was approximately the mid point between devices 1 and 3. Device 3 was placed at the approximate point of curvature, and device 4 was in the curve. The distances for each are noted in Table 2.

TABLE 2 Speed measurement locations

Site	Distance between devices (ft)		
	1-2	2-3	3-4
Lee	200	215	370
Greenup	400	400	435
Henry	250	250	250

Figure 22. Typical right curve with measurement locations



3.4 Statistical Approach

To test for differences among various treatments and determine which treatment has the potential for a greater speed reduction, a series of statistical tests were used. The general null hypothesis is that no treatment has any effect on the speed reduction. To test this, two different tests were employed.

The first tests the difference in average speeds, and the second examines the variances of the speed distributions. The test for the average speeds allows for simple comparisons between averages and identifies whether a treatment affected the average speeds. This is achieved with a z-test. Similarly, the 85th percentile speeds were tested to determine any treatment effects. The second test examines whether the treatments have impacted the distribution of the speeds by forcing more drivers to drive at similar speeds, i.e. reducing the variance among speeds.

The two tests use the Bonferroni test to determine if the two null hypotheses (the average speeds are equal and the variances are equal) can be rejected. This test was first tested for all cases. The alternate hypotheses are that at least two of the average speeds are not equal and that at least two of the variances are not equal. If the Bonferroni test determines that the null hypotheses should be rejected, then the Dunnett C test is performed. The Dunnett C test is used for non-homogeneous variances and determines which treatments affected the average speeds and variances significantly.

4 SITE TREATMENTS

The three sites were different in curve radii, existing signage, and tangent length. Therefore, each site had unique characteristics that enabled or prohibited certain treatments from being applied.

4.1 KY 52 (MP 19.5; WB), Lee County

Speeds were measured at the Lee County site for the following conditions:

1. Measurements were taken under the existing conditions: a Horizontal alignment sign with a 15 mph speed plaque in advance of the curve and 8 chevrons located on the outside of the curve.
2. Bright orange flags were placed on the existing warning sign.
3. A large arrow sign was placed between the second and third chevrons. The large arrow was placed so that it could be seen from the tangent section of the roadway.
4. The new combination Horizontal Alignment/Advisory Speed sign was located at the point of curvature, after the existing warning sign.
5. Eight post delineators were added throughout the curve. The first delineator was placed 100 feet before the point of curvature and the rest of the delineators were placed 100 feet subsequently throughout the curve.
6. A total of 15 transverse lines were used. The total length of the line combination was 550 feet, beginning 335 feet before the existing warning sign and ending at the point of curvature. The first (moving toward the curve) eight lines had a width of 4 feet and were the length of one 12-foot lane. The final seven lines had a width of 2 feet and were also the length of one 12-foot lane. The lines were only used in the westbound lane, because it was the tangent section that led into the curve. The spacing for the first two lines was 65 feet, the next three spacings were 50 feet, the next three were 40 feet, the next three were 30 feet, and the final three spaces were each separated by 20 feet. White highway paint was used with reflective beads.
7. The following year, speeds were measured again for the transverse lines as they were previously laid out.
8. Preformed tape to simulate rumble strips was placed on 12 of the transverse lines beginning at the point of curvature extending back into the tangent section.
9. The new combination Horizontal Alignment/Advisory Speed sign replaced the existing warning sign. Two 6-inch flashing lights were mounted on the upper portion of the sign and they were visible to drivers only at night. Post delineators were placed on the inside of the curve at 50-foot intervals from the point of curvature to the end of the curve. The rumble strips placed during the previous trial remained in place during this measurement as well.[2]

[2] The new combination sign was to supplement the existing sign but due to miscommunication with the District personnel it replaced the existing. To create a constant environment for comparisons, this installation was repeated in the other sites.

4.2 KY 1 (MP 5.7; SB), Greenup County

Speeds were measured at the Greenup County site for the following separate conditions:

1. Measurements were taken under the existing conditions: a Horizontal alignment sign with a 35 mph speed plaque in advance of the curve, 3 chevrons located on the outside of the curve, and a large arrow sign also located on the outside of the curve.
2. Two bright orange flags were added on the existing warning sign.
3. The new combination Horizontal Alignment/Advisory Speed sign was located at the point of curvature after the existing warning sign.
4. Two flashing lights were fixed on the upper portion of the existing warning sign. The flashing lights were 6-inch lights that are commonly used on construction barrels, and the flashing of the lights was only visible during darkness.
5. Flashing lights were located on both the existing warning sign and the new combination Horizontal Alignment/Advisory Speed sign, which was reinstalled for this treatment.
6. A total of 10 post delineators were added throughout the curve. The first delineator was placed 50 feet before the existing warning sign and the second delineator was placed 50 feet after the warning sign, with the rest of the delineators following in 50-foot intervals.
7. A total of 24 transverse lines were placed on the curve approach. The total length of the line combination was 885 feet, beginning 445 feet before the existing warning sign and ending at the point of curvature. The first (moving toward the curve) 13 lines had a width of 4 feet and were the length of one 12-foot lane. The final 11 lines had a width of 2 feet and were also the length of one 12-foot lane. The lines were only used in the westbound lane, because it was the tangent section that led into the curve. The first three line spacings were 65 feet, the next four spacings were 50 feet, the next six spacings were 40 feet, the next five were 30 feet, and the final five spaces were each separated by 20 feet. White highway paint was used with reflective beads.
8. One year later, speeds were measured again for the transverse lines condition as previously laid out.
9. Rumble strips were placed on 12 of the transverse lines beginning at the point of curvature extending back into the tangent section.
10. The new combination Horizontal Alignment/Advisory Speed sign replaced the existing warning sign. Two 6-inch flashing lights were mounted on the upper portion of the sign and they were visible to drivers only at night. Post delineators were placed on the inside of the curve at 50-foot intervals from the point of curvature to the end of the curve. The rumble strips placed during the previous trial remained in place during this measurement as well.

4.3 KY 146 (MP 5.5; EB), Henry County

Speeds were measured at the Henry County site for the following conditions:

1. Measurements were taken under the existing conditions: a Horizontal alignment sign with a 40 mph speed plaque in advance of the curve and 3 chevrons located on the outside of the curve.
2. Two bright orange flags were added on the existing warning sign.
3. The new combination Horizontal Alignment/Advisory Speed sign was located at the point of curvature after the existing warning sign.
4. Two flashing lights fixed on the upper portion of the existing warning sign.
5. Flashing lights were located on both, the existing warning sign and the new combination Horizontal Alignment/Advisory Speed sign, which was reinstalled for this scenario.
6. Three additional chevron warning signs were located before the existing three signs.
7. 10 post delineators were added throughout the curve. The first delineator was placed 50 feet before the existing warning sign and the second delineator was placed 50 feet after the warning sign, with the rest of the delineators following in 50-foot intervals.
8. A total of 24 transverse lines were placed on the curve. The total length of the line combination was 885 feet, beginning 445 feet before the existing warning sign and ending at the point of curvature. The first (moving toward the curve) 13 lines had a width of 4 feet and were the length of one 12-foot lane. The final 11 lines had a width of 2 feet and were also the length of one 12-foot lane. The lines were only used in the westbound lane, because it was the tangent section that led into the curve. The first three line spacings were 65 feet, the next four spacings were 50 feet, the next six spacings were 40 feet, the next five were 30 feet, and the final five spaces were each separated by 20 feet. White highway paint was used with reflective beads.
9. Speeds were measured again the following year for the transverse lines condition as previously laid out.
10. Rumble strips were placed on 12 of the transverse lines beginning at the point of curvature extending back into the tangent section.
11. The new combination Horizontal Alignment/Advisory Speed sign replaced the existing warning sign. Two 6-inch flashing lights were mounted on the upper portion of the sign and they were visible to drivers only at night. Post delineators were placed on the inside of the curve at 50-foot intervals from the point of curvature to the end of the curve. The rumble strips placed during the previous trial remained in place during this measurement as well.

5 RESULTS

The goal of this project was to evaluate the effectiveness of the treatments used on these sites. The data was analyzed using the average speeds, average speeds for day and night, overall changes in average speeds from one measurement location to another, percentage changes in average speeds from one measurement location to another, 85th percentile speeds, variances, and frequency distributions.

5.1 Lee County

Speed measurements were taken at the Lee County site for nine separate situations (Table 3).

TABLE 3 Lee County - Treatments and average speeds

	Speeds (mph)					Percent Change			
Treatment	1	2	3	4	Total reduction	1	2	3	4
Existing	51.1	46.6	43.4	29.5	-21.6	-[1]	-[1]	-[1]	-[1]
Flags	50.9	46.9	43.3	28.5	-22.4	-0.4	0.6	-0.2	-3.4
Arrow	51.4	47.4	43.9	29.0	-22.4	0.6	1.7	1.2	-1.7
New sign	52.0	47.9	44.3	29.2	-22.8	1.8	2.8	2.1	-1.0
Delineators	52.1	48.2	44.1	28.9	-23.1	2.0	3.4	1.6	-2.0
Lines	51.8	47.8	44.1	29.6	-22.3	1.4	2.6	1.6	0.3
Lines[2]	50.4	46.9	44.0	30.1	-20.3	-[3]	-[3]	-[3]	-[3]
Rumble	50.7	46.8	44.2	30.2	-20.5	0.6	-0.2	0.5	0.3
All combined	49.7	45.1	42.7	29.0	-20.7	-1.4	-3.8	-3.0	-3.7

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

The first test performed was to determine whether there was any difference in the overall speed distribution between the two transverse line measurements. The statistical analysis indicated that the means and variances for these two distributions are different and therefore the new measurements should be compared only to the new transverse lines condition. The average speeds noted in Table 3 indicate that no treatment had any significant effect on operating speeds. On the contrary, the speeds for some treatments were greater than the speeds of the existing conditions, which may indicate that most of the treatments may have increased the comfort level of the driver and thus encouraged them to drive faster than intended. Of interest here is the total speed reduction between the first and last measurement point. These figures indicate a small improvement for some treatments, where a larger reduction was observed compared to the existing conditions. A significant (both numerically and statistically) difference was noted for the treatment that combined several of the treatments indicating that this combination may be capable of drawing drivers' attention. It should also be noted that the current speeds at the transverse lines are lower than, and statistically different from, the speeds measured last year for all measurement sites with the exception of the last site. This indicates that the transverse lines had a significant lasting effect in maintaining the overall speed profile for this curve but all were higher than the existing conditions; unchanged from last year. The biggest change in speed from the first measurement location to the last measurement location was 23.1 mph (44.3%) by the post delineator treatment (Table 3). This could be possibly attributed to the fact that the post delineators were installed at the point of curvature (the third measurement location) and then carried on through the curve, whereas, all the other treatments were installed either before the point of curvature or no further into the curve than the point of curvature. Therefore, the post delineators had a warning effect well through the curve and the fourth measurement location.

The percentage change in the average speed shows that the biggest change can be seen at the second measurement location (Table 3). Therefore, the second measurement location was used to perform a statistical analysis to determine if any of the treatments have a significant impact on the average speeds. The statistical analysis revealed that the flags on the existing sign, the large arrow sign, the combination warning sign, the post delineators, the transverse lines (both installations), and the combination of treatments significantly affected the average speed for this site. The only treatment that showed speed reductions in comparison to the existing conditions was that of a combination of treatments. One can only speculate as to why the average speeds increased for the other treatments. A potential reason could be that the new treatments increased the driver comfort level, thus allowing the drivers to navigate the curve faster. Another possibility could be that the drivers disregarded the new warning signs and they had no effect on attracting the drivers' attention. A third reason could be that the additional warnings had no effect at all on operating speeds, and that the lower speeds for the existing treatment could have been caused by any number of random possibilities such as weather, construction, or crashes.

Another approach that can be used to reiterate or emphasize changes in the average speeds from the existing treatment is to observe the 85^{th} percentile speeds. The 85^{th} percentile speeds are expected to be larger than the average speeds and the speed changes are also expected to be similar to those observed for the average speeds (Table 4). The data indicate that the total speed reduction is greater for the 85^{th} percentile speed. However, it should be noted that the percent reduction, as measured in comparison to the speeds at the first measurement location, is similar to that observed in the average speed. The only exception to this was the combination of treatments, which showed a slightly larger total reduction. These data indicate that none of the treatments had a more significant impact on the 85^{th} percentile speeds.

TABLE 4 Lee County - Treatments and 85th percentile speeds

Treatment	Speeds (mph) 1	2	3	4	Total reduction	Percent Change 1	2	3	4
Existing	55.7	51.2	46.5	31.6	-24.1	-[1]	-[1]	-[1]	-[1]
Flags	56.4	52.0	47.3	31.5	-24.9	1.3	1.6	1.7	-0.3
Arrow	56.2	51.4	47.2	31.6	-24.6	0.9	0.4	1.5	0.0
New sign	56.9	52.6	47.7	32.0	-24.9	2.2	2.7	2.6	1.3
Delineators	57.1	52.8	47.4	31.5	-25.6	2.5	3.1	1.9	-0.3
Lines	56.8	52.5	47.6	32.3	-24.5	2.0	2.5	2.4	2.2
Lines[2]	57.9	53.9	49.5	34.7	-23.2	-[3]	-[3]	-[3]	-[3]
Rumble	58.5	53.8	50.4	35.3	-23.2	1.0	-0.2	1.8	1.7
All combined	57.9	52.7	48.9	33.3	-24.6	0.0	-2.2	-1.2	-4.0

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

It could be hypothesized that even if a treatment did not affect the average and 85th percentile speeds, it may influence the speeds of vehicles exceeding the 85th percentile speed. This is a positive indication, since these drivers could be considered as the ones that may have a larger crash potential. It should be noted here that the analysis was performed using the vehicles that were exceeding the 85th percentile speed at the first measurement location by examining their speed change as they proceeded to the other three measurement locations. The data of these speeds indicates that all treatments had an effect on the over the 85th percentile speeds. The effect was even greater for the last measurement location, since larger reductions are noted for all treatments. It should be noted here that the 85th percentile and average speeds in the fourth location did not show any differences as compared to the existing conditions. A notable trend for this analysis is the higher speeds for the fourth measurement location one year later. Even though the combination treatment produced similar percent speed reductions, the speeds are significantly higher than previously experienced.

TABLE 5 Lee County - Treatments and greater than 85th percentile speeds

Treatment	Speeds (mph) 1	2	3	4	Total reduction	Percent Change 1	2	3	4
Existing	60.4	55.3	50.0	34.1	-25.7	-[1]	-[1]	-[1]	-[1]
Flags	60.8	55.4	49.9	33.8	-27.0	0.7	0.2	-0.2	-0.9
Arrow	60.2	53.4	47.7	30.5	-29.7	-0.3	-3.4	-4.6	-10.6
New sign	60.1	53.3	48.2	30.7	-29.4	-0.5	-3.6	-3.6	-10.0
Delineators	61.0	53.8	48.5	31.0	-30.0	1.0	-2.7	-3.0	-9.1
Lines	60.6	53.7	48.1	31.5	-29.1	0.3	-2.9	-3.8	-7.6
Lines[2]	60.6	56.8	52.7	39.8	-20.8	-[3]	-[3]	-[3]	-[3]
Rumble	61.6	57.5	53.9	39.5	-22.1	1.7	1.2	2.3	-0.8
All combined	60.8	56.1	52.6	36.7	-24.1	0.3	-1.2	-0.2	-7.8

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

Although the average speeds indicate that there was no significant reduction in operating speeds, the analysis for the time of day indicated that average nightly speeds were noticeably reduced (Table 6). For instance, at the first measurement location, the warning sign with flags had almost a 4% (1.9 mph) reduction in average speed. This could be possibly attributed to the distance that the flags can be seen from, when headlights shine on them. Some other noticeable nighttime reductions were at the fourth measurement location, where several treatments experienced a 4-5% average speed reduction. Even though the overall speed reductions for this site are minimal (or nonexistent for most cases), the nighttime average speeds show a promising attribute in that several of the locations show a significant reduction in speed. A point that could be made here is that a dark environment has few distractions away from the roadway. So if there are fewer novelties to attract the attention of drivers, then more focus can be put on the road signs, warnings, and pavement markings. Therefore, the drivers pay closer attention to the attributes of the roadway and adjust their speeds accordingly.

TABLE 6 Lee County - Treatments and time of day average speeds

	Day Speeds (mph)				Night Speeds (mph)			
Treatment	1	2	3	4	1	2	3	4
Existing	51.1	46.7	43.4	29.2	50.9	46.2	43.3	30.3
Flags	52.1	47.9	44.1	29.2	49.0	46.4	43.4	28.9
Arrow	51.8	47.8	44.2	29.0	49.9	45.9	42.6	29.0
New sign	52.4	48.3	44.5	29.3	49.9	46.0	43.1	28.7
Delineators	52.4	48.4	44.2	29.0	50.5	47.2	43.5	28.7
Lines	52.2	48.3	44.4	29.6	49.8	45.7	42.5	29.4
Lines[1]	50.7	47.3	44.5	30.0	49.4	45.9	42.8	30.5
Rumble	50.8	46.7	44.0	29.7	50.4	47.3	44.8	32.4
All combined	50.0	45.2	42.2	28.9	49.0	44.9	44.1	29.3

Notes: [1] Transverse lines speed measurements one year later

5.2 Greenup County

The results for the speed measurements taken at the Greenup County site are shown in Table 7. It should be noted that the speed was not measured for the post delineators and transverse lines for the fourth measurement location due to uncontrollable circumstances.

TABLE 7 Greenup County - Treatments and average speeds

	Speeds (mph)					Percent Change			
Treatment	1	2	3	4	Total reduction	1	2	3	4
Existing	52.2	48.9	45.8	35.7	-16.5	-[1]	-[1]	-[1]	-[1]
Flags	51.3	47.6	44.5	35.6	-15.7	-1.7	-2.7	-2.8	-0.3
Lights	52.7	48.8	45.6	36.5	-16.2	1.0	-0.2	-0.4	2.2
New sign	52.5	48.7	45.0	35.7	-14.8	0.6	-0.4	-1.7	0.0
Both lights	53.0	48.4	44.3	35.9	-14.1	1.5	-1.0	-3.3	0.6
Delineators	52.8	49.4	45.3	--	--	1.1	1.0	-1.1	--
Lines	52.1	47.4	43.1	--	--	-0.2	-3.1	-5.9	--
Lines[2]	49.1	46.0	43.4	35.6	-13.5	-[3]	-[3]	-[3]	-[3]
Rumble	49.8	46.0	43.7	35.4	-14.4	1.4	0.0	0.7	-0.6
All combined	51.4	46.3	43.7	35.4	-16.0	4.7	0.7	0.7	-0.6

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

Similar trends are observed at this site as in Lee County. The statistical analysis indicated that the means and variances for the two distributions measured for the transverse lines a year apart are different and therefore the new measurements should be compared only to the new transverse lines condition. For most treatments the average speeds increased indicating no impact at this location. The only noticeable reductions were for flags, transverse lines (both times), and rumble strips. Of interest here is the observation that the combination treatment did not have significant reductions at each measurement point but had a larger overall speed reduction between the first and last measurement locations (16 mph, 31.4%) than the other two treatments. It should be also noted here that the speeds at the transverse lines were lower a year later indicating the potential for a lasting effect on impacting operating speeds in curves. The probable cause for the speed reduction involving the addition of the flags at the first measurement location is that it was the most visible treatment from a longer distance (400 ft) than any of the other treatments.

There were several treatments that experienced significant average speed reductions at the second measurement location. This is also where the existing curve warning sign was placed. The fourth measurement location experienced no significant average speed reductions compared to the existing conditions. On the contrary, some treatments showed an increase in average speeds. It should be noted here that the first installation of the transverse lines showed a potential for decreasing the speeds at the fourth location since they had the highest speed reduction among all treatments by the third measurement location.

The statistical analysis performed focuses on the third measurement location, because it had the largest overall change in speeds. These tests indicated that the warning sign with flags, both signs with flashing lights, the transverse lines (both installations), rumble strips, and combination treatment significantly affected the average speed and variances. Therefore, it can be concluded that these treatments had a direct impact on the reduction of speeds when compared to the existing conditions.

The 85th percentile speeds and 85th percentile percent changes are larger than the average speeds and percent changes, but the change compared to the existing conditions are very similar (Table 8). The only noticeable differences are at the third measurement location for the transverse lines (both installations), rumble strips, and combination treatment.

TABLE 8 Greenup County - Treatments and 85th percentile speeds

	Speeds (mph)					Percent Change			
Treatment	1	2	3	4	Total reduction	1	2	3	4
Existing	57.1	53.1	49.5	38.4	-18.7	-[1]	-[1]	-[1]	-[1]
Flags	56.1	51.5	47.7	38.3	-17.8	-1.8	-3.0	-3.6	-0.3
Lights	57.4	53.4	49.7	38.8	-18.6	0.5	0.6	0.4	1.0
New sign	57.5	53.1	48.7	38.3	-19.2	0.7	0.0	-1.6	-0.3
Both lights	57.3	53.1	47.9	38.5	-18.8	0.4	0.0	-3.2	0.3
Delineators	57.7	54.3	49.7	--	--	1.1	2.3	0.4	--
Lines	56.8	51.8	47.7	--	--	-0.5	-2.4	-3.6	--
Lines[2]	56.7	52.7	52.6	40.1	-16.6	-[3]	-[3]	-[3]	-[3]
Rumble	58.2	54.0	50.7	39.8	-18.4	2.6	2.5	-3.6	-0.7
All combined	58.6	53.7	50.6	39.8	-18.8	3.4	1.9	-3.8	-0.7

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

The data for the vehicles exceeding the 85th percentile speed indicated that only the transverse lines (initial installation) had any effect on these speeds (Table 9). Therefore, at this location, no treatment had any significant effect on the high speeds.

TABLE 9 Greenup County - Treatments and greater than 85th percentile speeds

	Speeds (mph)					Percent Change			
Treatment	1	2	3	4	Total reduction	1	2	3	4
Existing	61.0	55.9	50.7	38.6	-22.4	-[1]	-[1]	-[1]	-[1]
Flags	60.3	53.9	48.7	37.5	-22.7	-1.1	-3.6	-3.9	-2.8
Lights	61.3	55.5	50.5	39.6	-21.7	0.5	-0.7	-0.4	2.6
New sign	61.8	55.6	50.4	38.9	-22.9	1.3	-0.5	-0.6	0.8
Both lights	61.0	54.4	48.8	38.7	-22.3	0.0	-2.7	-3.7	0.3
Delineators	61.3	55.9	49.6	--	--	0.5	0.0	-2.2	--
Lines	60.4	54.0	47.9	--	--	-1.0	-3.4	-5.5	--
Lines[2]	60.3	55.8	53.1	42.4	-17.9	-[3]	-[3]	-[3]	-[3]
Rumble	61.0	56.5	54.6	42.4	-18.6	1.2	1.3	2.8	0.0
All combined	62.4	57.4	54.6	42.5	-19.9	3.5	2.9	2.8	0.2

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

Even though no significant differences were noted for the treatments when the average speeds were analyzed (Table 7), noticeable differences were noted in some treatments when analyzed by time of day (Table 10). The treatments involving the warning sign with flashing lights and the combination Horizontal Alignment/Advisory Speed sign experienced average speed reductions of well over 3% at nighttime. This could indicate that drivers reduce their speed while approaching the curve, but eventually reach the same or greater speeds entering the curve as under existing conditions.

TABLE 10 Greenup County - Treatments and time of day average speeds

	Day Speeds (mph)				Night Speeds (mph)			
Treatment	1	2	3	4	1	2	3	4
Existing	52.5	49.1	46.1	35.9	50.8	47.8	44.7	34.9
Flags	51.4	47.7	44.5	35.7	51.2	47.1	44.5	35.2
Arrow	53.0	49.1	45.8	36.6	51.7	47.3	44.6	36.1
New sign	52.6	48.7	45.0	35.61	52.1	48.2	45.2	36.2
Both lights	53.2	48.7	44.6	36.0	52.0	47.1	42.9	35.7
Delineators	52.9	49.5	45.4	--	52.0	48.5	44.9	--
Lines	52.1	47.5	43.4	--	52.8	47.4	43.2	--
Lines[1]	48.9	45.8	43.5	35.6	49.7	46.5	43.1	35.4
Rumble	50.0	46.2	44.1	35.4	49.1	45.3	42.1	35.6
All combined	51.8	47.0	44.3	35.3	49.2	44.4	41.5	35.6

Notes: [1] Transverse lines speed measurements one year later

5.3 Henry County

Speed measurements for the Henry County site are shown in Table 11. Data for the fourth location was not available for the first two treatments due to uncontrollable conditions.

TABLE 11 Henry County - Treatments and average speeds

Treatment	Speeds (mph) 1	2	3	4	Total reduction	Percent Change 1	2	3	4
Existing	53.5	53.4	48.5	--	--	-[1]	-[1]	-[1]	-[1]
Flags	53.9	53.4	48.5	--	--	0.7	0.0	0.0	--
Lights	55.4	51.2	49.6	45.3	-10.1	3.6	-4.1	2.3	--
New sign	54.6	50.6	48.7	44.5	-10.1	2.1	-5.2	0.4	--
Both lights	54.6	50.3	48.8	44.6	-10.0	2.1	-5.8	0.6	--
Chevrons	53.6	52.7	48.3	43.6	-10.0	0.2	-1.3	-0.4	--
Delineators	52.8	48.9	48.6	42.8	-10.0	-1.3	-8.4	0.2	--
Lines	52.9	50.2	49.6	46.2	-6.7	-1.1	-6.0	2.3	--
Lines[2]	51.9	52.2	47.0	46.8	-5.1	-[3]	-[3]	-[3]	-[3]
Rumble	52.9	49.0	48.7	44.4	-8.5	1.9	-6.1	3.6	-5.1
All combined	52.5	48.6	47.6	43.5	-9.0	1.2	-6.9	1.3	-7.1

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

The measurements for the two transverse line installations were different and therefore the newer measurements are compared to the new transverse line installation. All treatments showed a similar overall reduction which is lower than those observed in any of the other sites. The second measurement site showed some relevant speed reductions for all treatments and with higher reductions observed for the additional chevrons, post delineators, rumble strips and combination treatments. Given the fact that the measurements at the first location did not show any changes, on the contrary some showed an increase, these results may indicate that the drivers did not recognize or see the warnings, until after they passed the first measurement site. A possible reason for the sudden reduction in average speed for the second measurement could be the high level of speed (the average speed for all treatments combined was approximately 55 mph) associated with the first measurement. With a high speed, drivers would have less time to react to the warning, which could possibly result in a speed reduction after the first measurement location. Another possible reason for these differences may be the fact that the existing warning sign is a 36-inch sign, whereas, in other locations the signs are larger (48-inch sign). Of interest here is the large reduction observed at the fourth measurement location for the new installations (rumble strips and combination treatments) which indicates a higher effectiveness at this site from these treatments.

For this location the biggest changes in speed were noted at the second measurement location. Therefore, the statistical analysis will be performed using the measured speeds from the second measurement location. The tests revealed that the warning sign with flashing lights, the new combination warning sign, the additional chevrons, both signs with flashing lights, the rumble strips, post delineators, and combination of treatments significantly affected the average speed and variances. Therefore, it can be concluded that these treatments had a direct impact on the reduction of speeds when compared to the existing conditions.

The analysis of the 85th percentile speeds showed, in general, similar results as those observed for the average speeds (Table 12). The highest overall speed reduction was noted for the additional chevrons and the new treatments (rumble strips and combination treatment) had a larger overall speed reduction than in the average speeds.

TABLE 12 Henry County - Treatments and 85th percentile speeds

	Speeds (mph)					Percent Change			
Treatment	1	2	3	4	Total reduction	1	2	3	4
Existing	57.5	57.0	52.2	--	--	-[1]	-[1]	-[1]	-[1]
Flags	58.1	57.6	52.3	--	--	1.0	1.1	0.2	--
Lights	59.6	55.2	53.4	48.7	-10.9	3.7	-3.2	2.3	--
New sign	59.2	54.7	52.4	47.8	-11.4	3.0	-4.0	0.4	--
Both lights	59.2	54.3	52.4	47.8	-11.4	3.0	-4.7	0.4	--
Chevrons	58.4	55.9	51.9	46.2	-12.2	1.6	-1.9	-1.3	--
Delineators	57.2	53.4	52.7	46.7	-10.5	-0.5	-6.3	1.0	--
Lines	56.8	53.9	53.4	49.8	-7.0	-1.2	-5.4	2.3	--
Lines[2]	58.5	58.3	52.4	52.1	-6.4	-[3]	-[3]	-[3]	-[3]
Rumble	59.5	55.4	54.6	49.4	-10.1	1.7	-5.0	4.2	-5.2
All combined	58.9	55.1	53.7	48.9	-10.0	0.7	-5.5	2.5	-6.1

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

The analysis for the over the 85th percentile speeds did not produce any new insight for any of the treatments (Table 13). The overall speed reductions however were greater than in any of the other measures (average and 85th percentile speeds) which indicated that all treatments had an effect on reducing these speeds.

TABLE 13 Henry County - Treatments and greater than 85th percentile speeds

Treatment	Speeds (mph) 1	2	3	4	Total reduction	Percent Change 1	2	3	4
Existing	61.1	58.8	52.4	--	--	-[1]	-[1]	-[1]	-[1]
Flags	62.2	59.4	52.7	--	--	1.8	1.0	0.6	--
Lights	63.1	56.3	53.8	48.6	-14.5	3.3	-4.3	2.7	--
New sign	63.2	56.8	53.5	47.8	-15.4	3.4	-3.4	2.1	--
Both lights	63.2	56.6	53.6	48.0	-15.2	3.4	-3.7	2.3	--
Chevrons	62.5	56.4	52.8	48.1	-14.4	2.3	-4.1	0.8	--
Delineators	61.2	55.5	54.3	47.1	-14.1	0.2	-5.6	3.6	--
Lines	60.2	55.6	53.7	49.4	-10.8	-0.9	-5.4	2.5	--
Lines[2]	61.1	61.3	54.8	54.3	-6.8	-[3]	-[3]	-[3]	-[3]
Rumble	62.5	58.8	57.6	52.3	-10.2	2.3	-4.1	5.1	-3.7
All combined	61.8	58.6	56.4	51.9	-9.9	1.1	-4.4	2.9	-4.4

Notes: [1] Percent differences are to the existing conditions
[2] Transverse lines speed measurements one year later
[3] Percent differences are to the transverse lines

The analysis of the speeds by the time of day showed some reductions again at nighttime for some treatments (Table 14). These reductions included the warning sign with flashing lights, the combination Horizontal Alignment/Advisory Speed sign, the flashing lights on both warning signs, and the combination treatment. In addition to the effect of the treatment, another reason for the high average speed reductions for the nighttime readings could be attributed to the higher ADT for this site than the other two sites (Table 1). The higher ADT resulted in a larger sample for nighttime drivers in Henry County may also had a greater impact on the overall average speeds, thus decreasing the nighttime average speeds so significantly. An unexplainable increase was noted at the first measurement location after the addition of flashing lights to the existing warning sign, since during the daytime, this treatment essentially acts as the existing treatment would, considering the flashing lights do not flash during the day. A similar increase was also noted for the nighttime, which does not correlate well with the results from the other sites.

TABLE 14 Henry County - Treatments and time of day average speeds

	Day Speeds (mph)				Night Speeds (mph)			
Treatment	1	2	3	4	1	2	3	4
Existing	53.9	53.9	49.0	--	52.7	52.6	47.4	--
Flags	54.1	53.6	48.9	--	53.5	53.0	47.8	--
Arrow	56.1	51.9	50.3	45.8	54.2	49.9	48.3	44.5
New sign	55.2	51.3	49.3	45.0	53.1	49.0	47.3	43.4
Both lights	55.3	51.0	49.5	45.2	53.0	48.6	47.2	43.2
Chevrons	53.9	52.7	48.5	43.6	53.0	53.8	47.7	43.4
Delineators	53.6	49.7	49.2	43.4	51.2	47.4	47.4	41.7
Lines	53.1	50.5	50.0	46.4	52.4	49.6	49.0	45.8
Lines[1]	52.4	52.5	47.5	47.3	50.8	51.4	45.9	45.7
Rumble	53.0	49.3	48.9	44.4	52.6	48.4	48.2	44.4
All combined	52.7	48.8	47.8	43.5	52.3	48.5	47.4	43.5

Notes: [1] Transverse lines speed measurements one year later

5.4 Transverse Lines Effectiveness Over 1 Year Span

As noted above, the transverse lines treatment was tested twice with each test occurring about 1 year apart allowing for an additional comparison of their long term effectiveness (Table 15). The statistical analysis performed on the average speeds indicated that the measurements were different and the new average speeds were lower than the first measurements for several of the measurement locations. Therefore, it could be concluded that the changes that were observed after the initial installation were not due to the novelty effect but rather had a more permanent impact. It may be of interest to revisit these sites in the near future to examine the long-term effect of the rumble stripes.

TABLE 15 One year comparison of average speeds for transverse line treatments

Site	Treatment	Speeds (mph)			
		1	2	3	4
Lee	Old	51.8	47.8	44.1	29.6
	New	50.4	46.9	44.0	30.1
Greenup	Old	52.1	47.4	43.1	
	New	49.1	46.0	43.4	
Henry	Old	52.9	50.2	49.6	46.2
	New	51.9	52.2	47.0	46.8

6 CONCLUSIONS

The problem with inconsistently designed roadways is that they do not lend any clues to the driver as to the appropriate action to take at hazardous or unexpected curves. Two methods of conveying necessary roadway information to the driver are warning signs and pavement markings. For this study, several warning signs and pavement markings were implemented at rural curves to evaluate their effectiveness to reduce operating speeds. A literature review was performed to evaluate past experiences with similar situations and to potentially determine which warning signs and pavement markings are the most effective. Several curves were chosen as potential study sites and these sites were narrowed down based on several criteria including curvature, rural location, long tangent section, absence of vertical grade, intersections, driveways, or commercial activity, and willingness of the district to assist in treatment placement and removal. Speeds were measured at three locations at each site involving several treatments. The speed data was then analyzed to determine what treatments were the most effective.

The data from the three sites gave mixed results as to the effectiveness of treatments in reducing operating speeds and a summary for all sites is shown in Table 16, where statistical significance is noted with the check mark.

TABLE 16 Summary of treatment effectiveness

	County		
Treatment	Lee	Greenup	Henry
Flags @ existing sign	✓	✓	
Large arrow	✓	NA	NA
Lights @ existing sign	NA	✓	✓
New combination sign	✓		✓
Both signs with lights	NA	✓	✓
Chevrons	NA	NA	✓
Post delineators	✓		✓
Transverse lines	✓	✓	
Transverse lines[1]	✓	✓	
Rumble strips		✓	✓
All treatments combined	✓	✓	✓

Notes: [1] Transverse lines speed measurements one year later

The data for Lee County indicates no major speed reductions for most of the treatments but with all treatments tested showing a statistically significant difference when compared to the existing conditions. It should be noted that for most of the treatments the speeds were greater than the existing conditions. The data for Greenup County showed considerable speed reductions for all treatments. However, there were two treatments (post delineators and new combination sign) that the results were not statistically significant. Moreover, the two treatments that experienced the most significant speed reductions were the flashing lights on both warning signs and the transverse lines. Finally, the data for Henry County also showed speed reductions for some of the treatments. The treatments that experienced the most significant speed reductions were the post delineators, rumble strips, and combination of treatments.

Of interest here is also the fact that the combination of treatments also had a significant effect in reducing operating speeds at these sites. In order to have the most significant impact on operating speed, it is best to use warning treatments in combination, particularly in combination with rumble strips. Rumble strips were the only means of conveying an audible or physical message to the driver that a reduction in speed is necessary. It will be of interest to evaluate these treatments in the future to determine their long term effectiveness. Overall, the use of lights (both at the existing sign and both signs) had a significant effect in impacting operating speeds. These changes were even more significant at nighttime where the lights were more visible. The transverse lines also showed a promising trend, especially when considering that this treatment had a significant effect on maintaining its effectiveness regarding operating speeds a year later. The transverse lines showed considerable speed reduction for Greenup County and probably would have seen similar results at Lee County if the pavement pattern was longer (it was adjusted after the Lee County data collection to provide for a longer warning period).

A noteworthy finding of this work was that for all three sites, the average of the speeds over the 85th percentile speed showed a reduction indicating that most treatments have the potential to affect high speeds more than the average or 85th percentile speed. It can be concluded that some of the warning signs and pavement markings do moderately reduce the operating speeds of vehicles. The warning signs with flashing lights can reduce speeds and the new combination warning sign can also be quite effective with the addition of flashing lights.

The objective of this work was to determine if anything can be done to reduce operating speeds by providing additional warning information to the driver. Based on these findings, some of the treatments have shown promising results. The addition of flashing lights had such an effect as well as the use of rumble strips and a combination of treatments. However, there are possible options that could even enhance these treatments. For example, the flashing lights were only working at nighttime, which might explain their increased effectiveness as compared to the existing conditions. Therefore, the use of lights that could be visible also at daytime could have the same impact. Based on past research, transverse lines over a greater length are more effective at reducing speeds. Transverse lines could also be carried out through the curve, instead of stopping at the point of curvature. Finally the use of larger signs, especially for the new combination sign, may also improve the effectiveness of the treatment because drivers could see it from a further distance away.

An aspect of this work that was not addressed is the variability among the curves used here. All three curves have different characteristics but the effect of such parameters, such as volume and degree of curvature, cannot be evaluated with only these three sites. Therefore, there is a need to test these treatments at more curves in order to accurately determine whether drivers moderate their behavior based on the curve characteristics and not the treatment itself. Some of the differences that could impact the speed measurements are short tangent leading into the curve at Lee County and the bridge approximately 500 feet prior to the point of curvature at Henry County. Therefore, if all curves are different, then all speed reductions will behave differently, so the ideal type of curve to be studied should be determined.

The methodology developed here seems to be appropriate for the completion of the study. An improvement of this approach will be the longer data collection period. The time between speed measurements and the installation of new treatments is very important, because a suitable amount of time should be set aside for motorists to become acquainted with the new warning. A short time frame could lead to speeds that are not indicative of the true effectiveness of the treatment. Therefore, if a similar study is to be undertaken in the future, it is recommended to collect data over a longer period of time and to allow for a longer period before the data is collected.

The results of the study indicate that there are some promising treatments that have the potential to impact operating speeds and particularly high speeds. The new combination curve warning and suggested speed seems to have a positive effect on reducing speeds and its use is encouraged. However, it is recommended that it should be used with caution to avoid overuse and thus be disregarded by drivers. The use of flashing lights is recommended for most sites, since they at least have the potential to impact operating speeds at night. The transverse lines with or without rumble strips seem to be working adequately in reducing speeds and are expected to be promising treatments. Finally, the combination of treatments seems to be the only consistent treatment that had an impact on all three sites and therefore its use should be seriously considered.

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