Speed Limit Effectiveness in Short-Term Rural Interstate Work Zones

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ABSTRACT

Average speed and speed variance are two characteristics of traffic flow that affect accident rates and severity near work zones. Operationally, work zones account for approximately twenty-four percent of the non-recurring delay. A policy for work zone speed limits has to delicately balance the safety and the efficiency impacts. If speeds are set too low, then avoidable congestion and speed violations might result. If speeds are set too high then, again, safety may be compromised. In this paper, results from field studies conducted on three Interstate 70 maintenance short-term work zones in rural Missouri are presented for three different speed limit scenarios: 1) no posted speed limit reduction, 2) 10 mph posted speed limit reduction and 3) 20 mph posted speed limit reduction. The 85th percentile speeds and standard deviation of speed were found to be 81 mph and 10 mph; 62 mph and 8 mph; and 48 mph and 6 mph, respectively for the three scenarios. The differences in 85th percentile speed and standard deviation of speed among all three scenarios were statistically significant. The percent of drivers who exceed speed limit by over 10 mph were 15.4%, 4.8%, and 0.9%, respectively. Thus a reduction in posted speed limit was effective in reducing prevailing speeds and speed variances in short term work zones in rural Missouri.

Keywords: Speed limit Effectiveness, Work Zones, Rural Interstates

1. INTRODUCTION

According to Garber and Woo, two characteristics of traffic flow that affect accident rates and severity near work zones are average speed and speed variance (Garber and Woo, 1990). Chin et al. report that work zones account for approximately twenty-four percent of the non-recurring operational delay (Chin et al., 2002). High traffic speeds could be a major safety concern in highway work zones and a potential risk to both motorists and workers. According to Li and Bai (2008), up to 25% of fatal crashes in work zones involved high speeds. On the other hand, a large speed variance coupled with hazardous conditions at work zones (e.g., workers’ presence, lane closure, and narrow lanes) could also lead to higher crash rates at work zones. The study of Migletz et al. (1999) showed that crash rates increase as speed variance increases. According to Garber and Gadiraju (1988), large speed differentials occur at work zones where speed limits have been considerably reduced from normal speed limits because most drivers tend to drive at a speed that in their opinion is suitable for the prevailing conditions regardless of the posted speed limit. Therefore, in order to increase safety at work zones, it is important to establish an appropriate work zone speed limit that will achieve high driver compliance as well as low speed variance.

The Missouri Department of Transportation (MoDOT) desired to investigate the speed limit reduction strategy that is most effective for the safety of highway work zones. Many states have enacted temporary speed reduction regulations and a variety of speed limits are in place across the country. The most commonly used speed limits are 0 mph, 5 mph, 10 mph, and 20 mph reductions. This variation in speed limits also exists in terms of type of work zone activity, type of roadway, type of traffic control device used, method of enforcement, penalties, type of work and construction zone, and others. Several studies have been conducted on work zone speed limits. Richards et al. (1985) researched work zone speed limits in Texas. Their study recommended that existing speeds, work zone design speed, and work zone conditions be considered when selecting the speed limits and recommended speed reductions by different roadway types. Finley et al. (2008) studied motorist perceptions and reactions to reduced work zone speed limits and other work zone conditions, and concluded that work zone speed limit reduction should be selected based on work zone conditions such as lane encroachment, lane closure, and temporary diversion. NCHRP Project 3-41 developed a uniform procedure for determining work zone speed limits (Graham-Migletz, 1996). Migletz et al. (1999) summarized other studies that showed that accident rate increases with deviation from the average speed of traffic. A survey of states showed that 29 states consider certain factors to determine work zone speed limit reductions, five states always reduce speed
limits, and the remaining states avoid reducing speed limits. The Manual of Uniform Traffic Control Devices (MUTCD, 2009) states, “Research has demonstrated that large reductions in the speed limit, such as a 30 mph reduction, increase speed variance and the potential for crashes. Smaller reductions in the speed limit of up to 10 mph cause smaller changes in speed variance and lessen the potential for increased crashes. A reduction in the regulatory speed limit of only up to 10 mph from the normal speed limit has been shown to be more effective.” Mahoney et. al (2006) surveyed state DOTs about speed limit reductions adopted in work zones and found that the majority of states that responded to the survey had policies similar to the MUTCD guidance.

A number of speed control techniques are currently used by state DOTs in the U.S. These include the posting of regulatory and advisory speed limit signs, using the latest radar technologies and the involvement of law enforcement. While important for conveying information to the public, regulatory and advisory speed limit signs alone have been shown to have minimal impact on reducing traffic speeds (Maze et al., 2000). There have been studies showing that augmenting static signs with other techniques might increase driver compliance to speed limits. Benekohal et al. (1992) studied the speed reduction effects of speed limit signs augmented with strobe lights. Their results indicated that the average speeds of cars and trucks were reduced by 1.9–7.1 mph and 1.3–6.0 mph, respectively. The study concluded that, in general, the percentages of vehicles with excessive speeds at work zones decreased when strobe lights were flashing. Speed limits have also been imposed using changeable message signs. Recently, variable speed limits have also been evaluated in the states of Michigan and Maryland (Brewer et al., 2005). Motorists respond better to variable speed limits and can result in better driver compliance, lower speed variability, and higher safety as they are considered more realistic compared to static speed limits. McMurtry et al. (2009) developed a methodology to investigate the applicability and effectiveness of variable speed limits (VSL) signs at work zones in Utah. The study showed that the standard deviation of speed and the percentage of vehicles exceeding speed limits have reduced significantly when VSL signs were used. Effectiveness of law enforcement to improve the speed limit compliance of traffic through the work zone was also evaluated. According to Outcalt (2009), for situations requiring speed reductions of 15 mph or more, it is effective to add message signs and law enforcement vehicles and officers. The study also concluded that a speed reduction of more than 20 mph probably needs the presence of law enforcement to be effective. Benekohal et al. (2009) evaluated the effectiveness of speed photo-radar enforcement (SPE). The study found that SPE was effective to reduce the mean speeds of work zones as well as the percentage of vehicles exceeding speed limit. Previous related studies have used several performance measures to evaluate the effectiveness of speed limits in work zones. Measures such as mean speed, speed variance (Graham-Migletz, 1996), 85th percentile speed, compliance, and percentage of traffic exceeding the speed limit by 5 mph (Finley et al., 2008) have been used.

This study fills a specific gap in the existing work zone safety literature. Previous studies have primarily focused on driving behavior in long-term work zones where lane drops are in place for days, if not for weeks or months. On the other hand, the driving behavior in short-term work zones that last for a day or less is not well understood. Much of the DOTs’ maintenance work zones are of this nature. Despite their ubiquitous presence on freeways existing research in work zone safety has not focused on these short duration work zones. Possible reasons include the difficulty in collecting data at short notice – although maintenance schedules are planned well in advance, several factors such as weather and other contingencies make it difficult to predict the exact day of work zone. In rural areas, typically state DOTs do not have the same level of traffic monitoring as they would in urban areas (CCTVs, sensors, etc). This means that researchers must be prepared to deploy their own traffic monitoring equipment at short notice.
Nevertheless, it is important to understand the differences in driving behavior between short-term and long-term work zones and how they affect the operating speeds in work zones. Short-term maintenance work zones have an element of surprise as drivers may not know or plan in advance which would result in increased driver alertness. Due to their short duration drivers approaching a short-term work zone are likely to expect workers being present inside the work zone and therefore be more cautious. Although not always, long-term work zones use concrete barriers to separate workers from the traffic lanes unlike short-term work zones that typically use cones or delineators. All these factors could have an effect on the operating speeds of drivers.

The current study focuses specifically on such short short-term maintenance work zones whose durations are less than one day. The findings of this study will fill the gap in literature by providing a better understanding of the driving behavior and safety in short-term maintenance work zones. The main objective of this research was to conduct empirical examination of the relationship between speed limits and driving behavior at short-term work zones. Field studies were conducted on three Interstate 70 maintenance short-term work zones in Missouri for three different speed limit scenarios: 1) no reduction in the posted speed limit (i.e., the speed limit in the segment is the same with or without the work zone), 2) a 10 miles per hour (mph) reduction in the posted speed limit, and 3) a 20 miles per hour in the posted speed limit.

2. FIELD STUDIES
2.1. Data Collection

Short-term maintenance work zones on Interstate 70 were selected for studying the relationship between posted speed limits and traffic behavior. Special attention was given during the site selection process to ensure that the chosen sites had similar characteristics. This was important to ensure that the operating speeds at all the sites were similar during normal (non-work zone) conditions. Three sites on Interstate 70 within close proximity of each other (mile markers 102, 104, 148) were selected. Figure 1 shows a map of these study locations. All sites were in rural areas and were similar in terms of terrain, geometric, daylight hours, low volume, traffic composition, and driver population. All work zones involved a right lane closure with the passing lane open (2 to 1 work zone). In this research, only free flow vehicles were considered. A vehicle following another vehicle was constrained by the speed of the leader which was at a lower speed than desired. Therefore, the speeds of following vehicles were not considered their desired speeds and were dropped from further analysis. It is important to note that individual vehicle data was used in this study in contrast to studies that use aggregated data that do not eliminate following vehicles, such as 30 second loop data.

The speeds of vehicles approaching the work zone were measured using two methods, 1) a radar speed gun, and 2) video cameras in conjunction with video processing software. Speed gun data was used for calibrating the speeds extracted from videos. Delineators were placed at known distances and aligned with lane markings to assist with the calibration of video data processing. Missouri highway lane markings are spaced 40 feet apart according to the MUTCD (MoDOT, 2010). The layout of work zone delineator setting is shown in Figure 2. For all scenarios, the data collection began immediately after the work zone was set up.

Three work zone scenarios were captured in this study:

• **Scenario 1:** No speed limit reduction
The posted speed limit was 70 mph. Data was collected east of Kingdom City, Missouri at mile marker 148.4 on Interstate 70 on June 2, 2009. Approximate times of collection were from 9:00 a.m. to 4:30 p.m. Westbound traffic was monitored.

- **Scenario 2**: 10 mph speed limit reduction
  The posted speed limit was 60 mph. Data was collected near Boonville, Missouri at mile marker 105.1 on Interstate 70 on September 15 and 16, 2009. Approximate times of collection were from 12:20 p.m. to 4:00 p.m. for September 15, and from 9:40 a.m. to 2:10 p.m. for September 16. Eastbound traffic was monitored.

- **Scenario 3**: 20 mph speed limit reduction
  The posted speed limit was 50 mph. Data was collected near Boonville, Missouri at mile marker 102.0 on Interstate 70 on August 12, 2009. Approximate times of collection were from 7:30 p.m. to 10:15 p.m. (only data during day light hours was processed). Westbound traffic was monitored.

### 2.2. Data Analysis and Results

Automated video processing software was used in processing video for traffic parameters. The software recognized vehicles by detecting the pixel changes on screen generated by moving vehicles. Additionally, 5 minutes of speed radar data was used for calibrating speeds from the video processor. The calibration adjusted the speed trap distance to minimize the average absolute difference of speeds. The descriptive statistics of speeds for each scenario is shown in **Table 1**. Table 1 shows the posted speed limit as 70, 60 and 50 mph, the 85th percentile speeds as 81, 62 and 48 mph and the standard deviation as 10, 8 and 6 mph. The standard deviation decreased from 10 mph to 6 mph as the posted speed limit dropped from 70 mph (Scenario 1) to 50 mph (Scenario 3). According to TRB (1998), lower mean speeds and standard deviations are desirable for improving traffic safety.

Analysis of variance (ANOVA) was used to test for significant differences in means. **Table 2** shows that the 5 mph difference in mean speeds between the 50 mph and 60 mph speed limits was statistically significant. Similarly, the 14 mph difference in mean speeds between the 60 mph and the 70 mph speed limits was also statistically significant. Thus there was evidence that lower means speeds resulted from speed limit reductions.

Vehicle speed variability was analyzed statistically using the F-test. Scenario 1 (70 mph) was compared with Scenario 2 (60 mph), and Scenario 2 with Scenario 3 (50 mph). In **Table 3**, the F-test results indicate that speed variance differences were statistically significant in both comparisons. The standard deviation was reduced from 10 mph to 6 mph as the posted speed limit dropped from 70 mph (Scenario 1) to 50 mph (Scenario 3). According to TRB (1998), lower mean speeds and standard deviations are desirable for improving traffic safety.

In addition to examining the central tendency and variability of the speed distributions, the distributions themselves were also investigated using the Kolmogorov-Smirnov (KS) test. The cumulative distributions of speeds in all three scenarios followed S-shaped curves as shown in **Figure 3**. The KS test results indicated that the cumulative speed distributions from the three scenarios were statistically different across all three data sets. The KS test confirmed what is visually evident from **Figure 3**. Hence the reduction in the speed limit shifted the entire speed distribution to the left.

Driver compliance was examined using the following five indicators of speed limit compliance:
1) 85th percentile speed, 2) percent of traffic not exceeding (or complying with) posted speed limit, 3) percent of traffic exceeding posted speed limit by 5 mph or less, 4) percent of traffic exceeding posted...
speed limit by more than 5 mph but less than 10 mph and 5) percent of traffic exceeding posted speed by 10 mph or more. The 85th percentile speeds were previously presented in Table 1. Except for Scenario 1 for which the 85th percentile speed was 11 mph higher than speed limit, the 85th percentile speeds in other two scenarios were within 2 mph of the speed limits. The percentage of traffic complying with the posted speed limit increased with the lowering of speed limits in work zones. When the speed limit was not reduced, 50.8% of vehicles complied with the posted limit; whereas, 74.1% and 89.5% of vehicles complied when the speed limit was lowered by 10mph and 20mph, respectively.

The magnitude of speed by which speeders exceeded speed limits was further examined, because exceeding the speed limit by more than 10 mph is more severe than exceeding the speed limit by 5 mph or less. The percentage of speeding less than 5 mph, between 5 to 10 mph and over 10 mph is shown in Figure 4. In Scenario 1, 18.8% of drivers exceeded by 5 mph or less, 15.0% exceeded between 5 to 10 mph, and 15.4% exceeded by 10 mph or more. In Scenario 2, 13.9% exceeded by 5 mph or less, 7.1% exceeded between 5 to 10 mph, and 4.8% exceeded by 10 mph or more. In Scenario 3, 8.1% exceeded by 5 mph or less, 1.6% exceeded between 5 to 10 mph, and 0.9% exceeded by 10 mph or more. When the speed limit was reduced to 50 mph, the percentage of drivers exceeding the speed limit by between 5 to 10 mph and by over 10 mph decreased drastically. The binomial proportion test was used to examine the percentage of drivers exceeding the speed limit. The results show that the percentages across all three speed limits were statistically significant at a p-value of <0.0001. The box plots in Figure 5 show the difference between the speed and speed limit is tightest for the 20 mph reduction scenario. The plots also show slight skewness towards a positive difference for the no-reduction and the 10 mph reduction scenarios.

2.3. Discussion of Findings

One major distinction between the current study and previous studies is the duration of work zones. All previous studies focused specifically on long-term work zones that had work zone traffic control and lane closures set up for several days, if not weeks. In contrast, the focus of the current study was short-term maintenance work zones that lasted for one day. The current study also differs from previous studies such as NCHRP 3-42 (Graham-Migletz, 1996) in that the speed limit of 70 mph is higher than the speed limits of up to 65 mph found in the 3-42 test sites.

In this study, driver compliance to speed limits at maintenance work zones increased with the reduction in speed limit. The mean speed, 85th percentile speed, and speed variance all decreased due to the reduction of posted speed limit. These results are in partial agreement with previous field studies conducted at long-term work zones. Several studies have recommended that a 10 mph reduction in speed limit at work zone is ideal (compared to no-reduction or other scenarios) in terms of increased compliance, 85th percentile speeds (Finley et al., 2008), and minimal increase in speed variance between upstream and work zone locations (Graham-Migletz, 1996). However, any further reduction in the speed limit (say by 20 mph) has previously not been found to be effective in terms of speed performance measures. In the current study, the trend in compliance continued when the speed limit was reduced from 10 mph below the speed limit to 20 mph below the speed limit. Thus the current results from short term work zones differ slightly from previous results from long term work zones that found a 20 mph reduction to be ineffective.
In addition to the short-term versus long-term work zone differences there are some differences in the chosen measures of effectiveness among various studies. The NCHRP project 3-41 (Graham-Migletz, 1996) measured the increase in speed variance between upstream and inside the work zone. For a 10 mph reduction in speed limit, it was found that this variance increase was minimal and not statistically significant. In the current study, the speed variance of vehicles approaching the taper (after they passed the reduced speed limit sign) was computed. The current study focuses on the critical safety region just upstream of the taper. This location appears to be somewhere between the upstream and work activity locations used in the NCHRP study.

Finley et al. (2008) used the difference in 85th percentile speed upstream of the work zone (normal posted speed limit) and the 85th percentile speed at the work area. Another measure was the percent of traffic exceeding the work zone speed limit at the work area by 5 mph or more. Again, such field studies consisted of work activity lasting more than one day with work zone speed limits being in effect 24 hours a day and seven days a week. Based on the results of these two measures they concluded that a 10 mph maximum speed limit reduction is still warranted for work zones involving lane closures, especially when the existing speed limits are more than 65 mph.

To summarize, the results found in this study were measured at short-term maintenance work zones that lasted for a day or less and had a regular speed limit of 70 mph. The effectiveness of reduced speed limits was evaluated using speed-related parameters measured near the taper area after the vehicles have passed the reduced speed limit sign. The driver behavior observed in this study showed that drivers are possibly more compliant to the reduced speed limits at short-term work zones than at long-term work zones. As identified earlier, possible explanations include, 1) short-term work zones have an element of surprise associated with them as drivers may not know or plan in advance which would result in increased driver alertness, and 2) given the short duration of a work zone drivers are likely to expect workers being present inside the work zone and therefore be more cautious.

3. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study was to evaluate the effectiveness of three different speed limit reduction scenarios in work zones: no speed limit reduction, 10 mph reduction and 20 mph reduction. With the increase of speed limit reduction from 0 to 10 mph, the percentage of speeding was almost halved. When speed limit was further reduced by 10 mph, the percentage of speeding was about one fifth of the percentage under the no speed limit reduction scenario. If exceeding the speed limit by more than 10 mph was considered aggressive driving, then in the no speed limit reduction scenario about 1 in 7 was an aggressive driver, in the 10 mph speed limit reduction scenario about 1 in 21 was an aggressive driver, and in the 20 mph speed limit reduction scenario the aggressive drivers were almost non-existent.

The decline in the mean speed and 85th percentile speed when the posted speed limit was reduced was evidence that lowering the speed limit was successful in reducing prevailing traffic speeds in short-term work zones. Further analysis of speed variance showed that lowering the speed limit in work zones did not lead to greater variation in vehicle speeds. In this study, the speed standard deviations were 10 mph, 8 mph, and 6 mph for 70 mph, 60 mph, and 50 mph speed limits, respectively.

Lower speeds and the speed variance in work zones result in a safer environment for both vehicles and work zone personnel. The 20 mph speed limit reduction scenario turned out to be the most
effective in terms of lowering prevailing speeds and the speed variance. Almost a 90% compliance rate was achieved for the 20 mph speed limit reduction scenario. Within the 10% of those who exceeded speed limit, 80% of them were by less than 5 mph. The 10 mph speed limit reduction was also effective in reducing speeds and the speed variance. Thus the current results support the MUTCD recommendation that 10 mph reductions could be effective (FHWA, 2009). But this study also suggests that a 20 mph reduction might also be effective in short term rural interstate work zones with conditions similar to those found in this study (e.g. driver population, traffic composition (truck percentage), short-term maintenance work, rural interstate and 70 mph speed limit).

This article only addressed the speed-related safety aspects of rural work zone speed limit reduction where the field sites did not exhibit significant congestion. There are many other important factors that are typically considered in determining speed limit policies including traffic flow, congestion, queuing, proximity of work, type of work activity and the magnitude of the existing speed limit. Thus a policy for setting work zone speed limits has to delicately balance speed-related safety with other myriad factors.

ACKNOWLEDGMENTS

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REFERENCES


Table 1 Speed Statistics

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<th>Scenario 2</th>
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<tr>
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<td>70</td>
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<td>Duration of data collection (hrs)</td>
<td>7.5</td>
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<td>2483</td>
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Table 2 Result of T-Test on Average Speeds

a. Between 50 mph and 60 mph Speed Limit

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b. Between 60 mph and No Reduced Speed Limit

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Table 3 Result of F-Test on Speed Variance

a. Between 50 mph and 60 mph Speed Limit

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<th>Critical region</th>
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<td>Speed limit 50 mph</td>
<td>36</td>
<td>1.778</td>
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<td>Speed limit 60 mph</td>
<td>64</td>
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b. Between 60 mph and No Reduced Speed Limit

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Figure 1 Location of study work zones (Google, 2010).

Figure 2 Layout of delineator setting in the field.

Figure 3 Comparison of speeds distribution under different speed limits.

Figure 4 Percentage speeding by less than 5 mph, between 5 to 10 mph, and over 10 mph.

Figure 5. Box plots showing difference in speed and posted speed limit for different scenarios.
Boonville (2 study sites)

Kingdom City (1 study site)

Figure 1 Location of study work zones (Google, 2010).
Figure 2 Layout of delineator setting in the field.

ALL DELINEATORS ARE SPACED 40 FEET APART CORRESPONDING TO THE BACK OF THE STRIPING. THE BACK OF THE FIRST VISIBLE CENTER STRIPE CORRESPONDS TO CONE 2.
Figure 3 Comparison of speeds distribution under different speed limits.

Figure 4 Percentage speeding by less than 5 mph, between 5 to 10 mph, and over 10 mph.
Figure 5. Box plots showing difference in speed and posted speed limit for different scenarios.