**Marquette University**

**e-Publications@Marquette**

***Civil, Construction and Environmental Engineering Faculty Research and Publications/College of Engineering***

***This paper is NOT THE PUBLISHED VERSION*.**

Access the published version via the link in the citation below.

*Accudent Analysis & Prevention*, Vol. 83 (October 2015): 197-202. [DOI](https://doi.org/10.1016/j.aap.2015.07.024). This article is © Elsevier and permission has been granted for this version to appear in [e-Publications@Marquette](http://epublications.marquette.edu/). Elsevier does not grant permission for this article to be further copied/distributed or hosted elsewhere without express permission from Elsevier.

Determining The Effective Location of a Portable Changeable Message Sign on Reducing the Risk of Truck-Related Crashes in Work Zones

Yong Bai

Department of Construction Management and Engineering, North Dakota State University, NDSU Dept. 2475, PO Box 6050, Fargo, ND 58108-6050, USA

Yarong Yang

Department of Statistics, North Dakota State University, NDSU Dept. 2770, PO Box 6050, Fargo, ND 58108-6050, USA

Yue Li

Department of Civil, Environmental and Architectural Engineering, The University of Kansas, 1530 W. 15th Street, 2160 Learned Hall, Lawrence, KS 66045, USA

# Abstract

Truck-related crashes contribute to a significant percentage of vehicle crashes in the United States, which often result in injuries and fatalities. The amount of truck miles traveled has increased dramatically with the growing rate of freight movement. Regarding truck crashes in the highway work zones, many studies indicated that there was a significant increase in crash severity when a truck crash occurred in work zones. To mitigate the risk of truck crashes in work zones, a portable changeable message sign (PCMS) was frequently utilized in addition to standard temporary traffic control signs and devices required by the Manual on Uniform Traffic Control Devices. To justify the use of a PCMS in work zones, there is a need to study the effective location of a PCMS deployed in a work zone by measuring the changes of truck and passenger car speed profiles. The difference of speed changes between trucks and passenger cars was considered as one of the major reasons which caused truck-related crashes in work zones. Therefore, reducing the difference of speed changes between trucks and passenger cars could potentially improve safety in work zones. The outcomes of this study will provide required knowledge for traffic engineers to effectively utilize the PCMS in work zones with the purpose of reducing truck-related crashes. In addition, the success of this study will provide a roadmap to investigate the effective deployment of other temporary traffic control devices on mitigating the risk of truck-related crashes in work zones.

# Keywords

Safety, Work zone, Passenger car, Truck, Speed

# 1. Introduction

Work zone safety has become more challenging because of increasing travel demand and the aging highway system in the United States. Nationwide, there are more maintenance and reconstruction projects on the highway system. At the same time, the system is needed to safely transport increasing people and goods. Many efforts have been devoted to improve work zone traffic safety and mobility over the years. Regardless of these efforts, there is little indication of significant improvements in work zone safety nationwide. Although work zone crash rates by work zone travel mileage are not precisely known, statistics of work zone fatalities have shown a serious traffic safety problem. There were several hundred people loss of their life and nearly 40,000 people injured in work zone crashes each year (FHWA, 2011). Among work zone crashes, truck-related crashes contribute to a significant percentage of vehicle crashes in the United States, which often result in injuries and fatalities. Results of several studies have pointed out that truck-related work zone crashes were more severe than other crashes in work zones (Bai and Li, 2006, Hill, 2003, Pigman and Agent, 1990). There are several reasons that will increase the conditional probability of involving truck-related crash in highway work zones based on previous research (Bai and Li, 2006, Li et al., 2011). These reasons include number of traffic lanes, different geometric alignment configurations, light conditions, and driver errors such as misjudgment/disregarding traffic control signs and signals. In addition, trucks have bigger bodies and less flexibility which require drivers to have higher level of driving skills when maneuvering through the work zones. A brief literature review on truck-related crashes is presented in the following chapter along with the motivation of conducting this research project.

# 2. Literature review

The information from the Fatality Analysis Reporting System shows that there were 50,430 fatal crashes in 2008, 8.1% (4066) of them were large truck related, 37.8% (19,072) were light truck related (FARS, 2008). Here a light truck is referred to as a truck of 10,000 pounds gross vehicle weight or less; a large truck is over 10,000 pounds gross vehicle weight. Some researchers have investigated and analyzed truck-related crashes in work zones using various data sources and analyses techniques. Several studies found that the percentage of truck-involved crashes was much higher in work zones and heavy truck related crashes were more likely to involve multiple vehicles and hence frequently resulted in fatalities and large monetary loss (Bai and Li, 2006, Hill, 2003, Pigman and Agent, 1990).

Benekohal et al. conducted a statewide opinion survey of 930 semitrailer drivers in Illinois in 1993. Researchers found that about 90% of truck drivers consider traveling through work zones to be more hazardous than non-work zone areas (Benekohal et al., 1995). Garber and Joshua (1990) found 75% of all large-truck crashes and 91% of large-truck fatal crashes were attributed to driver-related errors. Hall and Lorenz (1989) found that the number and rate of truck-related crashes increased during the construction season in the State of New Mexico. Bezwada and Dissanayake (2009) pointed out that truck driver might face many challenges while traversing on Interstate or state highways at high speeds, at intersections, or while taking turns to have control over the vehicle because the physical dimension of a truck creates the blind spots. Richards and Faulkner (1981) discovered the disproportionate of large trucks involved in fatal and injury crashes. Other researchers indicated that work zone crashes involve large trucks were more severe than other crashes (Li and Bai, 2008, Daniel et al., 2000, Ha and Nemeth, 1995, Pigman and Agent, 1990, Richards and Faulkner, 1981). In summary, many research projects have been conducted to address the truck-related safety concerns in the highways and highway work zones. Some studies conveyed that the severity of truck-related crashes was higher than other types of crashes in work zones.

To mitigate the risk of truck crashes in work zones, a portable changeable message sign (PCMS) was frequently utilized in many work zones in addition to standard temporary traffic control signs and devices which were required by the Manual on Uniform Traffic Control Devices (MUTCD). To justify the use of a PCMS in work zones, there is a need to study the effective location of the PCMS and determine how deployment locations impact on truck and passenger car drivers’ behavior measured using vehicle speed changes.

# 3. Research objective

The objective of this research project was to study the effective location of a PCMS deployed in the upstream of a work zone by measuring the changes of truck and passenger car speed profiles. The difference of speed changes has been considered as one of the major reasons that caused crashes in two-lane highways (Garber and Ehrhart, 2000, Garber and Gadiraju, 1989). Therefore, reducing speed variability between trucks and passenger cars might potentially mitigate the risk of vehicle crashes in the work zones. The research objective was accomplished using the field experimental method. Based on the results of experimental data analyses, both passenger car and truck speed profile models were developed. In addition, speed changes between passenger cars and trucks were compared using the developed speed profile models. In this project, a truck means a freight truck whose gross vehicle weight is greater than 10,000 pounds and length is longer than 19 ft. A typical pickup truck was considered as a passenger car because its length dimension is not significantly larger than a typical passenger car. Other large vehicles such as school buses, construction vehicles, farm vehicles, and so on were not included in the study. Field experiments were conducted in the upstream of a one-lane two-way work zone located on the Highway US-36 in Kansas, USA from September to October in 2010. Besides the temporary traffic control devices and signs required by the MUTCD, a PCMS was utilized and deployed in three different locations in the upstream of the work zone. The outcomes of this study will provide required knowledge for traffic engineers to effectively utilize the PCMS in the upstream of work zones with the purpose of reducing the risk of truck-related crashes. In addition, the success of this study will provide a roadmap to investigate the effective deployment of other temporary traffic control devices on mitigating the risk of truck-related crashes in the work zones.

The scope of data analyses is limited to speed differences between cars and trucks. The authors assumed that drivers travel through the work zone on or under posted speed limit. Under this assumption and the fact that when a crash happens the distance between vehicles is zero, one of the safety measures to avoid vehicle crash is to keep distance between them unchanged, which means no speed variance between vehicles if possible. Since speed variance is an important factor, which is why the speed difference is the focus of data analyses in this research project. If additional resource is available, future analyses could be conducted in other areas such as looking into the speed decrease rate.

# 4. Data collection

The free-flow vehicle speeds were collected in the upstream of the work zone on the highway US-36. Based on the information provided by the Kansas Department of Transportation, the traffic volume on the US-36 was 3550 vehicles per day with 590 being trucks. Seven speed measurement sensors (TRAX Apollyon Automatic Traffic Data Recorder) were used to record the vehicle speed data from 7:00 a.m. to 7:00 p.m. during a two-week period.

Fig. 1 shows the set up of two tubes for one sensor on the road, which were connected to the sensor box. When collecting vehicle data, the sensor time-stamped every axle recorded during the field experiment. With the time-stamping information, the sensor determined the traffic volume, speed, classification, and gap data.



Fig. 1. Setup of tubes on the highway.

As indicated in Fig. 2, seven sensors were placed every 250 ft away in the upstream of the work zone with the  at the start point of the work zone which was the location of the first temporary traffic control sign (W20-1 Sign: Road Work Ahead). In order to measure the speed change of a vehicle over a certain distance in the upstream of the work zone, the distance of 250 ft between two sensors was used in the field experiments. The speed limit on US-36 was 65 mph. If the vehicle speeds were within this speed limit, then, the perception-reaction time is estimated at 2.5 s to do a simple action such as pushing the brake (FHWA, 2009). As a result, the distance traveling by a vehicle at 65 mph in the perception-reaction time is 238 ft. For the convenience of installing sensors in the site, the distance between two sensors was specified at 250 ft.

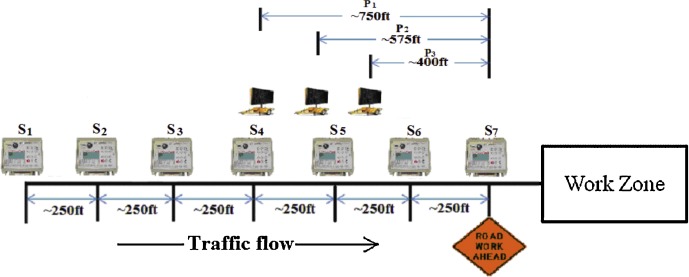


Fig. 2. Placements of sensors and PCMS in the US-36 work zone.

The PCMS was deployed at three different locations in the upstream of the work zone. These locations were labeled as  (750 ft from the W20-1 Sign),  (575 ft from the W20-1 Sign), and  (400 ft from the W20-1 Sign) as shown in Fig. 2. The messages displayed on the PCMS were: “WORK ZONE/AHEAD/SLOW DOWN” and “FLAGGER/AHEAD PREPARE/TO STOP.” These messages changed from one to the other every three seconds during experiments. The PCMS was placed on the shoulder of the highway about 9–10 ft away from the road. The inside edge of the PCMS panel was 3–4 ft away from the road. Fig. 3 shows the PCMS used in the field experiments.



Fig. 3. A PCMS used in the field experiments.

A complete experimental trial occurred when all sensors successfully collected the speeds of a vehicle at the seven sensor locations. If any one senor did not record the speed of a vehicle, then this vehicle data had to be discarded from all other six sensors. The speeds were matched by verifying the difference of the computer times and drawing the correlation among the data from Sensor  to Sensor . External factors, which occasionally interfered with vehicles and caused the data to be incorrectly recorded, included low-speed farm vehicles, vehicles turned off the road at an intersection in the upstream of the work zone, and construction related vehicles that either had very low speed or drivers had been well aware of the upcoming work zone conditions. At any given time during a field experiment, there were at least two research assistants who conducted the data collections in a work zone. They observed the traffic conditions and made the decision if collected data should be kept for future analyses. If not, they immediately marked a note on the data stored in the computer at the work zone. Therefore, before the data analyses, researchers were able to exclude these data with the note from the database.

A total of 3228 valid vehicle speeds were collected following the experimental procedure on the US-36 work zone. Of these, 1143 vehicle speed data were collected when the PCMS was placed at  location (813 were passenger cars and 330 were trucks); 1124 were collected when the PCMS was placed at  location (784 passenger cars and 340 trucks); and 996 were collected when the PCMS was placed at  location (674 passenger cars and 322 trucks). The sensors produced raw data files in a .DMP file format which was generated by a special software program. By exporting the raw data into an excel file, a spreadsheet was used to assort the data by date, time, lane, axles, vehicle class, vehicle length, speed, and among others. Therefore, analyses could be performed using the data in the spreadsheet.

# 5. Data analyses

The major tasks that needed to be accomplished in the data analyses were the development of the passenger car and truck speed profile models when the PCMS was placed at three different locations in the upstream of the work zone and the comparison of speed changes using the passenger car and the truck speed profile models. To clearly outline the data analyses process, when the PCMS was placed at 750 ft away from the W20-1 Sign, it was named as Situation One. Situations Two and Three mean that the PCMS was placed at 575 ft and 400 ft away from the W20-1 Sign, respectively.

## 5.1. Statistical summary of the collected data

Table 1, Table 2, Table 3 show the descriptive statistics of passenger car and truck speeds recorded by each sensor at three locations, respectively. In the table, the minimum speed, the maximum speed, the mean vehicle speed, and the standard deviation of the speeds at each sensor are presented.

Table 1. Descriptive statistics of passenger car and truck speeds for PCMS at 750 ft.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Vehicle type** | **Speed measurement location** | **Min (mph)** | **Max (mph)** | **Mean (mph)** | **Standard deviation** |
| Passenger car | Speed at Sensor 1 | 29 | 76 | 61.6 | 6.5 |
|  | Speed at Sensor 2 | 31 | 74 | 60.5 | 6.3 |
|  | Speed at Sensor 3 | 26 | 74 | 59.9 | 7.0 |
|  | Speed at Sensor 4 | 17 | 74 | 59.2 | 7.6 |
|  | Speed at Sensor 5 | 23 | 74 | 57.9 | 7.2 |
|  | Speed at Sensor 6 | 23 | 71 | 55.7 | 6.9 |
|  | Speed at Sensor 7 | 23 | 71 | 55.0 | 7.1 |
|  |  |  |  |  |  |
| Truck | Speed at Sensor 1 | 26 | 72 | 58.9 | 7.2 |
|  | Speed at Sensor 2 | 26 | 71 | 57.9 | 7.1 |
|  | Speed at Sensor 3 | 27 | 71 | 57.4 | 7.5 |
|  | Speed at Sensor 4 | 28 | 71 | 56.9 | 7.8 |
|  | Speed at Sensor 5 | 28 | 71 | 55.4 | 7.7 |
|  | Speed at Sensor 6 | 28 | 68 | 53.8 | 7.6 |
|  | Speed at Sensor 7 | 29 | 70 | 53.0 | 7.7 |

Table 2. Descriptive statistics of passenger car and truck speeds for PCMS at 575 ft.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Vehicle type** | **Speed measurement location** | **Min (mph)** | **Max (mph)** | **Mean (mph)** | **Standard deviation** |
| Passenger car | Speed at Sensor 1 | 30 | 82 | 63.2 | 6.7 |
|  | Speed at Sensor 2 | 31 | 78 | 59.2 | 7.0 |
|  | Speed at Sensor 3 | 29 | 82 | 59.3 | 7.4 |
|  | Speed at Sensor 4 | 26 | 80 | 58.7 | 8.0 |
|  | Speed at Sensor 5 | 30 | 76 | 56.6 | 8.2 |
|  | Speed at Sensor 6 | 23 | 70 | 52.8 | 7.2 |
|  | Speed at Sensor 7 | 21 | 74 | 52.2 | 7.1 |
|  |  |  |  |  |  |
| Truck | Speed at Sensor 1 | 37 | 78 | 61.9 | 5.9 |
|  | Speed at Sensor 2 | 35 | 72 | 57.1 | 6.0 |
|  | Speed at Sensor 3 | 36 | 76 | 58.6 | 6.6 |
|  | Speed at Sensor 4 | 35 | 79 | 58.2 | 7.1 |
|  | Speed at Sensor 5 | 34 | 77 | 56.0 | 7.2 |
|  | Speed at Sensor 6 | 32 | 74 | 51.9 | 6.7 |
|  | Speed at Sensor 7 | 31 | 71 | 51.4 | 6.7 |

Table 3. Descriptive statistics of passenger car and truck speeds for PCMS at 400 ft.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Vehicle type** | **Speed measurement location** | **Min (mph)** | **Max (mph)** | **Mean (mph)** | **Standard deviation** |
| Passenger car | Speed at Sensor 1 | 30 | 78 | 62.0 | 6.5 |
|  | Speed at Sensor 2 | 25 | 76 | 60.7 | 6.9 |
|  | Speed at Sensor 3 | 25 | 77 | 60.0 | 7.5 |
|  | Speed at Sensor 4 | 16 | 81 | 59.2 | 8.3 |
|  | Speed at Sensor 5 | 18 | 76 | 57.9 | 8.8 |
|  | Speed at Sensor 6 | 26 | 70 | 54.4 | 7.7 |
|  | Speed at Sensor 7 | 25 | 71 | 53.6 | 7.4 |
|  |  |  |  |  |  |
| Truck | Speed at Sensor 1 | 34 | 71 | 59.0 | 6.2 |
|  | Speed at Sensor 2 | 32 | 71 | 57.7 | 6.5 |
|  | Speed at Sensor 3 | 23 | 72 | 57.5 | 7.1 |
|  | Speed at Sensor 4 | 30 | 73 | 57.6 | 7.6 |
|  | Speed at Sensor 5 | 34 | 75 | 56.8 | 7.8 |
|  | Speed at Sensor 6 | 31 | 69 | 53.8 | 7.1 |
|  | Speed at Sensor 7 | 24 | 68 | 52.5 | 7.2 |

## 5.2. Speed profile models

Mathematically, the passenger car speed profile model and the truck speed profile model can be formalized as

(1)

and

(2)

respectively. In (1), (2), *t* varies at different sensor locations.  and  denote the vehicle speeds.  and  denote the underlying speed models. and are two independent homogeneous Gaussian random errors indexed by  with means  and variances  and  respectively for all . The term also implies that the errors at any two different sensors  and  with  and are independent for both . Since the authors were interested in the speed change difference between passenger cars and trucks, hypothesis was set up to test  for all  versus  for at least one .

Since the authors had no idea about the underlying  and , it was legitimate to estimate  and  by a nonparametric way. Different from a parametric method that assumes  and  to be an existing model (e.g., exponential) with a few parameters to be estimated, a nonparametric method is a data-based method, not a model-based method. In this research project, the authors used a nonparametric method, called the local regression method, described by Zhang (2012) to estimate  and . Suppose *t* was a location between Sensor 1 and Sensor 7 , then the passenger car (or truck) speed at location , namely , could be obtained as

(3)

where

was a kernel function (Parzen, 1962), and  was the window width (Parzen, 1962). There were many options for the kernel function . The authors used the standard normal density function for this research project. For , the authors picked 0.5 because the speed measurements were usually below 100 miles per hour in the work zone and 0.5 was a commonly used number for such type of speed range. From Eq. (3), it is easy to determine that  which is called the weight at location  keeps the same for the three situations and  which is the mean speed at location  varies at different situation.

Fig. 4, Fig. 5, Fig. 6 show the measured mean speeds at the seven sensors (marked by dots) and the fitted mean speed curves for the three situations. Generally, for all the three situations, both passenger cars and trucks gradually slowed down from Sensor 1 to Sensor 7. In Situation One, the mean speed of passenger cars was significantly larger than the mean speed of trucks at all seven sensor locations. In Situation Three, the mean speed of passenger cars was significantly larger than the mean speed of trucks at the first three sensor locations and the two mean speeds started to get closer to each other at the fourth sensor. Compared to the cases in Situations One and Three, the two mean speeds in Situation Two were closer to each other at all seven sensor locations.

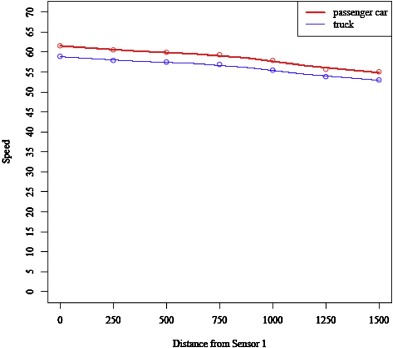


Fig. 4. Passenger car and truck mean speed profiles for Situation One (PCMS location was at 750 ft).

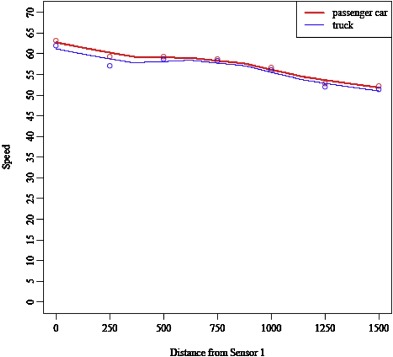


Fig. 5. Passenger car and truck mean speed profiles for Situation Two (PCMS location was at 925 ft).

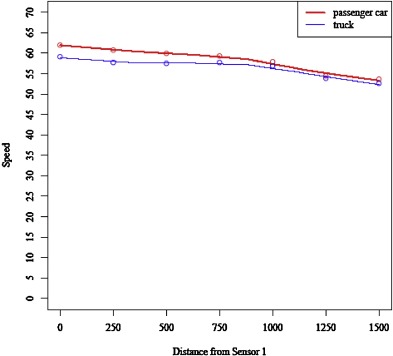


Fig. 6. Passenger car and truck speed profiles for Situation Three (PCMS location was at 1100 ft).

## 5.3. Speed change difference between passenger cars and trucks

As discussed in Section 5.2, to study the speed change difference between passenger cars and trucks, the authors were interested in testing  for all  versus  for at least one . Along with the nonparametric method developed to estimate the speed profile, Zhang (2012) derived the test statistic and the formula of the *P*-value for the hypothesis testing. Using their method, the computed *P*-values for Situation One to Three were 0.0000031, 1, and 0.00178, respectively. These *P*-values showed that the null hypothesis  was accepted at Situation Two but rejected at the other two situations with the level of confidence at 0.05.

# 6. Conclusions and recommendations

Truck-related crashes contribute to a significant percentage of vehicle crashes, which often result in injuries and fatalities. There was a significant increase in crash severity when a truck crash occurred in work zones. Due to the difference of driving patterns between passenger car drivers and truck drivers, there was a need to study the truck speed profile and passenger car speed profile in order to determine the effective location of utilizing a PCMS in the upstream of work zones. In this paper, the truck and passenger car speed profile models were developed for three situations: (1) a PCMS at 750 ft away from the W20-1 Sign; (2) a PCMS at 575 ft away from the W20-1 Sign; and (3) a PCMS at 400 ft away from the W20-1 Sign. Compared with the Situations One and Three, the Situation Two was the recommended setup of a PCMS in the upstream of a work zone because the traveling distance with significant speed differences between trucks and passenger cars was the smallest. Reducing speed variability between trucks and passenger cars could potentially mitigate the risk of vehicle crashes in the work zones. However, combined factors, not speed alone, impact on the vehicle safety in the work zones due to the complexity of the road environment.

The results of this study clearly indicated that the deployment location of a PCMS had a significant impact on reducing the speed variance between passenger cars and trucks. Since the speed variance between vehicles (working with other factors such as traffic flow and road geometric) is a risk factor that might cause crashes, therefore, it is important to determine an optimal deployment location of a PCMS that can be used to reduce such risk. Currently, the MUTCD does not specify the optimal deployment location of a PCMS in the work zones. As a result, traffic engineers have to rely on their experience to figure out the deployment location for a PCMS in the work zones. Thus, the potential effective location of a PCMS on reducing the risk of vehicle crashes in the work zones may not be realized. The authors recommend that the optimal deployment location of a PCMS in the upstream of work zones should be specified in the MUTCD with the purpose of reducing the risk of vehicle crashes based on the outcomes of this study. In addition, with the success of this project, the authors recommend to investigate the effective deployment of other temporary traffic control devices on mitigating the risk of truck-related crashes in the work zones.

The authors would like to indicate that the vehicle speed changes were due to the combination of the influence of the traffic signs and drivers’ awareness of work zone conditions. In this research project, traffic signs include the PCMS and other signs such as the W20-1 Sign (ROAD WORK AHEAD). The other traffic signs might have impact on drivers’ behavior as well. However, the authors did not directly measure the impact of other traffic signs at the experimental site due to the limited resource. The impact of other signs on drivers’ behavior is a research topic that should be investigated in the future. In addition, the drivers’ awareness of work zone conditions was difficult to measure using the existing technologies. In this project, the authors only measured the influence of the PCMS with the understanding that drivers’ awareness of work zone conditions might also have impact on the speed changes. Further research is needed to address the practical significance of the recommended PCMS deployment location due to the factor of small vehicle speed variance observed in the previous field experiments. Also, research is needed to quantify the impact of drivers’ awareness of work zone conditions on the vehicle speed changes. Finally, the authors recommend investigating if the seven sets of road tubes used to collect the speed data have an impact on driver's behavior.

# Acknowledgements

The authors would like to thank Lee Holmes, Leslie Fowler, Kristina Pyle, Kevin Palic, Jerry Haug, and Kerry Bramhall from Kansas Department of Transportation, and Karen Gilbertson and David LaRoche from Federal Highway Administration for their valuable help and advice during the course of this study. The authors recognize that financial support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers Program to the Mid-America Transportation Center, at the University of Nebraska-Lincoln.

# References

Bai and Li, 2006. Y. Bai, Y. Li. **Determining Major Causes of Highway Work Zone Accidents in Kansas. Final Report No. K-TRAN: KU-05-1.** Kansas Department of Transportation, Kansas (2006)

Benekohal et al., 1995. R.F. Benekohal, E. Shim, P. Resende. **Truck drivers’ concerns in work zones: travel characteristics and accident experiences.** J. Transp. Res. Rec. No. 1509 (1995), pp. 55-64

Bezwada and Dissanayake, 2009. N. Bezwada, S. Dissanayake. **Characteristics of Fatal Truck Crashes in the United States.** Proceedings of the 2009 Mid-Continent Transportation Research Symposium, Ames, Iowa, August, CD-ROM (2009)

Daniel et al., 2000. J. Daniel, K. Dixon, D. Jared. **Analysis of fatal crashes in Georgia work zones.** J. Transp. Res. Rec. No. 1715 (2000), pp. 18-23

FARS, 2008. FARS (Fatality Analysis Reporting System). **Vehicles Involved in Fatal Crashes by Vehicle Type – State: USA, Year: 2008. Fatality Analysis Reporting System Encyclopedia** (2008) Retrieved from: http://www-fars.nhtsa.dot.gov/Vehicles/VehiclesAllVehicles.aspx (accessed 24.02.11)

FHWA, 2009. FHWA. **Manual on Uniform Traffic Control Devices for Streets and Highways.** (2009 edition), Federal Highway Administration, Washington, DC (2009) (Chapter 6: temporary traffic control)

FHWA, 2011. FHWA. **Work Zone Safety Fact Sheet.** (2011) Retrieved from: http://safety.fhwa.dot.gov/wz/facts\_stats/ (accessed 24.02.11)

Garber and Ehrhart, 2000. N.J. Garber, A.A. Ehrhart. **Effect of speed, flow, and geometric characteristics on crash frequency for two-lane highway.** J. Transp. Res. Rec. No. 1717 (2000), pp. 76-83

Garber and Gadiraju, 1989. N.J. Garber, R. Gadiraju. **Factors affecting speed variance and its influence on accidents.** J. Transp. Res. Rec. No. 1213 (1989), pp. 64-71

Garber and Joshua, 1990. N.J. Garber, S.C. Joshua. **Traffic and Geometric Characteristics Affecting the Involvement of Large Trucks in Accidents. Report No. VTRC 91-R17.** Virginia Transportation Research Council, Virginia Department of Transportation, Richmond, VA (1990)

Ha and Nemeth, 1995. T.J. Ha, Z. Nemeth. **Detailed study of accident experience in construction and maintenance zones.** J. Transp. Res. Rec. No. 1509 (1995), pp. 38-45

Hall and Lorenz, 1989. J.W. Hall, V.M. Lorenz. **Characteristics of construction-zone accidents.** J. Transp. Res. Rec. No. 1230 (1989), pp. 20-27

Hill, 2003 R.W. Hill. **Statistical Analysis of Fatal Traffic Accident Data.** (Thesis) Texas Tech University, Lubbock, TX (2003)

Li and Bai, 2008. Y. Li, Y. Bai. **Comparison of characteristics between fatal and injury accidents in the highway construction zones.** Saf. Sci., 46 (4) (2008), pp. 646-660

Li et al., 2011. Y. Li, Y. Bai, S.D. Schrock, T.E. Mulinazzi. **Modeling Truck Speed in the Upstream of One-lane Two-way Highway Work Zones: Implications on Reducing Truck-related Crashes in Work Zones. Final Report No. MATC-KU: 362.** Mid-America Transportation Center/U.S. Department of Transportation Research and Innovative Technology Administration (2011)

Parzen, 1962. E. Parzen. **On estimation of a probability density function and mode.** Ann. Math. Stat., 33 (3) (1962), p. 1065

Pigman and Agent, 1990. J.G. Pigman, K.R. Agent. **Highway accidents in construction and maintenance work zones.** J. Transp. Res. Rec. No. 1270 (1990), pp. 12-21

Richards and Faulkner, 1981. S.H. Richards, M. Faulkner. **An Evaluation of Work Zone Traffic Accidents Occurring on Texas Highway in 1977. Report Number: FHWA/TX-81/44+263-3.** FHWA, U.S. Department of Transportation, Washington, DC (1981)

Zhang, 2012. Z. Zhang. **Curvetest: Test Equality of Curves with Homoscedastic or Heteroscedastic Errors.** (2012) http://cran.r-project.org/web/packages/curvetest/index.html