Determining Motorists' Response to Signage in Rural Highway Work Zones

Kris Finger, Research Assistant
Department of Civil, Environmental, and Architectural Engineering
University of Kansas
1530 W. 15th Street, 2150 Learned Hall
Lawrence, KS 66045
Tel: (785) 864-2991
Fax: (785) 864-5631
E-mail: finger84@ku.edu

Yong Bai, Ph.D., P.E.
Associate Professor
Department of Civil, Environmental, and Architectural Engineering
University of Kansas
1530 W. 15th Street, 2150 Learned Hall
Lawrence, KS 66045
Tel: (785) 864-2991
Fax: (785) 864-5631
E-mail: ybai@ku.edu
(Corresponding Author)

Yue Li, Research Assistant
Department of Civil, Environmental and Architectural Engineering
University of Kansas
1530 W. 15th Street, 2160 Learned Hall
Lawrence, KS 66045
Tel: (785) 864-2598
Fax: (785) 864-5631
E-mail: ylkx7@ku.edu

Umar Firman, Research Assistant
Department of Civil, Environmental and Architectural Engineering
University of Kansas
1530 W. 15th Street, 2160 Learned Hall
Lawrence, KS 66045
Tel: (785) 864-2598
Fax: (785) 864-5631
E-mail: umar_firman@yahoo.com

Submit Date: July 31, 2008
Word count: 6,650 (text: 3,900; tables: 6 x 250 = 1,500; figures: 5 x 250 = 1,250.)

ABSTRACT
For decades the importance of highway work zone safety has increased considerably with the continual increase in the number of work zones present on highways for repairs and expansion. Rural work zones on two-lane highways are particularly hazardous and cause a significant safety concern, due to the disruption of regular traffic flow. In this study, researchers determined motorists' response to warning signs in rural two-lane highway work zones. The researchers divided vehicles into three classes (passenger car, truck, and semitrailer) and compared the mean change in speed of these classes based on three different sign setups; portable changeable message sign (PCMS) off, PCMS on, and a temporary traffic sign (W20-1, "Road Work Ahead"). Field experiments were conducted on 2 two-lane rural highways in Kansas (US 36 and US 73/159). The mean change in speed of each vehicle class for each setup was calculated. Statistical software was used on the data to perform a univariate analysis of variance test to check whether or not there was a significant interaction between motorists' response and sign setups. The results showed that for the passenger car class there was a significant interaction with the signs.

INTRODUCTION

Safety within highway work zones has been an important issue and major concern of engineers, government agencies, the highway industry, and the public for decades due to the disruption of regular traffic flows. This safety concern has been a focus of both government organizations and researchers alike, and recently the federal government has recognized its importance and helped address the issue with the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU).

Though researchers have published numerous studies on various safety-related work zone issues, there are still numerous issues to be resolved and practices to be improved upon. Safety in work zones on two-lane rural highways is one such issue and the focus of this study. How safe a driver is driving is a big factor in how safe motorists and construction workers are. Temporary traffic control (TTC) measures are used to inform drivers of road conditions down stream of them. Work zone safety is also affected in large part by the type of vehicles passing through the work zone. Benekohal and Shim found that 90% of tractor-trailer truck drivers surveyed considered travelling through a work zone to be a more dangerous than traveling on roads not affected by construction (*1*). In this study researchers evaluated the effectiveness of TTC measures based on motorists' response to signage, by placing the motorist in one of three classes based on the length of their vehicle including passenger car, truck, and semitrailer.

LITERATURE REVIEW

A national study found that average fatalities per crash and fatal crash frequency were higher in work zones (*2*). The study found that rural highways accounted for 69% of all fatal crashes. Another study found that accident rates on highways are 7% to 119% higher in work zones than on roads without any construction (*3*). With the increased likely hood of crashes and fatalities in work zones and the raising number of work zones across the nation it is obvious that something needs to be done to increase work zone safety. Numerous studies have been conducted on the subject of work zone safety. These studies have focused on every thing from safety implications and risk analysis of highway work zones to analyzing crashes within work zones to the evaluation and development of technologies and signage in work zones.

According to the Manual on Uniform Traffic Control Devices (MUTCD) a work zone is divided into four areas: the advance warning area, the transition area, the activity area, and the termination area (*4*). Previous studies published agree that there is an unbalanced distribution of crash within these four areas. In different literature the advanced warning area (*5*), the activity area (*6, 7*), the transition area, and the termination area (*8, 9*) were highlighted as being the most dangerous area in terms of severe crash frequency. There have been plenty of studies done on the development, use, and effectiveness of changeable message signs (CMS) in reducing speeds and informing traffic of the pending work zone ahead. Various studies have shown that the using a CMS is more effective than traditional work zone traffic control devices at reducing the number of speeding vehicles in work zones (*10, 11, 12*). However, Richards and Dudek state that CMS could result in only modest reductions (less than 10 mph) when used alone and that they would lose their effectiveness if operated continuously for long periods with the same message.
Other researchers have decided to concentrate their efforts on examining the actual vehicles and drivers passing through the work zone. A major work zone safety concern is the frequent involvement of heavy trucks in work zone crashes. Studies have found that the percentage of truck-involved crashes was much higher in work zones (*2, 5*). Studies also found that heavy truck related crashes were more likely to involve multiple vehicles, thus frequently resulted in

fatalities and large monetary loss (*5, 7*). However, a study done in Georgia found that single-vehicle crashes, angle, and head-on collisions were the dominant type of fatal work zone crashes (*13*).

Though there has been a substantial amount of research conducted and studies published on work zone safety, particularly in the areas of use of CMS and vehicle type causality of crashes, questions remain. A vast majority of studies focus their efforts on the interstate highway system and on rural primary roads. There have only been a handful of studies which focus their efforts on two-lane rural highways. Few of these studies have attempted to evaluate CMS or focus on vehicle size. This study has evaluated the effects of a portable changeable message sign (PCMS) and a temporary traffic sign (TTS) based on the motorists' response.

OBJECTIVES

The primary objectives of this research are: 1) to determine the effectiveness of a PCMS and a TTS, specifically W20-1 ("Road Work Ahead") on rural two-lane highway work zones, 2) to determine motorists' response to signage in rural two-lane highway work zones.

DATA COLLECTION AND PRELIMINARY ANALYSIS

Data Collection

Field experiments were conducted on US 36 west of Seneca, Kansas and on US 73/159 from Horton to Hiawatha following a construction company as they moved from one segment to another down each road resurfacing the highway. The field experiments and data collection was conducted for 4 days (June 3 – June 6) on US 36 and for 1 day (June 13) on US-73. This research included two traffic signs (PCMS and W20-1) that were setup in three cases:

1. PCMS turned off
2. PCMS turned on ("Slow Down, Drive Safely")
3. TTS: W20-1 ("Road Work Ahead")

For cases 1 and 2 the two SmartSensor HD (Model 125) radar sensor systems were setup to collect vehicle speed and length data, one in front and one behind the PCMS. For case 3 the first sensor was setup around the first TTS (W20-1), in the advanced warning zone. Figures 1 and 2 below provide a further more detailed description of the layout and spatial referencing of materials for each case. Figure 3 shows the PCMS and typical sensor setup.

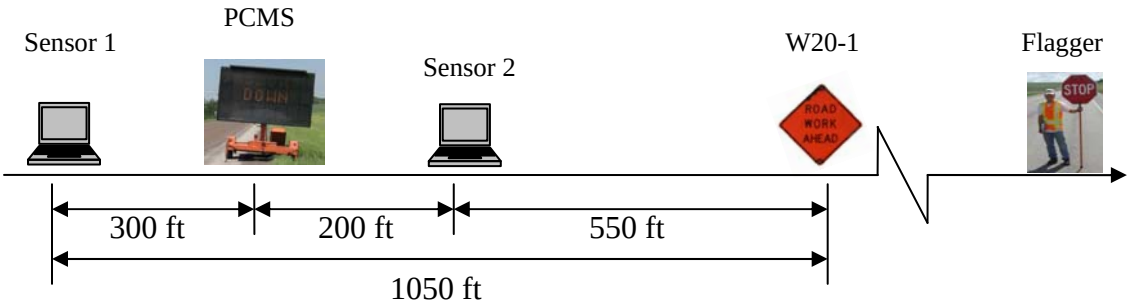

FIGURE 1 Location of sensors and PCMS sign in work zone for cases 1 & 2

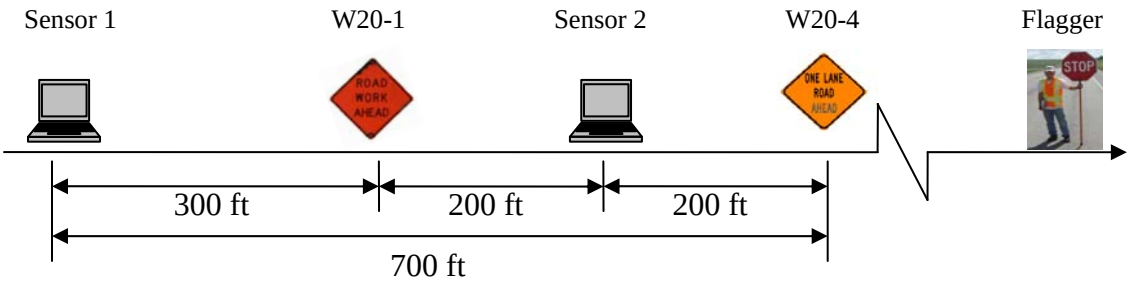

FIGURE 2 Location of sensors in work zone for case 3

FIGURE 3 PCMS and setup of sensors

Preliminary Data Analysis

The raw data collected from the field experiments went through an extensive screening and analysis process. The raw data was first thoroughly screened by matching individual vehicle data points recorded on both sensors 1 and 2. Any vehicle that was recorded on one sensor but that didn't have a corresponding data point on the other sensor was thrown out. Also, if there were two corresponding data points though one sensor's data didn't record an accurate vehicle length, speed, or any other value was missing the data point was discarded from the data population. Finally, any point that had a vehicle speed under 20 mph, for either sensor, was excluded from data set because the sensor's specifications stated that the sensor could not proper record speeds under 20 mph. Through this initial data screening and analysis the raw data was narrowed down and sorted before using a statistical analysis program to perform further calculations and analysis.

The values of speed and length for each vehicle collected by the two sensors were then inserted into a statistical analysis program along with a corresponding numerical value to represent which sign was present when the values were recorded. The differences in the values of speed and length between sensors 1 and 2 were then calculated and a frequency analysis was

performed based on these calculated values. The results showed that there was a wide range of values for change in length with a standard deviation of 3.5 feet. It was decided that the majority of values were within two standard deviations (7 feet), and therefore all other points with a positive or negative change greater than 7 were discarded. This was done to account for errors in the sensors ability to accurately read a vehicles length. The final population consisted of 876 vehicle-data points, they are broke down by case in Table 1 and by class in Table 2.

The vehicles classes were determined using AASHTO Green Book definitions. A passenger car is defined as being 19 feet long and the smallest semitrailer (WB-12[WB-40]) is defined as being 45.5 feet long (*14*). Therefore class 1 (Passenger Car) includes any vehicle with an average length of 19 feet or less and class 3 (Semitrailer) includes any vehicle with an average length equal to or greater than 45 feet. The result being that class 2 (Truck) is defined as any vehicle with an average length greater than 19 feet and less than 45 feet. After the individual data points were sorted by length and assigned a class statistical analyses were performed.

TABLE 1 Break Down of Data Points by Case

CASE	No. of Data	Percent of Total (%)
PCMS OFF	409	46.7
PCMS ON	334	38.1
TTS	133	15.2
Total	876	100.0

TABLE 2 Break Down of Data Points by Vehicle Class

Vehicle Class	No. of Data	Percent of Total (%)
Passenger Car	394	45.0
Truck	381	43.5
Semitrailer	101	11.5
Total	876	100.0

FREQUENCY ANALYSIS

The frequency of individual vehicle speed changes, sorted by vehicle class are shown in the histograms in Figure 4. Each histogram in Figure 4 also contains a bell curve which represents a plot of the normal distribution of the data set. The frequency of individual vehicle speed changes tends to follow the normal distribution of the bell curve, for each vehicle class. Table 3 shows the results of the data collected during field experiments. It breaks the data down by vehicle class and then displays the results for each case based on the vehicle class.

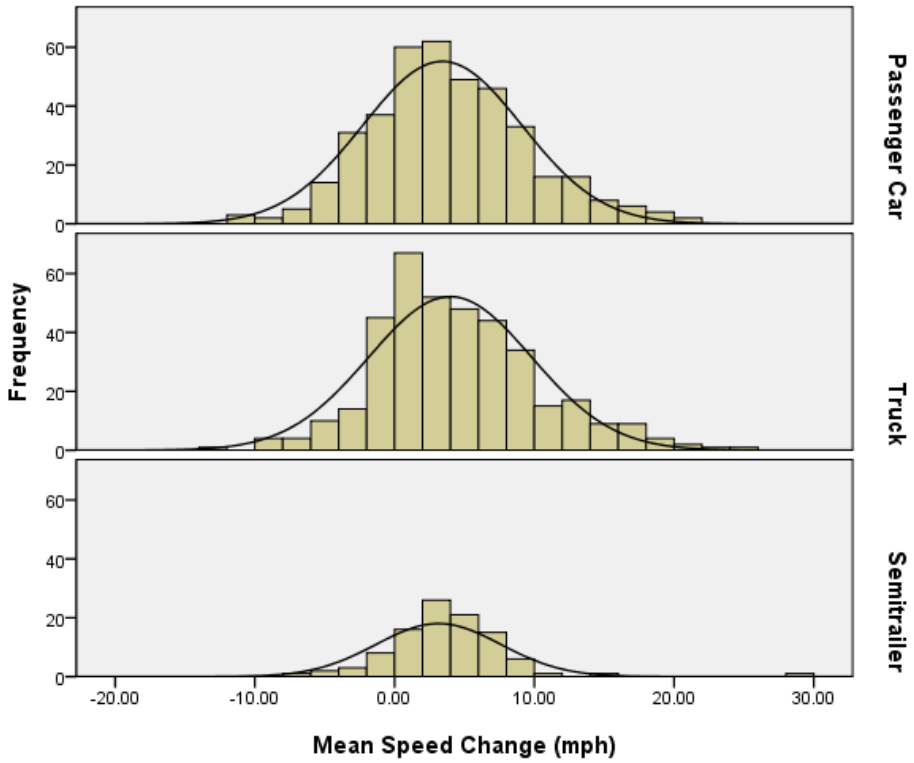

FIGURE 4 Histograms showing frequency of speed change by vehicle class

TABLE 3 Mean Speed Values Based on Class for Each Case

Vehicle Class	Case	N	Sensor 1 Speed (mph)	Sensor 2 Speed (mph)	Mean Speed Change (mph)	Speed Change Percentage
Passenger Cars	PCMS OFF	188	60.2	57.9	2.4	3.90%
	PCMS ON	132	58.5	54.5	3.9	6.70%
	TTS	74	50.5	45.3	5.2	10.30%
Trucks	PCMS OFF	174	59.4	55.7	3.7	6.20%
	PCMS ON	154	57.0	52.3	4.7	8.30%
	TTS	53	48.2	45.4	2.8	5.80%
Semitrailers	PCMS OFF	47	61.6	58.6	3.0	4.80%
	PCMS ON	48	59.1	56.1	3.1	5.20%
	TTS	6	49.2	44.2	5.0	10.20%

When the PCMS is turned off, for passenger car, truck, and semitrailer classes, the speed reductions are 2.4 mph, 3.7 mph and 3.0 mph, over a 500 foot distance, respectively. It shows that the PCMS, though it was turned off, it still can affect a vehicle's speed, and the truck class was the most affected up to 3.7 mph, up to 6.2% reduction over a 500 foot distance.

When the PCMS is turned on, for passenger car, truck, and semitrailer classes, the speed reductions are 3.9 mph, 4.7 mph and 3.1 mph over a 500 foot distance. It shows when the PCMS is on, the speed reduction of passenger car and truck classes goes up 1.5 mph and 1.0 mph respectively over a 500 foot distance. The PCMS affect truck's speed most, up to 8.3%.

When there was a TTS (no PCMS), for passenger car, truck, and semitrailer classes, the speed reductions are 5.2 mph, 2.8 mph and 5.0 mph, over a 500 foot distance, respectively. It

shows that of the vehicles approaching the advance warning area, the passenger car class slows down most, about 5.2 mph. For the semitrailer class, the speed reduction is about 5.0 mph. However, this is not the same effect as the PCMS. The TTS had less effect on the truck class, by only 2.8 mph.

For the passenger car class, from the Table 3 above, the greatest speed reduction occurred when approaching the TTS, in the advance warning area, with a 10.3% reduction. For the truck class, the most speed reduction occurred when the PCMS is on, there was 8.3% reduction. For the semitrailer class, the most speed reduction occurred when they are approaching the advance warning area, about 10.2% reduction.

The average speed of the semitrailer class, for two of the three conditions, was greater than the other two classes. It shows that the semitrailer drivers usually keep their high speed on rural highways. The PCMS is not effective on reducing semitrailer vehicle speeds in rural highway work zones. Based on the analysis results the PCMS had the most effect on the truck class when it was turned on or off, better than the TTS (8.3%, 6.2%, 5.8%). The change in speed for different vehicle classes is shown in Figure 5.

Figure 5 provides a visual of the breakdown of mean speed changes for each case based on vehicle class. The bar chart in Figure 5 indicates that the truck class is the most response vehicle class to cases 1 and 2, both involving the PCMS in rural work zones. The chart also indicates that the truck class is the least responsive vehicle class to case 3, involving the TTS in rural work zones. Another correlation that can be drawn from the chart is that the Passenger Car and Semitrailer classes are more responsive to warning messages than to the PCMS sitting on the side of the road in rural work zones.

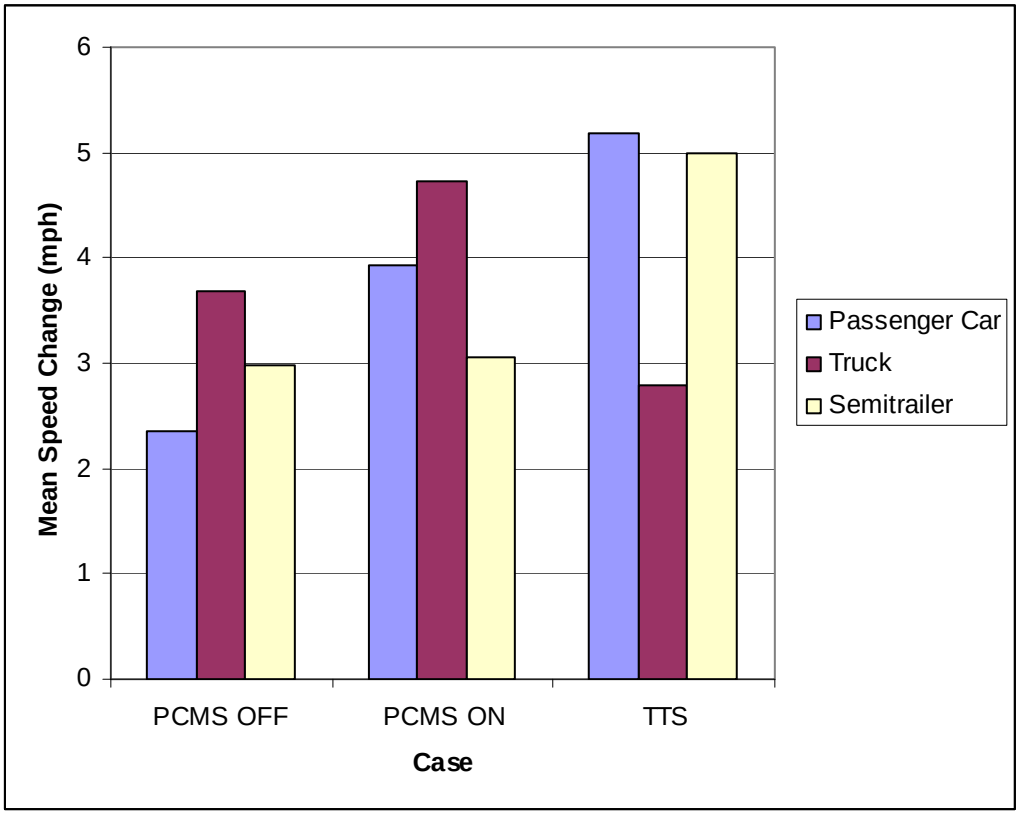

FIGURE 5 Mean speed change of vehicle classes for three cases

SIGNIFICANCE OF TEST ANALYSIS

Besides frequency analysis, hypothesis tests were conducted during the data analysis process. The null hypothesis of this research is that there is no change between cases in the mean speeds of the three vehicle classes. The alternative hypothesis is that there is a difference between cases in the mean speed of one or more of the vehicle classes. A univariate analysis of variance (UNIANOVA) was performed on the data to determine whether or not the interaction between the three cases and the three vehicle classes is significance. UNIANOVA is a two-way analysis of variance with vehicle class and case as the two factors. The results of the UNIANOVA test are shown in Table 4 and are based on a 95% confidence interval. Table 4 means that for the null hypothesis to be rejected, and for there to be a significant interaction between the two effects (vehicle class and case) the value must be less than 0.05. Since the test returned a significance value of 0.019 for the interaction of effects, the null hypothesis is rejected in favor of the alternative hypothesis.

Further UNIANOVA tests were performed to determine what factor(s) were causing there to be a significant interaction between vehicle class and case. Tables 5 and 6 show the noteworthy findings of this in depth pairwise comparison. Table 5 indicates that the passenger car class is the singular class having a significant effect and interaction with the three sign cases because the significance value is 0.00. Table 6 shows a more in depth pairwise comparison of the passenger car class with the three cases. The results in the Table 6 indicate that for the passenger car class there is a significant interaction between the PCMS OFF case and the other two cases.

TABLE 4 UNIANOVA Test of Between-Subjects Effects

Source	Type III Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Corrected Model	764.395[a]	8	95.549	3.072	.002
Intercept	4264.488	1	4264.488	137.097	.000
Vehicle Class	1.713	2	.856	.028	.973
Case	142.241	2	71.121	2.286	.102
Interaction (Vehicle Class by Case)	367.435	4	91.859	2.953	**.019**
Error	26968.540	867	31.106		
Total	39255.000	876			
Corrected Total	27732.935	875			

a R Squared = .028 (Adjusted R Squared = .019)

* Dependent Variable = Mean Speed Change

TABLE 5 Comparison of Individual Vehicle Classes with Cases

Vehicle Class	Analysis Type	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Passenger Car	Contrast	478.505	2	239.252	7.692	**0.00**
	Error	26968.54	867	31.106		
Truck	Contrast	175.1	2	87.55	2.815	0.06
	Error	26968.54	867	31.106		
Semitrailer	Contrast	22.268	2	11.134	0.358	0.699
	Error	26968.54	867	31.106		

Each F tests the simple effects of sign case within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means

TABLE 6 Pairwise Comparison of Class by Case

Vehicle Class	(I) Case	(J) Case	Mean Difference (I-J)	Std. Error	Significance[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
Passenger Car	PCMS OFF	PCMS ON	-1.588*	0.633	**0.037**	-3.107	-0.069
	PCMS OFF	TTS	-2.825*	0.765	**0.001**	-4.66	-0.989

Based on estimated marginal means

*. The mean difference is significant at the .05 level

a. Adjustment for multiple comparisons: Bonferroni.

CONCLUSIONS

Preservation, rehabilitation, and expansion of rural two-lane highways require the set-up of a large number of work zones. In Kansas, 63% of the fatal crashes and one third of all injury crashes took place in two-lane highway work zones (*15*). To improve safety in work zones, many types of signage have been developed and employed. However, the effectiveness of some signs has not been quantified. Researchers of this project determined motorists' response to signage (PCMS and TTS) in rural two-lane highway work zones using field experiments. The data analysis results show that the PCMS was effective on reducing passenger car and truck speeds in one way two-lane work zones. When the PCMS was turned on, it reduced passenger car vehicle speeds by 3.9 mph, truck vehicle speeds by 4.7 mph, and semitrailer vehicle speeds by 3.1 mph over a 500 foot distance. When the PCMS was turned off, it reduced passenger car vehicle speeds by 2.4 mph, truck vehicle speeds by 3.7 mph, and semitrailer vehicle speeds by 3.0 mph over a 500 foot distance. When there was a TTS (no PCMS) on the road and the vehicles approaching the advance warning area, passenger car speeds dropped by 5.2 mph, truck speeds by 2.8 mph, and semitrailer speeds 5.0 mph over a 500 foot distance. Based on these results, researchers concluded that a visible and active PCMS in a work zone significantly reduced the speed of truck vehicles approaching the work zones. One TTS, W20-1, has more effect on passenger car and semitrailer drivers than PCMS ON does at reducing vehicle speed. A reduction in vehicular speed allows for greater reaction time to avoid crashes and potentially creates a safer environment for drivers and workers in the work zones.

ACKNOWLEDGMENTS
The authors would like to express their gratitude and thanks to Mr. Kevin F. Palic, P.E., Construction Engineer, Mr. Luke Perry, Senior Engineering Technician, and Mr. Pat Haverkamp, Senior Engineering Technician from the Kansas Department of Transportation for their valuable help during the course of this study. The authors would also like to thank to Mr. Mickey Waxman, Statistic Consultant for his advice and help in statistical analysis. Special thanks also go to the University of Kansas Transportation Research Institute, KDOT, and the Federal Highway Administration for providing generous financial support.

REFERENCES
1. Benekohal, R. F. and Shim, E. Multivariate Analysis of Truck Drivers' Assessment of Work Zone Safety. *ASCE Journal of Transportation Engineering*, Vol. 125, No. 5, 1999
2. AASHTO (1987). Summary Report on Work Zone Crashes. Standing Committee on Highway Traffic Safety, American Association of State Highway and Transportation Officials, Washington, D.C.
3. Wang, J., Hughes, W. E., Council, F.M., & Paniati, J.E. (1996) "Investigation of Highway Work Zone Crashes: What We Know and What We Don't Know". *Transportation Research Record 1529*, Transportation Research Board, Washington D.C., pp. 54-64.
4. FHWA (2003). "Temporary Traffic Control". *Manual on Uniform Traffic Control Devices for Streets and Highways*. 2003 Edition, Chapter 6, Federal Highway Administration (FHWA).
5. Pigman, J. G. and Agent, K. R. (1990). "Highway Crashes in Construction and Maintenance Work Zones". *Transportation Research Record 1270*, Transportation Research Board, Washington D.C., pp12 – 21.
6. Garber, N. J. and Zhao, M. (2002). "Crash Characteristics at Work Zones". Research Report VTRC 02-R12, Virginia Transportation Research Council, Charlottesville, Virginia.
7. Schrock, D. S., Ullman, G. L., Cothron, A. S., Kraus, E., and Voigt, A. P. (2004). "An Analysis of Fatal Work Zone Crashes in Texas". Report FHWA/TX-05/0-4028-1, FHWA, U.S. Department of Transportation.
8. Nemeth Z. A., and D. J. Migletz. 1978. Accident Characteristics Before, During, and After Safety Upgrading projects on Ohio's Rural Interstate System. *Transportation Research Record 672*, Transportation Research Board, Washington, D.C., pp. 19-23.
9. Hargroves, B. T. (1981). "Vehicle Crashes in Highway Work Zones". *Journal of Transportation Engineering 107(TE5)*, ASCE, pp525 – 539.
10. Garber, N. J. and Patel, S. T. (1994). Effectiveness of Changeable Message Signs in Controlling Vehicles Speeds in Work Zones Report No. VTRC 95-R4. Virginia Transportation Research Council, Charlottesville, Virginia.
11. Garber, N. J. and Srinivasan, S. (1998). Effectiveness of Changeable Message Signs in Work Zones: Phase II. Report No. VTRC 98-R 10. Virginia Transportation Research Council, Charlottesville, Virginia.
12. Brewer, M. A., Pesti, G., and Schneider, W. IV (2006). "Improving Compliance with Work Zone Speed Limits: Effectiveness of Selected Devices." *Transportation Research Record 1948*. Transportation Research Board, Washington, D.C., pp. 67–76.
13. Daniel J., K. Dixon, and D. Jared (2000). Analysis of Fatal Crashes in Georgia Work Zones. *Transportation Research Record 1715*. Transportation Research Board, Washington D.C., pp. 18-23.

14. AASHTO. AASHTO Green Book: A Policy on Geometric Design of Highways and Streets, 5th Edition. American Association of State Highway and Transportation Officials, Washington, D. C., 2004
15. Li, Y. F. and Bai, Y. (2008). "Comparison of Characteristics between Fatal and Injury Accidents in the Highway Construction Zones." Safety Science, Elsevier, Vol. 46, No. 4, pp. 646-660