A VISION-BASED APPROACH TO STUDY DRIVER BEHAVIOR IN WORK ZONE AREAS

Yichang (James) Tsai
Associate Professor
School of Civil and Environmental Engineering
Georgia Institute of Technology
210 Technology Cir. Savannah, GA 31407
Phone: (912) 963-6977 Fax: (912)966-7929
e-mail: james.tsai@ce.gatech.edu

Chieh (Ross) Wang
Graduate Student
School of Civil and Environmental Engineering
Georgia Institute of Technology
790 Atlantic Dr. Atlanta, 30332
Phone: (404) 457-9967
e-mail: chiehwang@gatech.edu

Yiching Wu
Research Engineer
School of Civil and Environmental Engineering
Georgia Institute of Technology
210 Technology Cir. Savannah, GA 31407
Phone: (912) 965-6264 Fax: (912)966-7929
e-mail: yw23@mail.gatech.edu

Submitted to the 3rd International Conference on Road Safety and Simulation,
September 14-16, 2011, Indianapolis, USA

ABSTRACT

Work zone safety is a pressing concern, and it has been intensified by the increasing number of roadway maintenance and rehabilitation projects. However, the majority of work zone studies are based on crash data analysis, and there is limited research on monitoring and studying actual driver behavior in work zone areas. In this study, a vision-based sensing system developed through a research project sponsored by the National Academy of Science NCHRP IDEA program was used to monitor driver behavior in work zone areas. The purpose of this study is to investigate driver behavior at work zones. Work zone transition and advance warning areas were divided into four zones so the merge timing and behavior of vehicles (e.g. trucks and others) under different roadway geometry could be evaluated quantitatively. Two right lane one-lane closure work zones, one on a straight road segment and the other on a curved road segment, were

studied by reviewing two sets of 30-minute video collected on I-95. Preliminary results show that vehicles tend to merge close to the work zone taper on a curve, and truck drivers tend to merge earlier than other drivers. Future research needs are also discussed.

INTRODUCTION

Work zone safety is a pressing concern and it has been intensified with the increasing number of roadway widening, rehabilitation, and reconstruction projects. To address these concerns, many studies have been conducted, including identifying the work zone crash factors (Klauer et al., 2006; Akepati and Dissanayake, 2011), performing the corresponding countermeasures (Kang and Chang, 2006; Kwon et al., 2007), and developing hazard warning systems (Li et al., 2007; Gordon et al., 2008). However, due to lack of methods recording and extracting the vehicle information and driver's behavior prior to the crashes occurred, current studies have focused on corrective actions that highly rely on the police crash reports (Ullman et al., 2011). There is a need to increase our understanding of the driver behavior at work zones.

For the first time, a vision-based sensing system is proposed in this paper to study the driver behavior at work zones. The objective of this vision-based sensing system is to provide a means to collect work zone images for studying the driver behavior and for ultimately developing a work hazard awareness and early warning system. This paper is organized as follows. This section introduces the need for the study of driver behavior at work zones using the actual video. The second section presents the proposed methodology for studying driver behavior with a special focus on merge behavior in this paper. The next section presents the experimental test by analyzing the actual video collected on I-95 work zone. Finally, conclusions and recommendations are made.

PROPOSED METHOD

This section presents a framework on studying the driver behavior at work zones with a special focus on vehicle merge. Four zones in the work zone advance warning transition areas were defined so the merge timing and behavior of the vehicles (e.g. trucks and sedans) under different roadway geometry can be studied quantitatively. A vision-based sensing system with multi-views cameras is then proposed to ensure that the collected videos cover the 4 zones at work zone areas. The following are the detailed discussion.

Framework of the Study on Merge Timing and Behavior

Figure 1 depicts a novel framework in support of work zone driver behavior study. Three major elements including vehicle merge, causal factors, and the impacts are considered. Vehicle merge, the focus of this study, details the statistics of merge timing/location and behavior of vehicles at work zones. The first focus of this framework is to record the frequency of vehicle merge at each of the 4 zones shown in Figure 2 separately at work zones to support merge timing and behavior study. Then, the causal factors and impacts of the merge behavior are discussed. We also consider the causal factors, including driver's attention, roadway geometry, sight distance, traffic condition, etc., that lead to different merge timing and behavior. These factors can be divided into two critical categories, i.e., driver exclusive and non-driver exclusive factors. While the former describes factors related to driver's individual behavior such as driver's inattention, fatigue, and distraction; the latter focuses on other aspects such as roadway geometry, sight distance, and traffic conditions. Impacts, on the other hand, describe the consequences of different merge behavior.

The three main elements, besides crash records, can enrich the work zone driver behavior study and can be further extended to different work zone safety and mobility applications as shown in Figure 1. For example, the development of a hazard awareness and early warning system can be based on the study of merge timing and behavior to identify potential dangerous cases and therefore prevent possible hazards of the work zone intrusion. Moreover, the study on causal factors can lead to recommendations on the adjustments of work zone configuration and traffic control strategy according to different roadway geometry conditions.

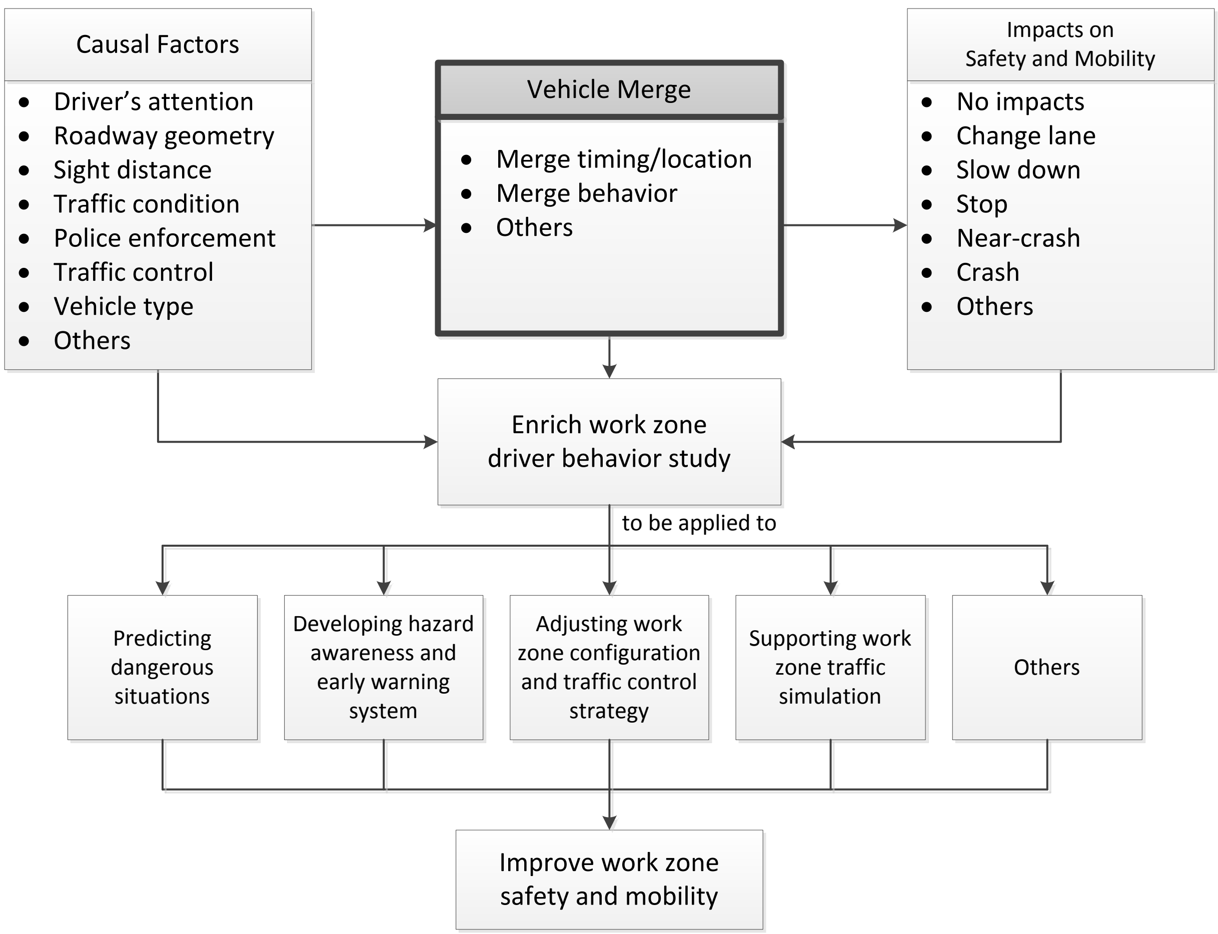


Figure 1 Framework of the driver merge timing and behavior study

Four Merge Zones and the Vision-Based Multi-View Sensing System

In this study, we divided the work zone transition area and the advance warning area into 4 zones in order to better observe and classify vehicle merges at different locations. As illustrated in Figure 2, Zone 1 represents the whole transition area; Zone 2, Zone 3, and Zone 4 cover the advance warning area that they are 0 ft. to 500 ft., 500 ft. to 1000 ft., and over 1000 ft. to the beginning of the transition area, respectively.

A vision-based sensing system with multi-view cameras is established to collect video data in support of the work zone driver behavior study. Figure 3 shows the sensing system which consists of a 30 ft. tower on which multiple cameras can be mounted. Video images of different views collected using the multi-view sensing system are shown in Figure 4, where Figure 4(a) focuses on Zones 1 and 2 and Figure 4(b) focuses on Zones 3 and 4. The entire advance warning area as well as the transition area can therefore be clearly covered by the multi-view cameras. In addition to fulfilling the need of work zone driver behavior study, the video data collected by the sensing system can be incorporated with vehicle detection and tracking algorithms to further identify and detect potential work zone intrusion vehicles to enhance work zone safety in the future.

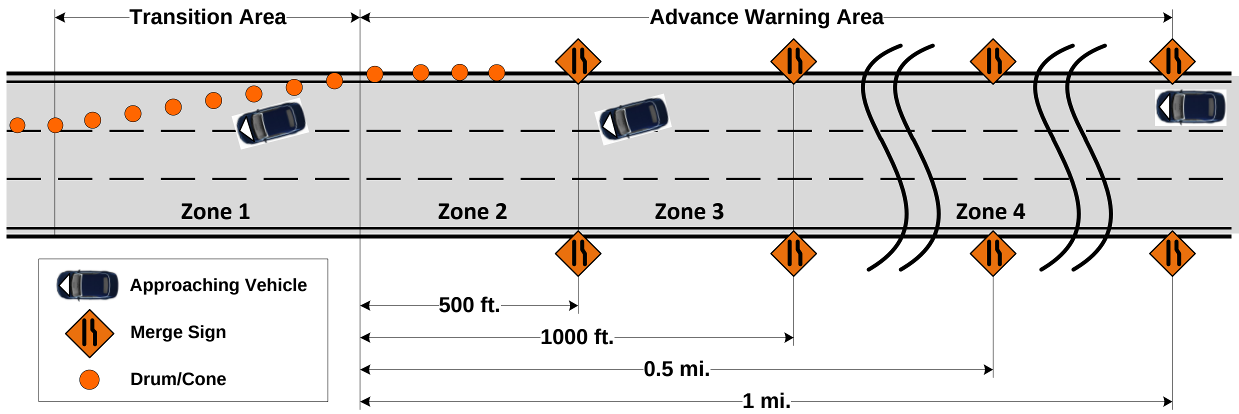


Figure 2 Four zones defined in the advance warning and transition areas

Figure 3 Vision-based sensing system

(a) Far view covering Zones 1 and 2 (b) Close view covering Zones 3 and 4

Figure 4 Example images captured by multi-view cameras

EXPERIMENTAL TEST

The purpose of this section is to study the influence of different roadway geometry and vehicle type on the merge timing and behavior of vehicles at work zones using actual video data collected at I-95 pavement resurfacing construction site near Richmond Hill, Georgia. Two sets of data, collected at 1:30pm on Mar. 21 and Mar. 24, 2011, were analyzed with a focus on the merge timing at work zones. The first set of data, which was collected at location A in Figure 5, was in northbound direction at milepost 86 on I-95, where there was a right lane closure work zone on a straight road segment. Similarly, the second set of data was collected at location B in Figure 5, which was also in northbound direction at milepost 90 on I-95, where there was a right lane closure work zone on a curved road segment.

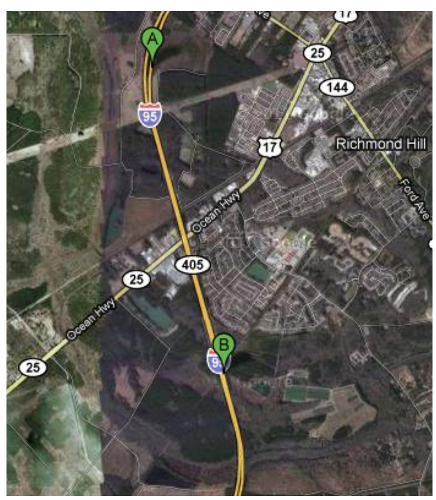
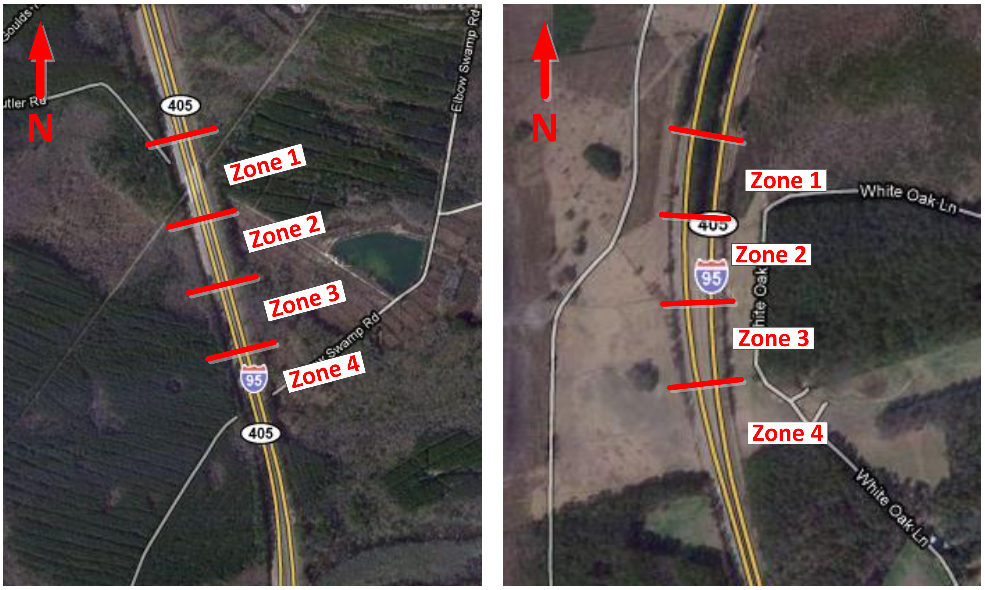


Figure 5 Data collection map on I-95 (source: Google maps)

In order to objectively compare the two sets of data with a focus on the influence of roadway geometry and vehicle type, besides to collect data in the same direction at the same time of the day, we also prudently selected the data so that they have similar traffic conditions, (i.e. a traffic count around 2000 vehicles per hour.) Moreover, each set of data consists of two views to enable the observation of merges at the 4 zones for the straight and curved road segments as illustrated in Figure 6.

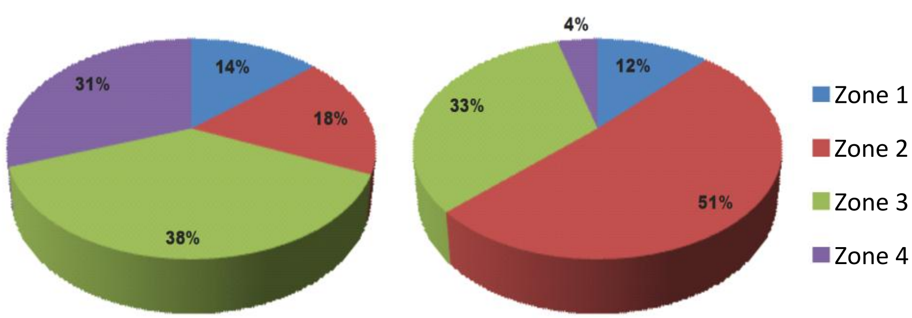


(a) Four zones on the straight road (b) Four zones on the curved road

Figure 6 The four zones for data collection on the straight and curved road segments

The study on merge timing and behavior was conducted by analyzing the merge frequency at each of the 4 zones. During the 30-minute period of study, the first set of data collected at on the straight road had 927 total traffic counts and 95 of them were in the closed lane; the second set of data collected on the curved road had 1034 total traffic counts and 143 of them were in the close lane. In addition to traffic counts, merging vehicles were recorded and classified based on two types: trucks and other vehicles.

Figure 7 shows the results of merge frequencies at different zones under different roadway geometry. Figure 7(a) shows the observation results for the straight road: 31% of vehicles in the closed lane merged in Zone 4, 38% in Zone3, 18% in Zone 2, and 14% in Zone 1. Results for the curved road are shown in Figure 7(b), where 4% of vehicles in the closed lane merged in Zone 4, 33% merged in Zone 3, 51% merged in Zone 2, and 12% merged in Zone 1.

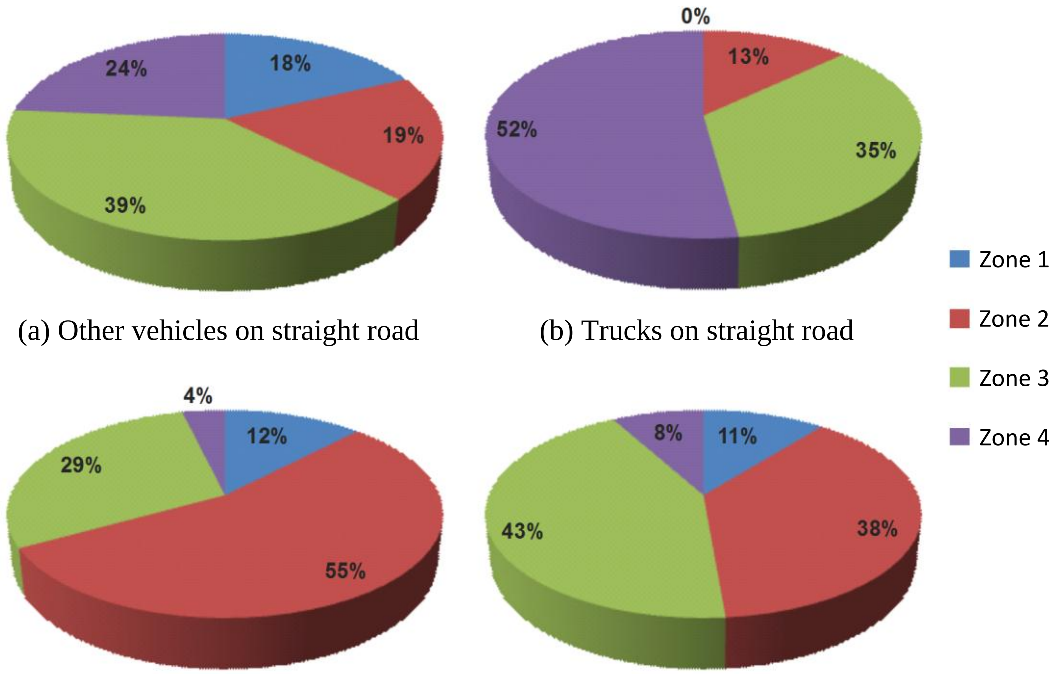


(a) Straight road (b) Curved road

Figure 7 Merge frequency at different zones under different roadway geometry

On a straight road, a total 69% of the vehicles merge early in Zones 3 and 4. This might be because the drivers have a longer sight distance and can see the incoming work zone taper (transition area) better and the causes need to be further studied to confirm. On the contrary, on a curved road, only 37% of the vehicles merge early in zones 3 and 4. This may be due to the shorter sight distance or the presence of obstacles such as plants or vehicles that could limit the view of the driver.

It is interesting to see that 14% and 12% of the drivers merged in Zone 1 on a straight and a curved road, respectively. They might be the reckless drivers and they will merge late regardless they can see the taper in a longer distance. Again, further study needs to be conducted to better understand the causal factors.



(a) Other vehicles on straight road (b) Trucks on straight road

(c) Other vehicles on curved road (d) Trucks on curved road

Figure 8 Merge timing/location based on different vehicle types

Results of merge frequencies at different zones based on different vehicle types are illustrated in Figure 8. The results reveal that for both road segments, no matter on a straight or a curved one, most trucks merged in Zones 3 or 4, yet higher percentages of other vehicles merged in Zones 1 or 2. Figure 8(c) depicts that among all non-truck vehicles observed in the closed lane on a curved road, 67% merged in Zones 1 or 2 and 37% merged in Zones 3 or 4. However, Figure 8(d) shows that among all trucks, 49% merged in Zones 1 or 2 and 51% merged in Zones 3 or 4. Namely, based on our observation, trucks tend to merge earlier (farther away from the taper) than other vehicles in the closed lane at work zones. The results might be because truck drivers have better view and sight distance than other drivers.

Our preliminary study on the merge timing and behavior at work zones indicates that driver behavior could be influenced by factors such as roadway geometry and vehicle type. Two findings were identified in the results: First, vehicles at work zones on a curved road, in comparison with those on a straight road segment, tend to merge late (i.e., closer to the taper.) Second, trucks tend to merge earlier than other vehicles at work zones. Both findings lead to one potential causal factor, i.e. driver's sight distance. Further studies could be conducted by analyzing eye-level height, recognition distance of lane closure work zone configuration, vehicle speed, adjacent traffic condition, etc. to better understand the driver's sight distance.

CONCLUSIONS AND RECOMMENDATIONS

It is crucial to improve work zone safety and minimize delays at work zones. However, except for crash records, there is limited data to support the study of driver behavior at work zones. This paper is the first time to propose a vision-based multi-view sensing system to collect and monitor the continuous driver behavior at work zones. The following are the findings of the preliminary study:

Conclusions

1. A vision-based sensing system with multi-view cameras that covers 4 zones is the first time proposed to study the merge timing and behavior of drivers at work zone transition and advance warning areas.
2. Preliminary results show that vehicles tend to merge closer (late) to the work zone taper on a curved road than those on a straight road.
3. Preliminary results also indicate that trucks tend to merge farther (early) away from the work zone taper than other vehicles.

Recommendations

1. More data is needed to be collected (e.g. more video data) and extracted (e.g. traffic information other than traffic count and vehicle type) in order to better understand and analyze the merge timing and behavior of drivers at work zones.
2. It is recommended to develop image processing algorithms to extract traffic information such as distance to the taper, vehicle speed, and traffic volume to better support driver merge behavior study.
3. As the sight distance between the driver and traffic control devices could be one of the potential causal factors impacting driver behavior, future research is needed to qualitatively and quantitatively analyze the impact of sight distance on driver's merge timing and behavior at work zones.
4. The impact of different merge behaviors on work zone safety and mobility needs to be further studied by developing a better measure to categorize and measure different levels of impacts on safety and mobility.

ACKNOWLEDGEMENTS

The work described in this paper was supported by the National Academy of Sciences (NAS), National Cooperative Highway Research Program (NCHRP), Innovations Deserving Exploratory

Analysis (IDEA) program. The authors would like to thank Mr. Chengbo Ai's assistance on collecting the data.

REFERNNCES

Akepati, S. R. and Dissanayake, S. (2011), Characteristics and Contributory Factors of Work Zone Crashes, *Transportation Research Board 90th Annual Meeting*, Washington D.C.

Kang, K. P. and Chang, G. L. (2006), A Robust Model for Optimal Time-of-Day Speed Control at Highway Work Zones, *IEEE Transactions on Intelligent Transportation Systems*, **7**(1), 115-123.

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D. and Ramsey, D. J. (2006), The Impact of Driver Inattention on near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data, in National Highway Traffic Safety Administration, Washington D.C.

Kwon, E., Brannan, D., Shouman, K., Isackson, C. and Arseneau, B. (2007), Development and Field Evaluation of Variable Advisory Speed Limit System for Work Zones, *Transportation Research Record*, 2015, 12-18.

Li, W., Zhang, R., Liu, Z. K., Zhao, H. J. and Shibasaki, R. (2007), An Approach of Laser-Based Vehicle Monitor, *Applied Mathematics and Computation*, **185**(2), 953-962.

Gordon, T., Bareket, Z., Kostyniuk, L., Barnes, M., Hagan, M., Kim, Z., Cody, D., Misener, J., Skabardonis, A., Vayda, A. and Perez, M. (2008), SHRP 2 S09: Site-Based Video System Design and Development, in National Highway Traffic Safety Administration, Washington D.C.

Ullman, G. L., Finley, M. D. and Theiss, L. (2011), Categorization of Work Zone Intrusion Crashes, *Transportation Research Board 90th Annual Meeting*, Washington DC.