Work Zone Safety: Physical and Behavioral Barriers in Accident Prevention

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16. Abstract

This report discusses the usefulness of creating a work zone traffic safety culture as a methodology to improve the overall safety of both work zone personnel and the traveling public in Missouri. As part of this research, the existing MoDOT Work Zone Rating Survey was analyzed and augmented to collect public perception of work zone safety, historical data on work zone crashes were evaluated to identify trends that are particular to, and attributes that are associated with severe crashes were identified.

Results from the existing Work Zone Rating survey show a difference in stakeholder perceptions regarding the adequacy of work zone warning signs and the safety level in traveling through work zones. Based on survey responses from current MoDOT employees, existing work zone warning signage and guidance (barrels, cones, and striping) are adequate to protect the driving public and are in accordance with the MoDOT Temporary Traffic Control Elements. However, responses from the general public reveal that a plurality of respondents perceived that the warning signs were insufficient in terms of information provided, provided inaccurate information, or were wrongly placed.

An evaluation of crash data shows that there is not an elevated risk in work zones when compared to non-work zones. Fatal and severe crashes occur more frequently when roadway conditions were dark or involved multiple vehicle interactions. Contributing circumstances in work zone crashes involving vehicle interactions suggest that human factors are key risk elements. Solutions to mitigate fatal or severe crashes should include stakeholder education, higher enforcement and legislation designed to minimize distracted driving, and engineering solutions designed to increase driver awareness.

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Executive Summary

This project focused on the usefulness of creating a work zone traffic safety culture as a methodology to improve the overall safety of both work zone personnel and the traveling public in Missouri. This research collected the general public's perception of work zone safety using the existing and augmented versions of the MoDOT Work Zone Rating Survey, evaluated the historical data on work zone crashes and identified trends that were specific to Missouri, and identified attributes that were associated with severe crashes.

The Work Zone Rating survey showed a difference in stakeholder perceptions regarding the adequacy of work zone warning signs and the safety level in traveling through work zones. Based on survey responses from current MoDOT employees, existing work zone warning signage and guidance (barrels, cones, and striping) are adequate to protect the driving public and are in accordance with the MoDOT Temporary Traffic Control Elements. However, responses from the general public reveal that a plurality of respondents perceived that the warning signs were insufficient in terms of information provided, provided inaccurate information, or were wrongly placed. One possible reason for the difference in stakeholder perception is that the general public lacked the safety awareness and knowledge of existing protocols and standard operating procedures for work zones. Anecdotal evidence from the comments received through the surveys suggests that the lax enforcement of traffic laws in Missouri contributes to the general public's disregard of work zone signs and warnings, especially the reduced speed limit warning. Another possible reason is the influence of organization culture on MoDOT employees. Thus MoDOT employees seek confirmation of the existence of signage and warning when they approach a work zone.

Missouri work zone crash data from 2009 to 2011 was used for analysis. As a comparison, overall Missouri crash data from 2009 to 2011 was also used, including non-work zone data. In addition, crash analyses from reports such as the MoDOT Tracker and Missouri's Blueprint to Save More Lives were also used as references. The result shows that there is not an elevated risk in work zones when compared to roadways with no work zones. The percentage of crashes in the fatal, injury, and PDO categories between work zones and non-work zones differed by less than one. In contrast, other states have reported an elevated risk in work zones.

Crashes that occurred when dark seemed to be overrepresented in fatal and severe crashes. Therefore it might be useful to consider improving lighting, delineation, and visibility at nighttime work zones. In terms of accident type, a large number of work zone crashes involved vehicle interactions. These crashes point to possible factors such as traffic queues, lane drops or distracted driving. Of the two-vehicle collisions, rear-end crashes are the most significant, and they tend to be more severe. The failure to stop could be due to a failure of perception/reaction or a failure to brake. Countermeasures that increase driver attention and compliance such as enforcement, larger fines, and education could be useful in reducing two-vehicle and read-end crashes. If the contributing circumstances categories of aggressive drivers, distracted drivers and failure to yield/violation were viewed together, it implies that human factors are a great contributing factor to crashes. This fact again points to solutions related to education, enforcement, and legislation more than just engineering.

In contrast to all crashes, work zone crashes involved fewer ran-off-road and more on-road crashes. In terms of traffic conditions, accident ahead was overrepresented which means congestion and lane drops at work zones could be significant factors. For probable contributing circumstances, aggressive and distracted driving are major problems. The examination of the crash distribution of MoDOT districts, urban versus rural, functional classification, speed limit, and AADT shows rural crashes are disproportionally more severe. Major collectors experience the highest percentage of severe crashes, almost three times as much as interstates and freeways. Low AADT routes are overrepresented in more severe crashes. And rural fatal and disabling injury crashes occur at a higher proportion than in urban or urbanized regions.

Statistical models using Multinomial Logistic Regression were used to analyze the influence of light conditions, road conditions, traffic conditions, weather conditions, road profile, road alignment and two-vehicle analysis on severity of the crash. The model produced descriptive statistics of the features of the crashes and a comparison of attributes of crashes with minor injury relative to property damage only and disabling injury/fatality relative to property damage only.

Acknowledgement

The authors gratefully acknowledge the assistance provided by the following MoDOT employees. Dawn Haslag assisted with the development and launch of the stakeholder survey. Dianne Haslag assisted with troubleshooting all aspects of the ODBC connection. Myrna Tucker assisted with querying various MoDOT databases, providing sample queries, and clarifying TMS database formats. John Miller assisted with safety and crash data information and coordinating with other MoDOT staff at IS (Information Systems) and TMS. Dawn Haslag assisted with the Work Zone Rating survey. We further thank graduate research assistants Paul Robin and Venkat Sravan Kothapalli for their assistance.

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1. Introduction

Work zones can involve reduced speeds, traffic congestion and lane transitions. Between 2008 and 2012, 61 people were killed and 3,654 people were injured in Missouri work zones (ARTBA, 2014). Since 2000, there have been 16 MoDOT employee fatalities in the line of duty.

There is a wide range of literature available on work zones in the US. This literature provides important usable information on different aspects of work zone crashes and modelling information. According to the Fatality Analysis Reporting System (FARS), maintained by the National Highway Traffic Safety Administration (NHTSA), the number of fatal motor vehicle traffic crashes in the state of Missouri was 826 of which 7 of them took place in work zones (1). According to the Federal Highway Administration (FHWA), motor vehicle fatal injuries in work zones average around 900 persons every year, and fatalities increased more than 50 percent in a span of 5 years. The majority of work zone crashes occurred under daylight conditions (79%) and in clear weather (58.4%) (Akepati, 2010). Inattentive driving and following too closely are two major factors. Most crashes are Property Damage Only (PDO). In a study of 5 states, 72.2% of them were PDO (Dissanayake and Akepati, 2007). Driver error was involved in 82% of injury crashes. Rear end collision was the most common cause for crash injuries, and head-on collision was the most common cause for fatal work zone accidents (Bai and Li, 2007a). Some research suggested that following too close, failure to control, and improper lane change/improper passing accounted for 71% of all fatal and injury crashes at interstate freeways in Ohio work zones (Salem, 2007). During 2003-2007 approximately 70% of accidents occurred between 8 AM to 4:59 PM (Pegula, 2010).

Traffic safety culture is a new area of research that examines the behavior of roadway users and the effect of various behaviors on the traffic safety outcome. Traffic safety culture is an extension of safety culture research and is still in its infancy. Ward et al. (2010) explained that the term “traffic safety culture” contains the three elements of cognition, behavior, and artifacts. General public’s perceptions of a work zone affect their cognition and thus affect their behavior while traveling through work zone. This study evaluated the public’s perception of work zone signage and perceived safeness when traveling through a work zone.

The first section of this report discusses the MoDOT Work Zone rating survey, followed by an analysis of historical data on work zone crashes in general, and an analysis on attributes of severe crashes.

2. Work Zone Rating Survey

2.1 Introduction

This chapter presents an overview of MoDOT's work zone survey on public perception, and evaluates and identifies the potential for obtaining more information. The results from an expanded survey are also presented.

This chapter is organized as follows. First, a brief literature review on the factors that affect roadway user behavior is presented, including behavior approaching and traversing work zones. Second, existing MoDOT work zone survey results are analyzed. Third, the potential to obtain in-depth information from roadway users is identified. Fourth, a modified survey is presented along with the results from the pilot study. A comparative study between the existing survey and the expanded survey is presented. Last, recommendations based on the results are presented.

2.2 Literature Review

Literature that are relevant to examining work zone safety surveys are organization culture, safety culture, and situation awareness. Organization culture presents the norms, behavior, and effects of decision making by people within an organization. Safety culture represents attitudes and behavior towards safety. And situation awareness represents how humans process information in a dynamic situation and make decisions based on that information.

2.2.1 Organizational Culture

The study of culture by sociologists, psychologists, and anthropologists generally focus on understanding the norms, thoughts, and behaviors of people within a group. Organizational culture focuses on people within a certain organization or within an industry. Organization culture is distinctive from military culture, college culture, etc.

Schein's (1985) definition of organizational culture is the most often-cited definition. Schein (1985) defined organization culture as "…a pattern of basic assumptions – invented, discovered, or developed by a given group as it learns to cope with its problems of external adaptation and internal integration that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems".

The relationship between organization culture and organization performance is well established in literature. Deal and Kennedy (1982) found that strong organization culture leads to strong performance; Denison (1990) established that the effectiveness of an organization is a function of values, beliefs, policies, and practices. Studies also found that organization culture affect organization effectiveness, job satisfaction, quality, safety, and reliability (Sandoval, 2005). The literature on organization culture suggests that driver culture in Missouri and MoDOT's organization culture both influence work zone safety.

2.2.2 Safety Culture

Safety culture studies generally focus on the norms and behavior of an organization in terms of how they approach work safety. U.K. Health & Safety Commission (1993) defined safety culture as "the product of individual and group values, attitudes, competencies, and patterns of behavior that determine the commitment to and the style of proficiency of an organization's safety and health programs. Organizations with a positive safety culture are characterized by communications founded on mutual trust, shared perceptions of the importance of safety, and confidence in the efficacy of preventive measures."

Cooper (2002) stated that unless safety is the dominant characteristic of the organization, as in high-risk industry (e.g. nuclear, aircraft carrier, air traffic control), safety culture is "a subcomponent of corporate culture, which alludes to individual, job and organizational features that affect and influence safety." In other word, for organizations operating in non-high-risk industry, safety is usually not the driving force behind the organization culture; instead, the organization culture has strong influence on the safety culture.

With regards to the safety culture in transportation, Ward et al. (2010) explained that the term "traffic safety culture" contains the three elements of cognition, behavior, and artifacts. Cognitive is defined as the perceptions people have about what behaviors are normal in their peer group, and their expectations for how that group reacts to violations to these behavioral norms. In terms of traffic safety, behaviors can either increase crash risk (e.g., speeding) or decrease risk (e.g., wearing seatbelts). Behaviors can also relate to the acceptance or rejection of traffic safety interventions." Artifacts are symbols that reveal cognition and the resulting behavior. Traffic safety artifacts include traffic laws and traffic safety policies.

2.2.3 Situation Awareness

Situation awareness was first introduced in aviation psychology, and was later applied to various industries including aviation, the military, medicine, and nuclear power. The focus of situation awareness research is on factors that influence decision making in highly complex and dynamic environments (Sandoval, 2005). Situation awareness is generally defined as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1998)". The three main requirements of situation awareness, as defined by Endsley (1998) are:

- Level 1: Perception. This is the first step in situation awareness and requires the user to identify the information in the environment.
- Level 2: Comprehension. This level requires the user to understand the information identified.
- Level 3: Projection. This level requires the user to predict the change of information in the environment.

To increase the likelihood of making a good decision, a user must accurately achieve all three levels listed above, and then the user will be able to form a realistic view of the situation, and thus make a good decision (Sandoval, 2005).

2.3 MoDOT Work Zone Rating survey

The MoDOT Work Zone Rating Survey is an instrument to evaluate the safety of the work zone within the state of Missouri. Both MoDOT employees and non-employees (general public) are encouraged to participate in the survey to provide feedback to MoDOT. To provide useful feedback to MoDOT, this survey is analyzed in terms of organizational culture, safety culture, and situation awareness.

MoDOT employees are influenced by the organization culture of MoDOT. In addition to the norms and behavior, this influence also includes the organizational knowledge and the understanding on how things should be done. Thus MoDOT employees rate work zone safety differently than the general public, who, as an outsider, are not influenced by the organization culture and do not have prior knowledge on standard operating procedures (SOP) and work zone protocols. The feedback from both MoDOT employees and the general public are equally important, as they serve different functions and purposes. Understanding the effect of situation awareness is especially important in understanding the perceptions of the general public, as the way the general public perceives work zone warning signs will inadvertently affect their comprehension and decision on how to perceive and navigate through a work zone.

2.3.1 Existing Work Zone Rating Survey

As an ongoing effort to evaluate work zone safety, MoDOT utilizes the Work Zone Rating Survey which is available on the internet and in a post card form. The Work Zone Rating Survey allows road users and MoDOT employees to provide input to MoDOT on their perceived safety of MoDOT work zones throughout Missouri. The Work Zone Rating Survey provides a tool to quantitatively measure the safety of MoDOT work zones. Quantitative measures are simple and effective for communicating with stakeholders. This section examines the existing survey setup, and the results received over a six-week period. The implications of the results and the potential for making work zone safety improvements are also discussed.

The current Work Zone Rating Survey consists of five Yes/No questions, two of which allows the user to enter the reason for a "No" response. The survey also contains background questions on roadway location, date, time, weather condition, and the user's vehicle type. See Appendix A for a printout of the web-based survey.

2.3.2 Cross Sectional View

Between May 1 and June 13, 2013, 487 respondents participated in the MoDOT Work Zone Rating Survey. Of the 487 participants that completed the survey, 426 of the participants (87%) identified themselves as MoDOT employees, and 61 participants (13%) identified themselves as non-MoDOT employees.

Figure 2.3.2.1 shows the response to the first question, "Did you have enough warning before entering this work zone?" Almost all of MoDOT employees answered yes, while 73% of non-employees answered yes. The total percentage who answered yes was 96%.

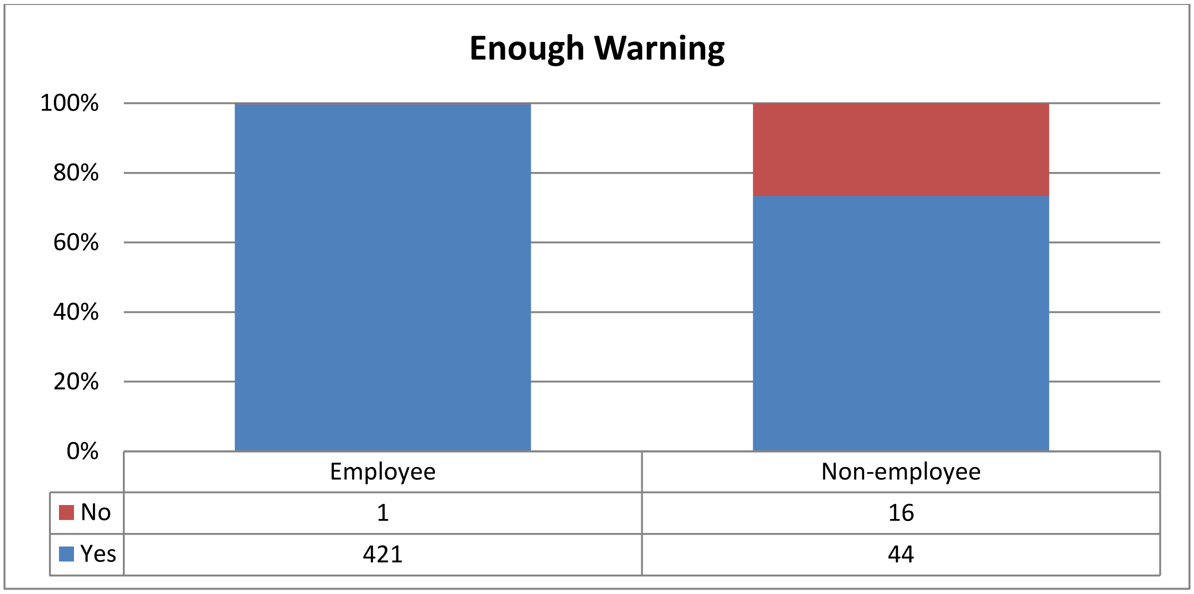

Figure 2.3.2.1 Enough warning before entering work zone?

Figure 2.3.3.2 shows the responses to the second question, “Did the sign provide clear instructions?” Again, almost all MoDOT employees answered yes, while 63% of non-employees answered yes.

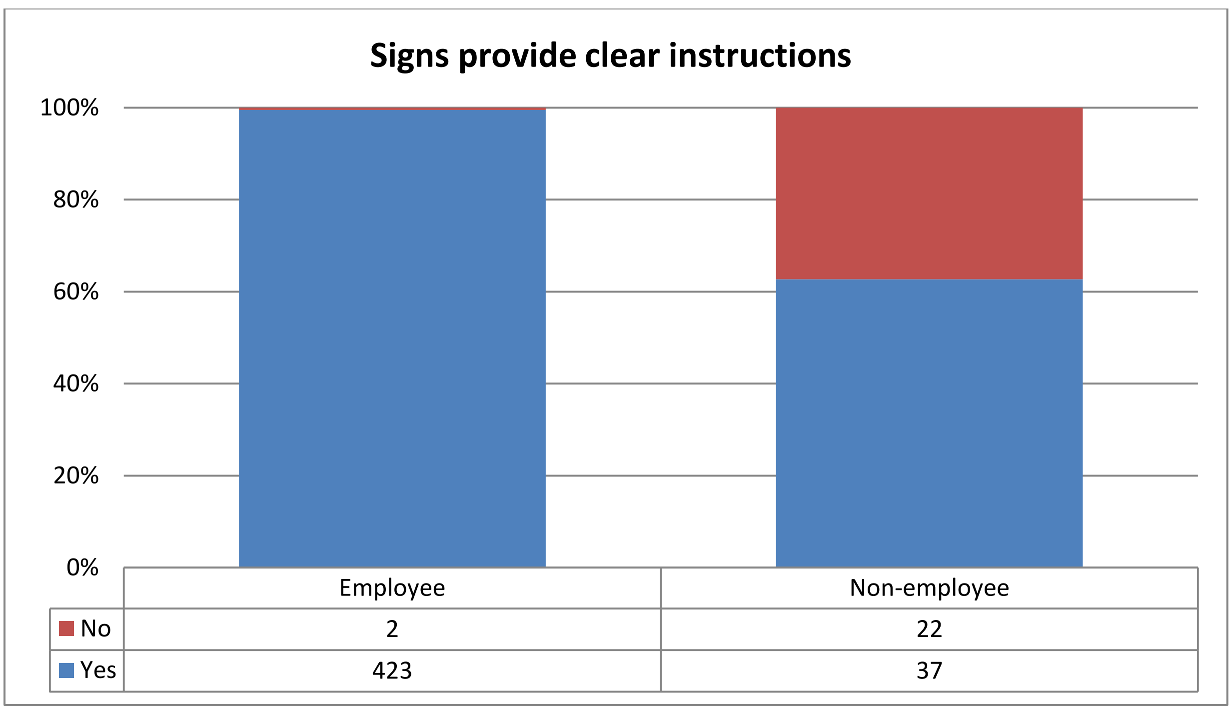

Figure 2.3.2.2 Clear instructions?

Figure 2.3.2.3 shows the response to the question, “Did the cones, barrels, or striping adequately guide you through the work zone?” Of the MoDOT employees, 12% responded that none were present, 0.4% responded no, and 87% responded yes. Of non-employees, 10% responded that none were present, 16% responded no, and 74% responded yes. The gap between employees and non-employees was smaller than previous questions.

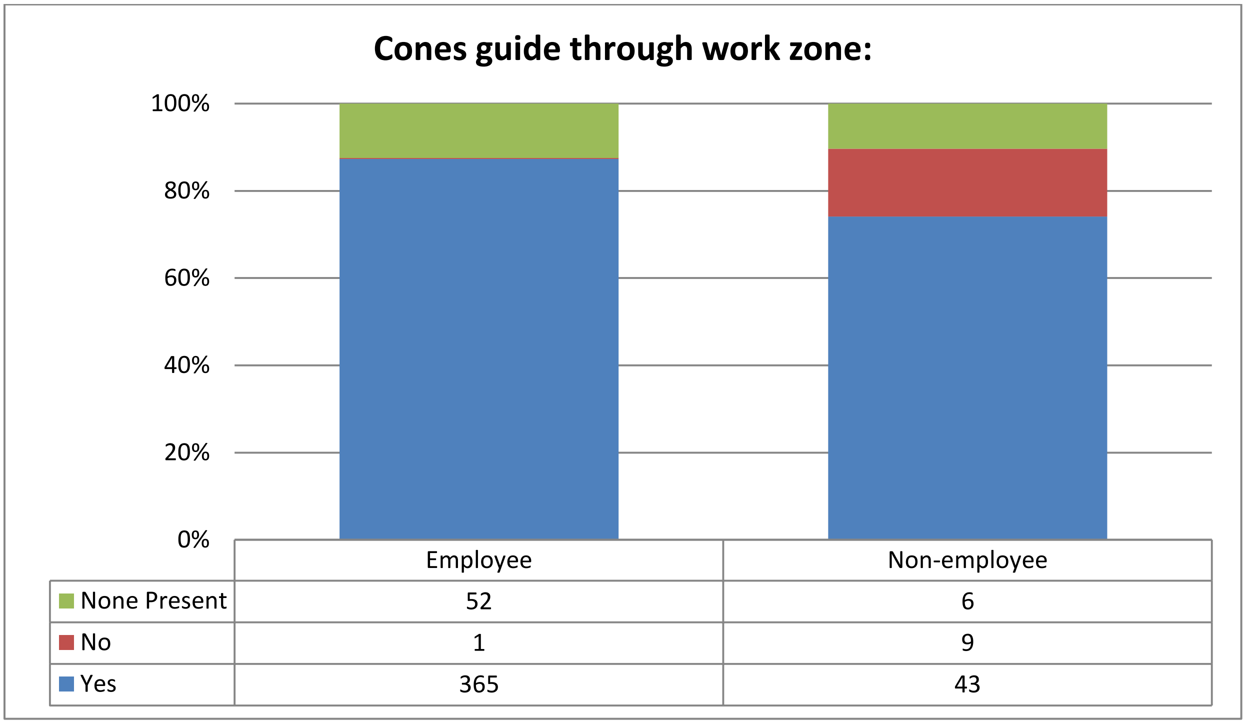

Figure 2.3.2.3 Adequacy of cones, barrels, or striping?

Figure 2.3.2.4 shows the response to the question, "Did you make it through the work zone in a timely manner?" Most of the MoDOT employees, 99%, answered yes, while 58% of non-employees answered yes.

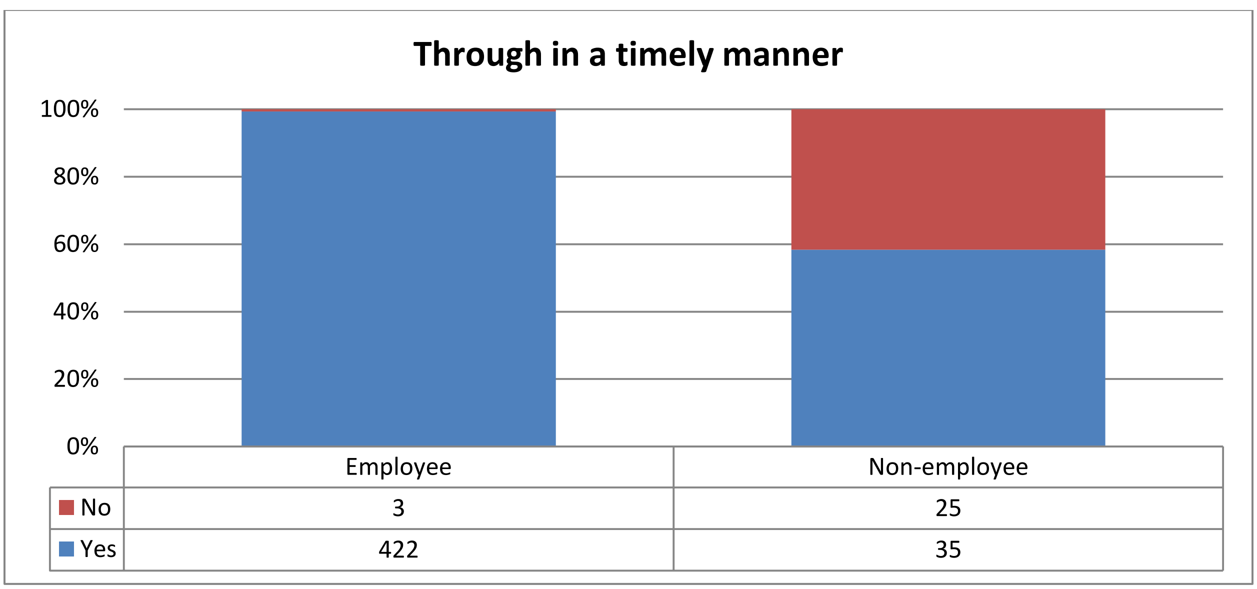

Figure 2.3.2.4 Responses to question on getting through work zone in a timely manner

Figure 2.3.2.5 shows the response to the question, "Were you able to travel safely in the work zone?" All MoDOT employees responded yes, while 63% of non-employees responded yes. For a detailed breakdown of the survey results, please see Appendix B.

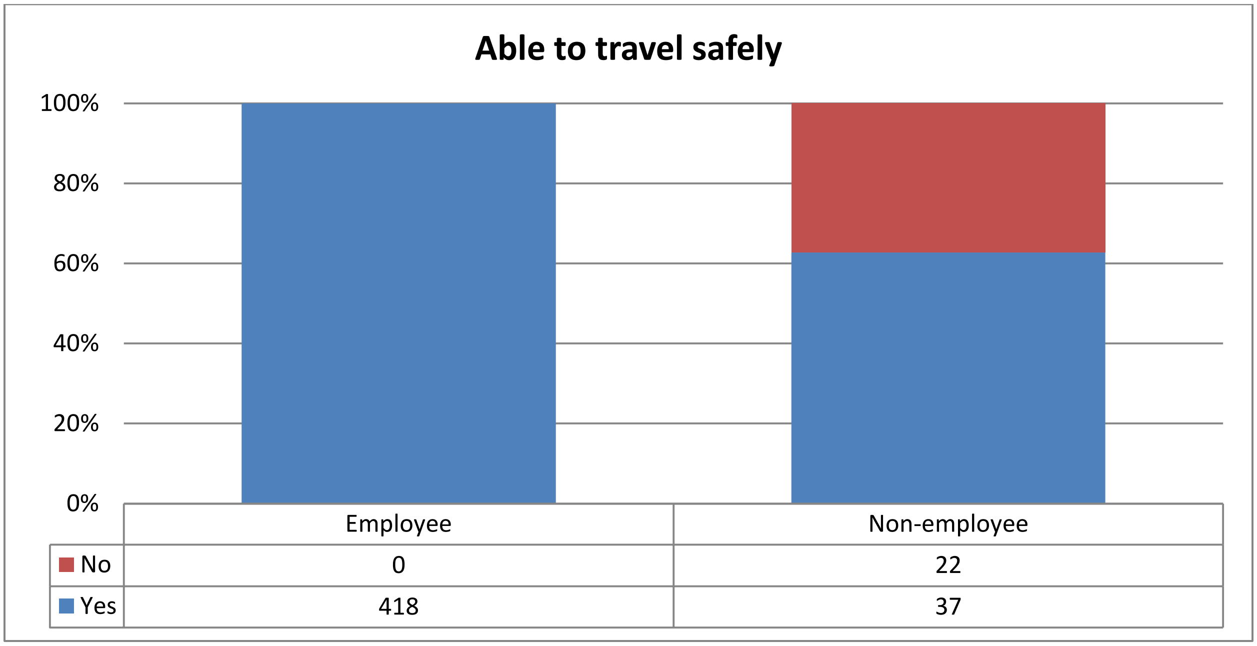

Figure 2.3.2.5 Responses to question on safe travel in the work zone

2.3.3 Results and Analysis from Existing Survey

The results were obtained from, May 1 to June 13, 2013. This time period was when there was heavy road work as well as high travel demand. The total trend of the results was positive: the "Yes" rating to all questions was over 93%, with some as high as 96% positive rating. From the total survey response, one can conclude that the "No" rating was negligible. However, as shown in Figures 2.3.2.1 through 2.3.2.5, the responses differed significantly between MoDOT employees and non-employees. The non-employees responded more negatively than MoDOT employees. Because the non-employee respondents were much fewer in number than employee respondents, the non-employee results were masked.

Current survey design is intended for MoDOT employees and the general public to rate the work zone that they have experienced. The limited number of questions and answer choices allow users to complete the survey easily, thus generating a large response rate. This fulfills MoDOT's goal of collecting work zone rating information, and allows MoDOT to have a measurable rating on the work zones in Missouri.

2.3.4 Implications of Survey Results

The discrepancy between the ratings by MoDOT employees and non-MoDOT employees is most likely due to the baseline upon which the ratings were given. MoDOT employees evaluate the work zone based on the established safety protocols and SOP, where as non-MoDOT employees evaluate the work zone based on the perceived safety level and perceived inconvenience that the work zone created.

MoDOT employees are trained and have good knowledge on the setup and standard operating procedure SOP of work zones. This organizational knowledge is crucial in the rating of the work zone – especially on whether a work zone complies with warning and signage requirements. This prior knowledge allows MoDOT employees to immediately spot any warning signs that are missing, which is essential to rating the work zone safety. The organizational culture has conditioned MoDOT employees to quickly spot the lack of safety in a work zone from the perspective of established work zone safety protocols and SOP.

However, MoDOT employees' work zone rating is different from how the general public perceive the warning signs. General public do not have the knowledge of how a work zone should be set up, and thus, they are not bound by the organizational knowledge on what is required of work zones. The general public rates work zones based on their perceived usefulness of signage and warnings. The general public is more concerned about perceived safety and perceived inconvenience due to work zone activities, and less concerned about SOP and work zone safety protocol. This is evident from the comments from the general public along the line of "ruining my Saturday", "ridiculous schedule", and "work zone sign but no workers".

Even though survey participants had the opportunity to input open-ended comments, the small number of "No" responses resulted in very few comments. Because the general public did not have knowledge of engineering terminology and procedures, the comments were more descriptive of the entire situation, and reflected personal experience and feelings.

The knowledge of the perceived safety and concern of work zone safety management is crucial in improving work zone safety. As research in situation awareness has shown, the perception of the situation by the user will affect the user's decision-making in a given situation. Identifying the perception of the general public regarding work zone safety and signage will allow MoDOT to utilize this information to modify the work zone signage to increase the general public's awareness and to conduct work zone educational campaigns.

2.4 Expanded Work Zone Safety Survey and Pilot Study

An expanded survey was created in order to gather more information about public perception of work zones. Once a participant completed the original survey on the MoDOT website, the participant was given an opportunity to take this expanded survey. The expanded survey contains the same five-question with a "Yes/No" rating as the original work zone rating survey by MoDOT. The additions to the expanded survey only occur if the survey participant rated "No" to any of the questions.

The data collected from the existing Work Zone Rating Survey directly feed into MoDOT's TRACKER, a compilation of performance indicators for MoDOT. Any changes to the existing survey will have long term effect on the MoDOT database. The expanded survey is treated as an external link to prevent making changes to the database. Participants whom answered "Yes" to all questions will get the exact same questions in the expanded survey, without seeing any of the conditional questions. This is necessary to prevent any unnecessary changes to be made to the performance indicators tracker database.

2.4.1 Expanded Survey Questions

A question was added to identify the distance to the work zone when a warning sign was spotted. This question allowed the assessment of the perceived distance and attentiveness of road users.

Additional questions were asked only if the survey participants answered “no” to any of the lead questions. Once the participant selected “no”, a list of potential reasons for the response was presented along the opportunity to type in a non-pre-defined reason. For example, the additional question related to Question 2 on sufficient signage is presented in Figure 2.4.1.1.

2) Did the signs provide clear instructions?
[ ] Yes [ ] No

Logic: If answer “No” in Question 2, display the following:

Please let us know the issues with the signs. Please check all that applies.*
[ ] Confusing symbol
[ ] Confusing message
[ ] Message too long
[ ] Words too small
[ ] Better locations
[ ] More visible signs
[ ] Other (Please provide more information):____*

Figure 2.4.1.1 Extension on Question 2 of the expanded survey

The benefits of providing a predefined list of potential reasons are two-fold. First, this reduces the likelihood of a participant entering an overly long description of the situation without actually stating the reason. Second, the list of potential reasons serves as a guide for the participant on the type of information that is of interest to MoDOT, especially for those who are unsure of the type of information that is asked. See Appendix C for the complete Expanded Work Zone Rating Survey.

2.4.2 Pilot Study

A pilot study was conducted from May 1, 2013 through December 31, 2013. Upon completion of the original survey on the MoDOT website, a link to this pilot study on the expanded survey was provided to the participant. Upon entering the site for this expanded survey, the participant is informed that if their responses were all “Yes” on the original survey, then the expanded survey will be identical to the original. The participant is then informed that he/she may exit the survey at any time.

2.4.3 Pilot Survey Results

A total of 194 participants clicked on the link provided at the end of the original survey. Of the 194 participants, 176 of the participants completed the expanded survey in its entirety. Of the

176 participants that completed the survey, they always have the option to skip any questions that they did not want to answer. The participant affiliation is divided nearly evenly between MoDOT employees (51%) and non-employees (49%). The following figures present the findings from the survey. The detail survey results are presented in Appendix D.

Figure 2.4.2.1 shows the responses to first question, “Did you have enough warning before entering this work zone?” The figure shows almost all MoDOT employees answered yes, while 58% of non-employees answered yes.

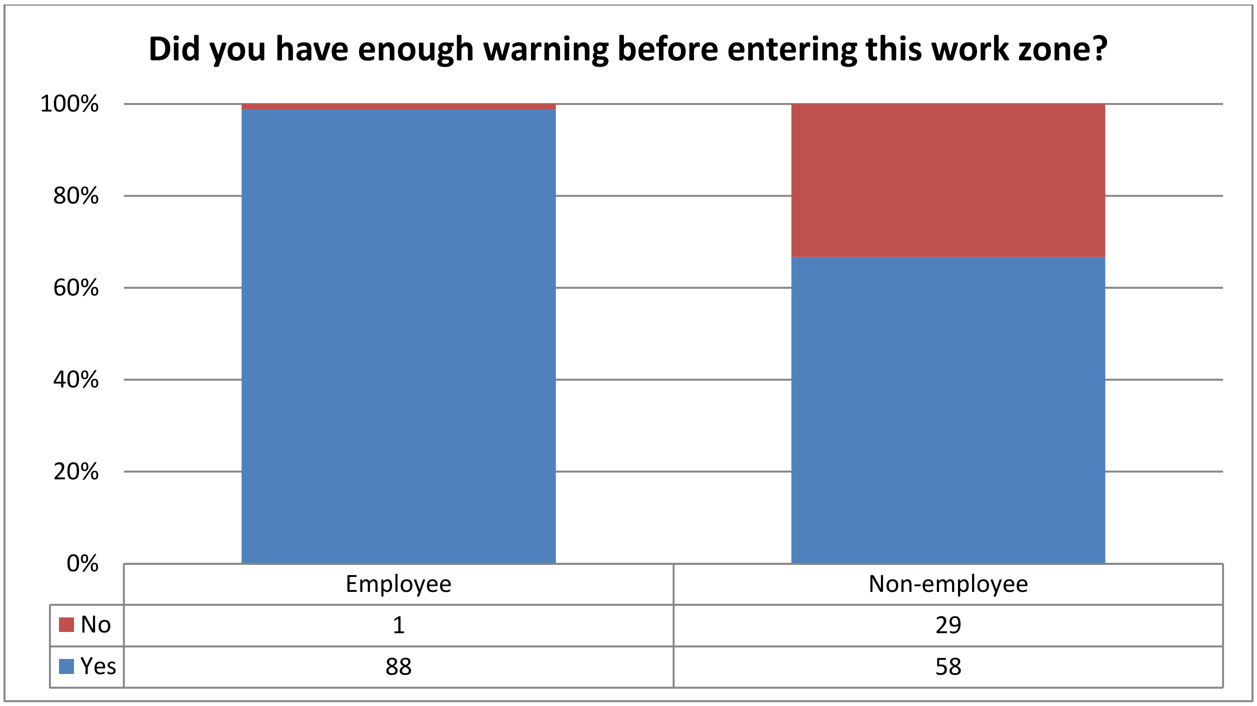

Figure 2.4.2.1 Enough warning before entering work zone?

Figure 2.4.2.2 shows the responses to second question, “Did the sign provide clear instructions?” Again, almost all MoDOT employees answered yes, while 56% of non-employees answered yes.

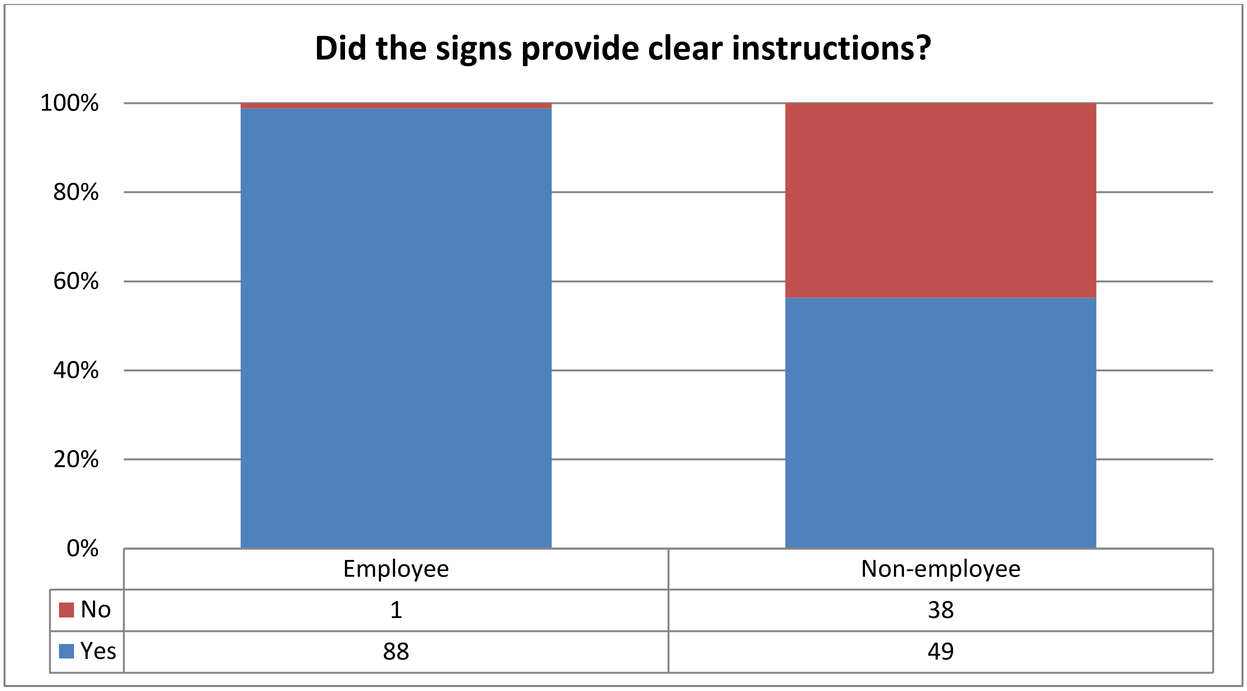

Figure 2.4.2.2 Clear instructions?

Figure 2.4.2.3 shows the response to the question, "Did the cones, barrels, or striping adequately guide you through the work zone?" None of the MoDOT employees answered no, while 18% of the non-employees answered no.

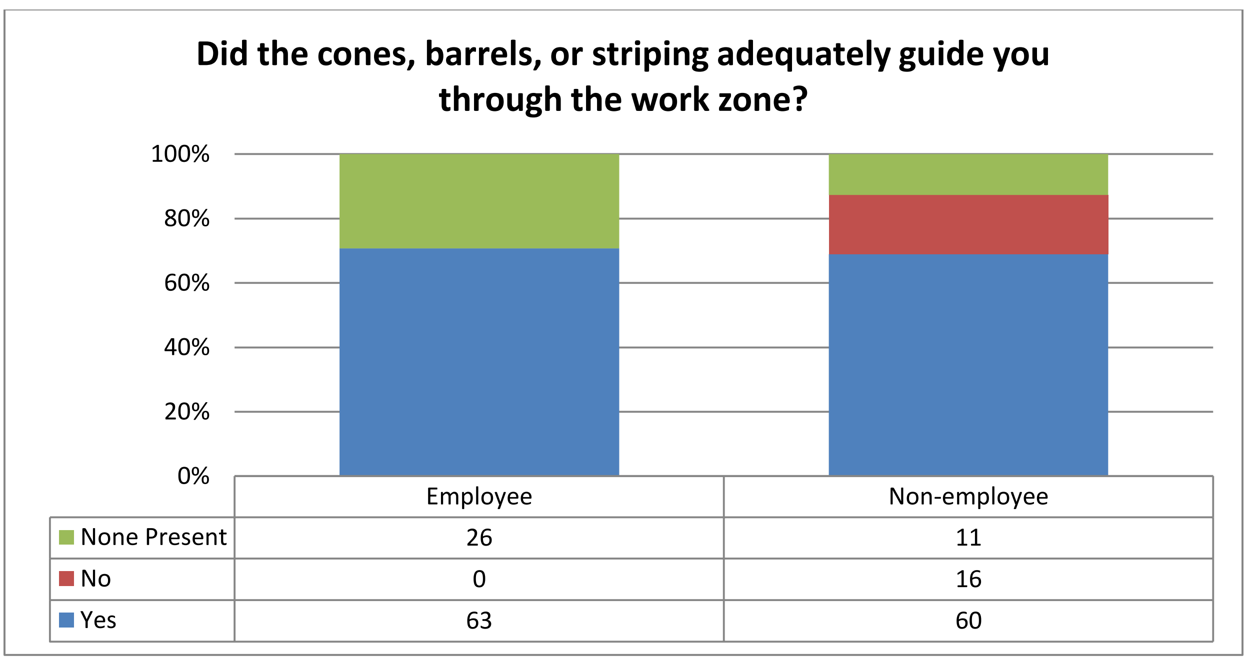

Figure 2.4.2.3 Adequacy of cones, barrels, or striping?

Figure 2.4.2.4 shows the response to the question, “Were you able to travel safely in the work zone?” Almost all MoDOT employees answered yes while 66% of the non-employees answered yes.

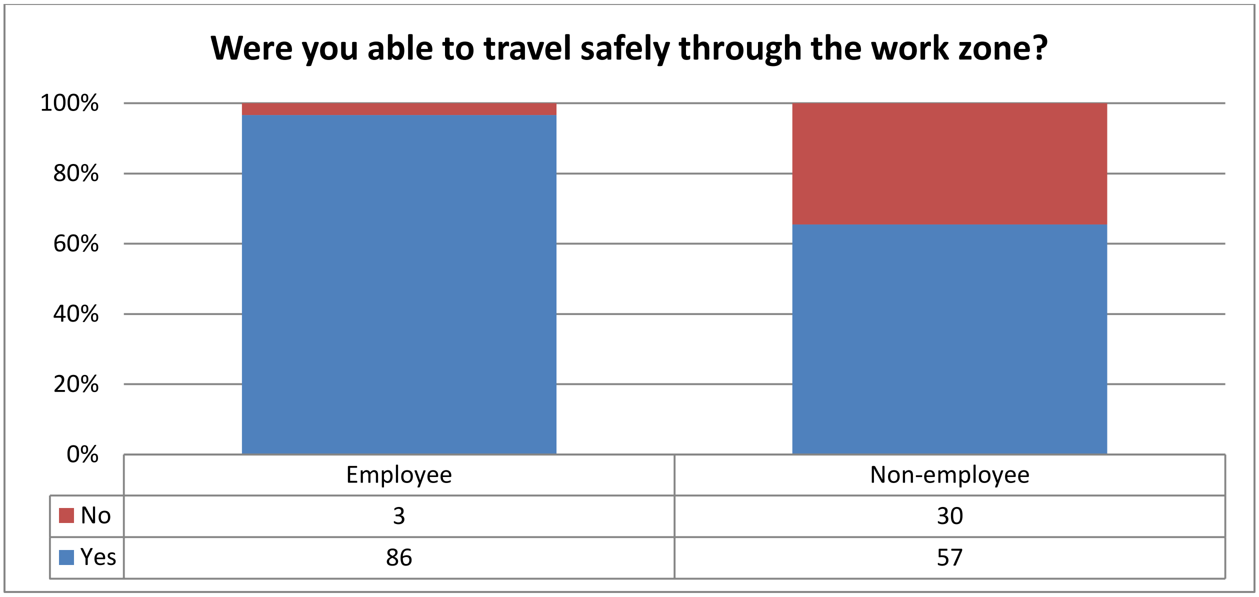

Figure 2.4.2.4 Safe travel in the work zone?

2.4.4 Results from Expanded Questions

Three questions contained expanded questions, which only appeared if the participant answered “No” in the prompting question. Participants were encouraged to select all the reasons that applied for the “no” response. Figure 2.4.3.1 shows the breakdown of the reasons provided by the participants for a negative rating for each of the three questions.

Question 2: Did the signs provide clear instructions?		**Question 3: Did the cones, barrels, or striping adequately guide you through the work zone?**		**Question 5: Were you able to travel safely in the work zone?**	
Yes	137	Yes	123	Yes	143
No	39	No	16	No	33
Count	*Reasons for "No" Rating*	*Count*	*Reasons for "No" Rating*	*Count*	*Reasons for "No" Rating*
0	Confusing symbol	1	Wrong location	7	Roadway too narrow
7	Confusing message	3	Too few/missing	8	Worker's proximity to the roadway
0	Message too long	7	Confusing	2	Speed limit at work zone was too high
0	Words too small	1	Not visible	11	Stopped traffic or traffic backups
9	Better locations	11	Other	23	Others
10	More visible signs				
27	Other				

Figure 2.4.3.1 Reasons provided by participants for no response for Questions 2, 3, and 5

On whether the signs provide clear instructions, 39 participants believed that the signs did not provide clear instructions, 10 of them believed that the signs should be more visible, 9 believed that the sign should be at a better location, and 7 of the participants felt that the signs had a confusing message. On whether the cones, barrels, or striping guided them through the work zone adequately, 16 participants felt that they were inadequate, with 7 participants indicated that they were confusing.

On whether they were able to travel safely in the work zone, 33 of the participants did not feel safe traveling in the work zone, 11 indicated that stopped traffic or traffic backups posed an unsafe travelling condition, 8 indicated that the workers are too close to the roadway, and 7 indicated that the roadway was too narrow.

At a first glance, the "Other" category seems to have the highest numbers, indicating that the reasons for their negative ratings were not listed. However, when compared to the overall negative ratings for each of the questions, the reasons that were provided to the participants seem to cover a large number of the negative ratings. For example, in Question 2, ten of the 39 participants that responded "No" on this question felt that more visible signs are necessary to provide clear instructions for the general public, nine of the 39 participants felt that the locations for the signs need to be adjusted, and seven of 39 felt that the message was confusing.

One commonality among the comments entered by non-MoDOT employees is on the warning signs: signage not providing enough information, improperly placed signage, and signage was up but no activities in the work zone.

These expanded questions with reasons for negative ratings simplify the process for MoDOT to identify potential changes that can be made to work zone signage and warnings. These changes could be a simple usability issue or to modify the perception by the general public. Appendix E shows the breakdown on the reasons provided by the participants for negative ratings on the questions. For comparative purposes, Appendix F shows the comments received through MoDOT's original Work Zone Rating Survey for Question 5, "Able to travel safely in the work zone?"

Figure 2.4.3.2 shows the weather condition when the participants passed through the work zone, and the type of vehicles that the participant drove. Due to the small sample size (174), and large percentage of participants driving a car or pickup and passing through a work zone in clear weather conditions, the analysis based on weather and vehicle type is not conclusive.

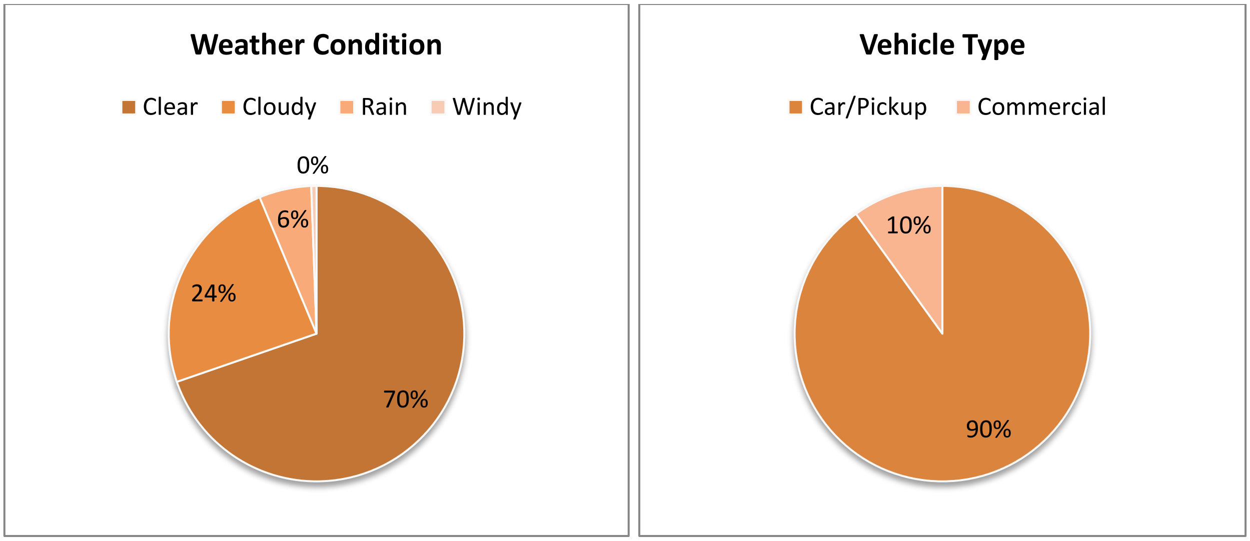

Figure 2.4.3.2 Weather condition at the work zone and participants' vehicle type

2.4.5 Perception of Distance of First Warning and Time in Traveling Through Work Zone

In the expanded survey, Question 1 and 4 ask the participants the distance between the first warning sign that they saw and the actual work zone, and the time they think it took them to travel through the work zone. As most of roadway users rarely take an actual measurement of the distance, or measure the actual time, both of these questions are largely based on the perception of the participants. As research has shown, perception is influenced by the environment and prior experience. The results from these two questions mainly demonstrate how the participants perceived the distance and time.

Participants for this expanded survey rated work zones in 41 counties with a few unknown counties. Counties with the most participants are Greene and Jackson, with 23 and 22 participants respectively. Due to the spread in geographical area, non-standardized method in identifying the work zone they rate, and with at most two participants rating possibly the same work zone, the results from these two questions are not conclusive, but remains illustrative.

Figure 2.4.4.1 shows the perceived distance when the participants first saw the work zone warning sign. This is the first question in the expanded survey. It is interesting to note that both the general public and MoDOT employees noticed the first warning sign between half to one mile prior to entering the work zone. A rather high percentage of the general public did not see the warning sign at all.

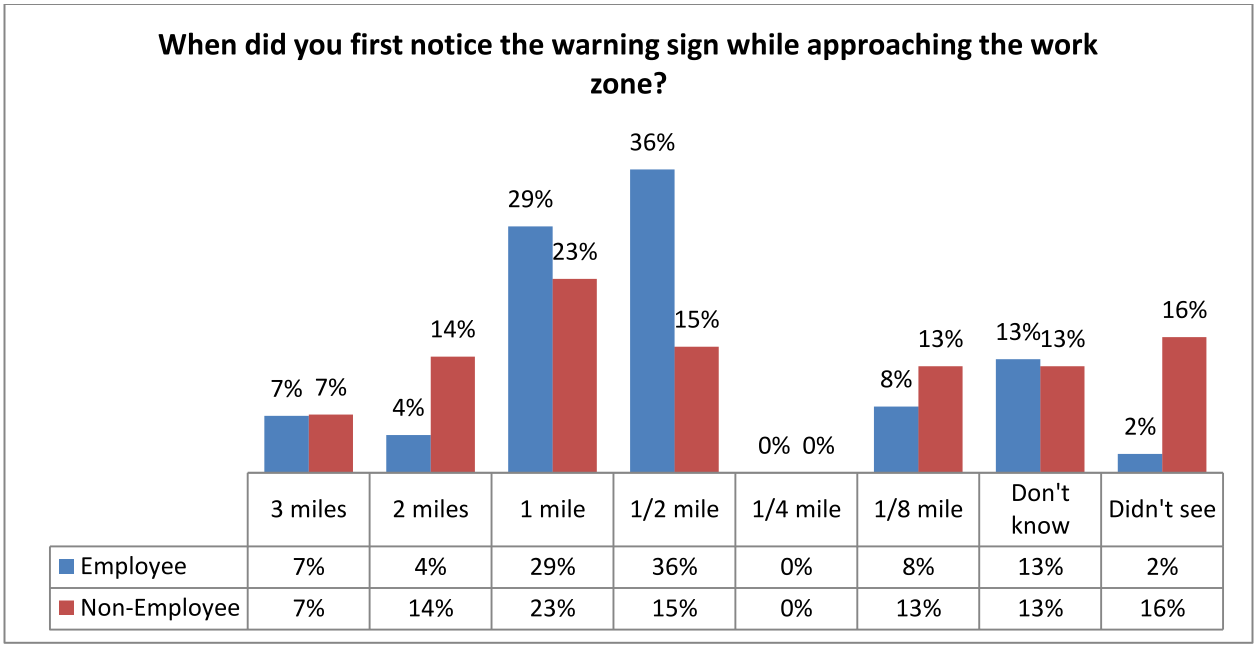

Figure 2.4.4.1 Distance between the first warning sign and the work zone

Figure 2.4.4.2 shows the response to the time it took participants to travel through work zones. It is interesting to note that MoDOT employees' perception of the time it took to travel through a work zone is skewed towards the 5 or less minutes whereas only 52% of the general public self-report that it took them 5 or less minutes to travel through the work zone.

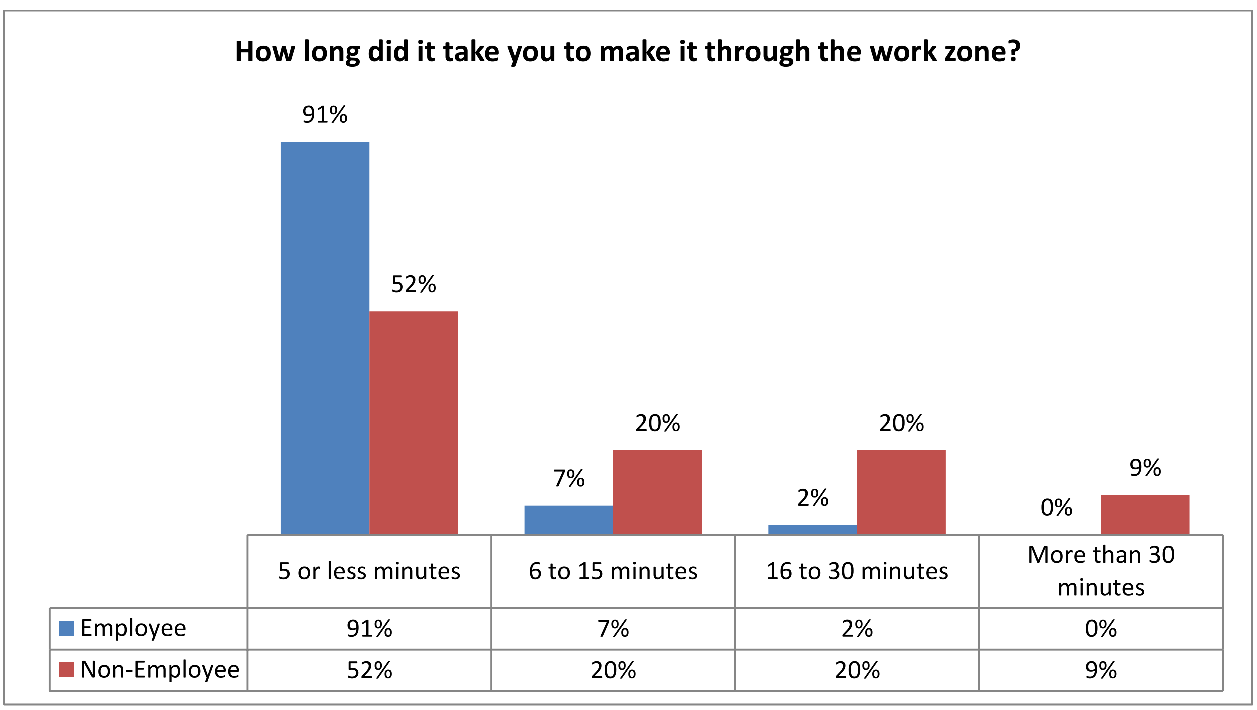

Figure 2.4.4.2 Time it took to travel through the work zone.

2.4.6 Discussion of Expanded Survey Results

In the expanded survey, the participants were nearly evenly distributed between MoDOT employees (51%) and non-employees (49%). Table 2.4.5.1 can be used to compare the original survey results (May 1 through June 13, 2013) with the expanded survey results (May 1 through December 31, 2013). The results show that MoDOT employees consistently rate the work zone higher than non-employees. As discussed earlier, this is likely due to employees and non-employees rating the work zone from different baselines. Employees have the organizational knowledge of the SOP and protocols of work zones, and rate the work zone accordingly. Whereas non-employees do not have a baseline per se, and rate the work zone based on their perceptions, and their perceptions can be easily influenced by the surrounding environment at that time.

Table 2.4.5.1 Comparison of Results between Original and Expanded Survey

	Existing Survey			Extended Survey		
Affiliation						
MoDOT Employee	426	87.47%		89	50.57%	
Non-Employee	61	12.53%		87	49.43%	
Sum	487			176		
Question 1: Enough warning:						
	Yes	No	Sum	Yes	No	Sum
Overall	96.47%	3.53%	100.00%	82.95%	17.05%	100.00%
Employee	99.76%	0.24%	100.00%	98.88%	1.12%	100.00%
Non-employee	73.33%	26.67%	100.00%	66.67%	33.33%	100.00%
Question 2: Signs provide clear instructions:						
	Yes	No	Sum	Yes	No	Sum
Overall	95.04%	4.96%	100.00%	77.84%	22.16%	100.00%
Employee	99.53%	0.47%	100.00%	98.88%	1.12%	100.00%
Non-employee	62.71%	37.29%	100.00%	56.32%	43.68%	100.00%
Question 3: Cones guide through work zone:						
	Yes	No	None Present	Yes	No	None Present
Overall	85.71%	2.10%	12.18%	69.89%	9.09%	21.02%
Employee	87.32%	0.24%	12.44%	70.79%	0.00%	29.21%
Non-employee	74.14%	15.52%	10.34%	68.97%	18.39%	12.64%
Question 5: Able to travel safely:						
	Yes	No	Sum	Yes	No	Sum
Overall	95.39%	4.61%	100.00%	81.25%	18.75%	100.00%
Employee	100.00%	0.00%	100.00%	96.63%	3.37%	100.00%
Non-employee	62.71%	37.29%	100.00%	65.52%	34.48%	100.00%

The “Yes” response by MoDOT employees in both studies indicated that MoDOT work zones met the requirements in terms of warning and signage, and there was no concern in terms of work zone signage and warning compliance. Some reasons for explaining the differences between MoDOT employee responses and the general public responses are as follows. One reason is that the general public lacked the safety awareness and knowledge of existing protocols and SOP for work zones. Thus their perception naturally differed from existing standards. Anecdotal evidence from the comments received through the surveys suggests that the lax enforcement of traffic laws in Missouri contributes to the general public's disregard of work zone signs and warnings, especially the reduced speed limit warning.

Another possible reason is that the existing SOP and protocols (e.g. Engineering Guide Policy) were insufficient for certain work zone locations due to geometrics, terrain, and other challenges of the location. The response discrepancy between employees and non-employees may be due to the influence of organization culture on MoDOT employees. Under the influence of organization knowledge, MoDOT employees seek confirmation of the existence of signage and warning when they approach a work zone. Employees can easily spot missing signage and warnings and will disregard information that are not pertinent to the work zone protocols. The mental process to eliminate or disregard information that is not pertinent to the decision on hand is a mechanism that is used to cope with the dynamic and ever changing environment and is not a conscious process to disregard information.

A further reason is that some drivers just require and expect more instructions and guidance than the majority of drivers. Another possibility, as suggested by anecdotal evidence, is that the general public is less tolerant of work zones as it affects their daily routine, and they are not willing to modify their daily routine. To improve the work zone safety, re-calibrating the general publics' perception and expectations of the work zone is crucial. As indicated by research, the perception of the situation will affect the comprehension and thus the decision making of the drivers that pass through work zones.

2.5 Conclusion and Recommendation

The original work zone rating survey with a limited number of questions is very effective in evaluating user work zone perceptions and provides quantitative measures for simple evaluations. Expanding on this original survey allows the collection of the reasons behind the responses which could lead to the devising of strategies for improving work zone safety.

Survey respondents from the general public can be classified as two populations: one that is genuinely interested in providing useful input to MoDOT, and one that is more interested in venting frustrations about work zones. Both populations can provide useful information, though in different manners.

For the future of the work zone survey, the simple original survey and the expanded survey bring different trade-offs. Even though the expanded survey reveals more information, it requires a change in the MoDOT information system, and its interpretation requires further analysis. And the expanded survey does not fit easily within the space of a postcard for the mail-back version.

In terms of safety culture, since most of the contractors operating on the work zones are not part of MoDOT, the effect of a change in MoDOT organization or safety culture on the contractors' organization culture may be insignificant. To increase work zone safety from the behavioral aspect, tightening the guidelines for the contractors and consistent monitoring by MoDOT employees (using the work zone rating survey) may be more effective.

3. Historical Data Analysis

3.1 Introduction

This chapter presents a review of the recent historical data on work zone accidents and crashes, including fatal and severe crashes. The result is a cross-sectional view of the existing level of work zone safety. This view includes an examination of the hazards and risks resulting from both human and environmental factors. This chapter is organized as follows. First, existing reports on work zone crashes are summarized, including tables and results that are particularly noteworthy. Second, the historical data and the data querying procedures are documented. Last, work zone data is described in various ways using descriptive and inferential statistics.

3.2 Overview of Work Zone Safety

One useful resource on work zone safety is NCHRP Report 500 Volume 17 (Antonucci et al., 2005) entitled, “A Guide for Reducing Work Zone Collisions.” Taken from this report, Table 2.1 compares work zones fatal crashes against all fatal crashes. For each factor, the percentage distribution of each category is given. For most of the factors the difference in the percentage distribution are not large. For example for work zone crashes, there is a slight decrease in the winter season and a slight increase in the summer season. This difference is intuitive since construction is either reduced or put on hold during the winter. Even if the seasonal differences were to be large, it would only reflect the number of work zones (i.e. exposure) and not the underlying safety. In terms of roadway function, work zone crashes represent a larger percentage on interstates, both rural and urban. If this is not due to a larger number of work zones on the interstate, then this fact could be used to understand work zone safety. The speed limit factor might be correlated with the previous factor since interstates have higher speed limits and prevailing speeds than other facilities. Here, work zone crashes occur at a higher percentage on higher speed limit facilities. The number of vehicles involved in crashes occurs at a slightly higher percentage for work zones. This could be related to a difference in accident types such as single-vehicle run-off-the-road versus multi-vehicle crashes. In other words, there are fewer single-vehicle run-off-the-road crashes in work zones. The NCHRP study did not try to correlate these related factors. A factor exhibiting large differences in percentages is the manner of two-vehicle collisions. There is a much larger percentage of rear-ends in work zones and smaller percentages of head-on, angle and side-swipes. The higher percentage of rear-ends is related to the larger number of multi-vehicle crashes and the decrease in capacity in work zones which can result in queuing.

Table 3.2.1 Comparison of Fatal Crash Factors from FARS 2003 (Antonucci et al., 2005)

Factor	All Fatal Crashes (%)	Work Zone Fatal Crashes (%)
Time of day		
Night	49	47
Day	50	52
Unknown	1	1
Day of week		
Weekend	34	31
Weekday	66	69
Season		
Winter	22	16
Spring	24	26
Summer	27	31
Autumn	27	27
Roadway function		
Rural, Interstate	7	13
Rural, other	51	39
Urban, Interstate	6	15
Urban, other	35	32
Unknown	1	1
Speed limit		
1-50 mph	44	38
55-75mph	52	58
Unknown	4	4
Number of vehicles involved		
One	57	53
Two	36	35
More than two	7	12
Manner of two-vehicle collision		
Rear-end	13	35
Head-on	26	21
Angle	32	22
Side-swipe, opposite direction	21	15
Side-swipe, same direction	6	7
Other or unknown	2	0

There are some existing reports from Missouri that discuss work zone crashes. One, the MoDOT Tracker (MoDOT, 2012), contains a discussion on the number of fatalities and injuries in work zones as reported under Section 3g of the chapter on a Safe Transportation System. This report was used as a consistency check for this project as is discussed in the chapter on historical data analysis. Another, Missouri's Blueprint to Save More Lives ("the Blueprint") (MCRS, 2012), is published by the Missouri Coalition for Roadway Safety. Even though the Blueprint does not analyze work zone crashes in much detail, it does paint a general picture of crashes in Missouri. This picture can be compared against the one painted by work zone crashes.

Table 3.2.2 shows select crash types that resulted in fatalities or serious (disabling) injuries. For both severities, the highest-occurring crash type is run-off-the-roads crashes, accounting for around 35-36% of the crashes listed. Horizontal curve crashes was second, being around a quarter of the crashes. Table 3.2.3 shows select driver/passenger characteristics that resulted in fatalities and serious injuries. The two highest-occurring characteristics were aggressive drivers and unrestrained occupants, accounting for approximately a quarter. Distracted drivers, young drivers and substance-impaired drivers were also significant.

Table 3.2.2 Fatalities and Serious Injuries by Crash Type (MCRS, 2012)

	Fatalities					**Serious Injuries**					
Crash Type	2009	2010	2011	Total	%	2009	2010	2011	Total	%	**Total**
Run-Off-Road	398	395	398	1,191	36	2,692	2,543	2,312	7,547	35	8,738
Horizontal Curves	293	262	270	825	25	1,783	1,636	1,521	4,940	23	5,765
Intersection	150	165	113	428	13	1,926	1,747	1,642	5,315	23	5,743
Tree Collisions	162	145	162	469	14	911	772	696	2,379	11	2,848
Head-On	140	106	121	367	11	582	478	487	1,547	8	1,914

Table 3.2.3 Fatalities and Serious Injuries by Driver/Passenger Characteristics (MCRS, 2012)

	Fatalities					**Serious Injuries**					
Crash Type	**2009**	**2010**	**2011**	**Total**	**%**	**2009**	**2010**	**2011**	**Total**	**%**	**Total**
Aggressive Drivers Involved*	370	339	310	1,019	24	2,337	2,237	1,971	6,545	26	7,564
Unrestrained Occupants	425	392	380	1,197	28	1,703	1,598	1,451	4,752	19	5,949
Distracted Drivers Involved	155	182	161	498	12	1,590	1,428	1,327	4,345	17	4,843
Young Drivers Involved (15-20)	156	119	151	426	10	1,646	1,444	1,252	4,342	17	4,768
Substance-Impaired Drivers	264	229	221	714	17	1,103	926	900	2,929	12	3,643
Unlicensed, Revoked, or Suspended Drivers	123	120	135	378	9	756	686	594	2,036	8	2,414

*Includes speeding, driving too fast for conditions and following too close

The Blueprint presented some discussions on work zones. For example, it mentioned that approximately 70 percent of fatal crashes that occurred in a Missouri work zone involved a distracted, speeding or substance-impaired driver. The Blueprint presented the number of fatalities per age group but the sample size was too small to result in any meaningful conclusions. The key strategies for improving work zone safety were divided into six areas. For education, it recommended good training of contractors, engineers, maintenance personnel and law enforcement; regular flagger training and certification; work zone surveys; and incident management responder education on quick clearance. For emergency medical services (EMS), it recommended high-visibility apparel for responders and greater coordination. For enforcement, it also recommended high-visibility apparel for officers and increased enforcement. The highest number of recommendations was for engineering. These included proper work zone setup, traffic plans that minimize traffic impacts, requiring contractors to submit worker and traffic safety plans, implementing sequential lighting, including contractors in work zone reviews, using simulation to predict impacts, and promoting contractor safety incentives. In terms of technology, it recommended speed/delay/queue monitoring, safety and alerts on Dynamic Message Signs and traffic-impacts traveler information. Lastly, it recommended the banning of hand-held cell phones and texting through work zones.

All the reports discussed previously will be compared with the project data in the subsequent sections. Similarities and differences between work zones crashes and other crashes will be highlighted and discussed.

3.3 Historical Data Procedure

This section is written in a comprehensive manner so that any person who intends to replicate this research using crash data in future years can do so easily. This also allows future research to be compatible with the current one so that work zone safety can be tracked over time. Thus certain sections of this report will be familiar to MoDOT employees who work in the safety area. Some of the details related to technology could become outdated due to software changes such as a new operation system, e.g. Windows 8.

3.3.1 Accident Data Overview

The Statewide Traffic Accident Records System (STARS) manual (MTRC, 2002) is the document that describes in detail the Missouri Uniform Crash Report (MUCR). As the name of the report implies, the STARS manual seeks to bring uniformity to accident reporting throughout the state of Missouri. Such uniformity allows for the effective analysis of traffic crashes throughout the state. The STARS manual gives guidance and procedures for completing the MUCR. The four-page MUCR contains information such as the location of the accident, driver information, vehicle information, collision diagram, road characteristics and even traffic condition. Figure 3.3.1.1 shows examples of sections from the MUCR. Figure 3.3.1.1a shows general information about the accident, including date, time and location. Figure 3.3.1.1a also shows detailed information about drivers and vehicles. Figure 3.3.1.1b shows other relevant information about the circumstances surrounding the crash, including road characteristics, weather, visibility and probable contributing circumstances. Specifically, Figure 3.3.1.1b shows Field 21, Traffic Control, which denotes if the accident occurred in a work zone. It is easy to see from Figure 3.3.1.1 how this wealth of information can be used for identifying and understanding and patterns that might exist with work zone crashes.

MISSOURI UNIFORM ACCIDENT REPORT PAGE ____ OF ____

SPACE USED FOR BARCODE

1 - AGENCY NAME AND ORI

LEFT THE SCENE ☐ YES ☐ NO | CLEARED ☐ YES ☐ NO | ACCIDENT CLASSIFICATION | PROPERTY DAMAGE ONLY ☐ | NUMBER INJURED | NUMBER KILLED | REPORT / CASE / INCIDENT NUMBER

NUMBER OF VEHICLES INVOLVED | ACCIDENT DATE | ACCIDENT TIME (MIL.) | TIME NOTIFIED (MIL.) | TIME ARRIVED (MIL.) | INVESTIGATION DATE

2 - LOCATION

COUNTY | MUNICIPALITY | BEAT / ZONE | TRP / DIST / PCT | INVESTIGATED AT SCENE ☐ YES ☐ NO

ON | DISTANCE FROM ____ FEET ___.___ MILES | LOCATION ☐ AFTER ☐ BEFORE ☐ AT | INTERSECTING STREET OR ROADWAY

ROADWAY DIRECTION | SPEED LIMIT | SPEED LIMIT | GEO - CODE | GPS LONGITUDE ____ LATITUDE

ROAD MAINTAINED BY ☐ 1. STATE ☐ 2. COUNTY ☐ 3. MUNICIPAL ☐ 4. PRIVATE PROPERTY ☐ 5. OTHER

3 - DAMAGE TO PROPERTY OTHER THAN VEHICLES ☐ NONE

GIVE OWNER'S NAME AND ADDRESS, DESCRIPTION OF PROPERTY, AND DAMAGE.
☐ MoDOT

4. DRIVER 1 — DRIVER'S FULL NAME (LAST, FIRST, MI) | ADDRESS (STREET, CITY, STATE, ZIP)

DRIVER LICENSE NUMBER / ID NUMBER | STATE | TYPE OF LICENSE ☐ 1. OPERATOR CLASS ____ ☐ 2. CDL CLASS ____ ☐ 3. PERMIT ☐ 4. UNLICENSED ☐ 5. MC ONLY | MC ENDORSEMENT ☐ YES ☐ NO ☐ NA

PROOF OF INSURANCE ☐ YES ☐ NO ☐ NOT REQUIRED | INSURANCE COMPANY | ☐ DRIVER ☐ VEHICLE | POLICY NUMBER ☐ NA

VEHICLE 1 — YEAR | MAKE | MODEL | COLOR

LIC. PLATE NO. | STATE | YEAR | VIN | TOTAL NO. OF OCCUPANTS

VEHICLE OWNER NAME (LAST, FIRST, MI) / COMMERCIAL CARRIER | ADDRESS (STREET, CITY, STATE, ZIP) ☐ SAME AS DRIVER

VEHICLE DAMAGE (Circle all damaged areas) ☐ NONE | INITIAL IMPACT NO. ☐ NA | 2 3 4 5 6 7 / 1 15 16 17 8 / 14 13 12 11 10 9 REAR | 18 - Undercarriage 19 - Windshield 20 - Burned 21 - Towed Unit 22 - Cargo | TOWED FROM SCENE ☐ YES ☐ NO | TOW CO. INFORMATION

Figure 3.3.1.1a Page 1

REPORT # ____ PAGE ____ OF ____

18. PROBABLE CONTRIBUTING CIRCUMSTANCES (V1 V2; P1 P2)
☐ ☐ 1. Vehicle Defects (explain)
☐ ☐ 2. Traffic Control Inoperable or Missing
☐ ☐ 3. Improperly Stopped on Roadway
☐ ☐ 4. Speed - Exceeded Limit
☐ ☐ 5. Too Fast for Conditions
☐ ☐ 6. Improper Passing
☐ ☐ 7. Violation Signal / Sign
☐ ☐ 8. Wrong Side (not passing)
☐ ☐ 9. Following Too Close
☐ ☐ 10. Improper Signal
☐ ☐ 11. Improper Backing
☐ ☐ 12. Improper Turn
☐ ☐ 13. Improper Lane Usage / Change
☐ ☐ 14. Wrong Way (One-Way)
☐ ☐ 15. Improper Start From Park
☐ ☐ 16. Improperly Parked
☐ ☐ ☐ ☐ 17. Failed to Yield
☐ ☐ ☐ ☐ 18. Alcohol
☐ ☐ ☐ ☐ 19. Drugs
☐ ☐ ☐ ☐ 20. Physical Impairment (explain)
☐ ☐ ☐ ☐ 21. Inattention (explain) P1 ____ P2 ____ V1 ____ V2 ____
☐ ☐ ☐ ☐ 22. None

19. PEDESTRIAN INVOLVEMENT ☐ NA (P1 P2)
☐ ☐ 1. At Intersection
☐ ☐ 2. Not At Intersection
CROSSING ROAD
☐ ☐ 3. With Signal
☐ ☐ 4. Against Signal
☐ ☐ 5. No Signal
☐ ☐ 6. Diagonally
☐ ☐ 7. Within Crosswalk
☐ ☐ 8. Within Marked Crosswalk
☐ ☐ 9. Behind / In Front of Parked Car
☐ ☐ 10. With Traffic
☐ ☐ 11. Against Traffic
☐ ☐ 12. Getting On / Off Vehicle
☐ ☐ 13. Standing / Lying / Sitting on Road
☐ ☐ 14. Pushing / Working on Vehicle
☐ ☐ 15. Other Working
☐ ☐ 16. Playing on Road
☐ ☐ 17. Off Roadway

20. VISION OBSCURED (V1 V2)
☐ ☐ 1. Windshield
☐ ☐ 2. Load on Vehicle
☐ ☐ 3. Trees / Brush
☐ ☐ 4. Building
☐ ☐ 5. Embankment
☐ ☐ 6. Signboards
☐ ☐ 7. Hillcrest
☐ ☐ 8. Parked Cars
☐ ☐ 9. Moving Cars
☐ ☐ 10. Glare
☐ ☐ 11. Other (explain)
☐ ☐ 12. Not Obscured

21. TRAFFIC CONTROL (V1 V2)
☐ ☐ 1. Construction Zone
☐ ☐ 2. Other Work Zone
☐ ☐ 3. School Zone
☐ ☐ 4. Stop Sign
☐ ☐ 5. Electric Signal
☐ ☐ 6. RR Signal / Gate
☐ ☐ 7. Yield Sign
☐ ☐ 8. Officer / Flagman
☐ ☐ 9. No Passing Zone
☐ ☐ 10. Turn Restricted
☐ ☐ 11. Signal on School Bus
☐ ☐ 12. None

22. ROAD CHARACTER
ALIGNMENT
☐ 1. Straight
☐ 2. Curve
PROFILE
☐ 1. Level
☐ 2. Grade
☐ 3. Hillcrest

23. LIGHT CONDITION
☐ 1. Daylight
☐ 2. Dark with Street Lights On
☐ 3. Dark with Street Lights Off
☐ 4. Dark - No Street Lights
☐ 5. Indeterminate (explain)

24. WEATHER CONDITION
☐ 1. Clear
☐ 2. Cloudy
☐ 3. Rain
☐ 4. Snow
☐ 5. Sleet
☐ 6. Freezing (temp.)
☐ 7. Fog / Mist
☐ 8. Indeterminate (explain)

25. ROAD CONDITION
☐ 1. Dry
☐ 2. Wet
☐ 3. Snow
☐ 4. Ice
☐ 5. Slush
☐ 6. Mud
☐ 7. Standing Water
☐ 8. Moving Water
☐ 9. Other (explain)

26. ROAD SURFACE
☐ 1. Concrete ☐ 2. Asphalt ☐ 3. Brick ☐ 4. Gravel ☐ 5. Dirt / Sand ☐ 6. Multi-Surface

Figure 3.3.1.1b Page 4

Figure 3.3.1.1 Examples of the MUCR (MTRC, 2002).

The Missouri State Highway Patrol is the lead agency in providing STARS training for all police agencies and partners with the Missouri Department of Transportation (MoDOT) to store and archive this information. Because such information is composed of standardized fields and stored in an electronic database, it can be queried using common database language such as ANSI's (American National Standards Institute) SQL (Structured Query Language). Thus the data for this project is obtained from MoDOT's Transportation Management System (TMS) database. The data querying process will be described in more detail later.

The most recent version of the manual was published in January, 2012. For the new revision, the name of the committee that develops this manual changed its name slightly from Missouri Traffic Records Committee to Missouri STARS committee. This most recent version was not used for this project because the crash data used for this project was collected before this version took effect. Thus the 2002 version was used in this project.

3.3.2 MoDOT TMS Overview

MoDOT TMS was designed to collect, organize and process data to support decision making throughout the organization (Noble et al., 2003). TMS's primary components include data inventory, report generation and data analysis. Some types of data available within TMS that is relevant to this project include safety/accident, travelway and pavement. TMS supports various interfaces such as desktop, web and ODBC (Open Database Connectivity). The desktop solution is generally used by MoDOT employees. The web-based applications can be available to MoDOT's research partners via the use of VPN (Virtual Private Network). A VPN is a dedicated connection that allows access to MoDOT's intranet via a public network. Such a VPN connection requires a MoDOT-approved account and is not available to the general public. Web-based TMS utilizes graphical user interfaces for obtaining items such as maps, ARAN (Automatic Road Analyzer) video, accident data, traffic data, reports and facility inventories (MoDOT, n.d.). ODBC provides platform-independent remote access to database management systems at MoDOT. A DSN (Data Source Name) is a connection to a specific data source provided by a system administrator. Using ODBC, the TMSPROD DSN can be accessed using common database client software such as Microsoft Access. ODBC was the data access method employed for this research because of the complexity of the queries that had to be issued for this project. Such queries could not have been performed using web-based applications.

The instructions for establishing a remote ODBC connection are outlined below:

- Step 1. Install Cisco's AnyConnect VPN Client software from MoDOT website.
    - Installation URL: https://vpn.modot.mo.gov
    - Establish VPN connection
- Step 2. Map Network Drives to Fixed Drive Letters
    - Map as K: \\ghapps011\apps
    - Map as Y: \\ghsmdata01\tms
- Step 3. Install TMS ODBC Software
    - Execute Y:\Setup\TMSinstall.bat
    - For Windows 7 machines, also execute Y:\Temp\00981\00981.vbs
- Step 4. Confirm TMSPROD DSN Driver Installation
    - Open Microsoft ODBC Administrator

- Confirm that TMSPROD is available under the System DSN using Oracle in OraHome 1120 Driver
- Test connection

3.3.3 TMS Databases

The databases used for this research are described in Table 3.3.3.1. The name "table" is often used for referring to databases, but such a name is avoided in this report to avoid confusion with the tables in the report text. The first four databases are mostly information derived from the MUCR report. Thus they are specific to particular accidents. The fifth database is independent from any accidents and refers to the traffic information from a road segment. Database 1 contains such information from the accident such as date, time, travelway identification, route name, route direction, log mile reference, accident severity, number of persons injured or killed and number of vehicles. Database 2 provides vehicle and driver specific information such as the type of vehicle(s) involved, and operator and vehicle license state. Database 3 is derived from Field 18 of the MUCR which contains a checklist of possible contributing circumstances such as "too fast for condition" or "physical impairment". Database 4 is derived from Field 17 of the MUCR and describes vehicles actions and the sequence of events leading to the accident, e.g. changing lanes. Finally Database 5 provides road segment information such as AADT.

Table 3.3.3.1 TMS Databases Used

#	TMS Database Name	Brief Description
1	TMS_HP_ACCIDENT_VW	Accident specific information
2	TMS_HP_VEHICLE_DRIVER	Vehicle specific information for each vehicle involved in accident
3	TMS_HP_CONTRB_CIRCM	Probable contributing circumstances to the accident
4	TMS_HP_SEQ_OF_EVENTS	Sequence of events leading to the accident
5	TMS_TRF_INFO_SEGMENT_VW	Segment traffic information

For Databases 1-4, there is a unique identification number assigned by the highway patrol for each accident. This number, HP_ACC_IMAGE_NO, is used to link or join together the records pertaining to the same accident from the four databases. An inner join was used because there are matching values in a field common to all databases.

The SQL syntax for the inner join operation is:

FROM *table1* INNER JOIN *table 2* ON *tabl1.field1 compopr table2.field2*

Where *table1*, *table2* are the names of the database from which records are combined
field1, *field2* are the names of the fields
compopr is a relational comparison operator

Figure 3.3.3.1 shows graphically the joining of the four databases.

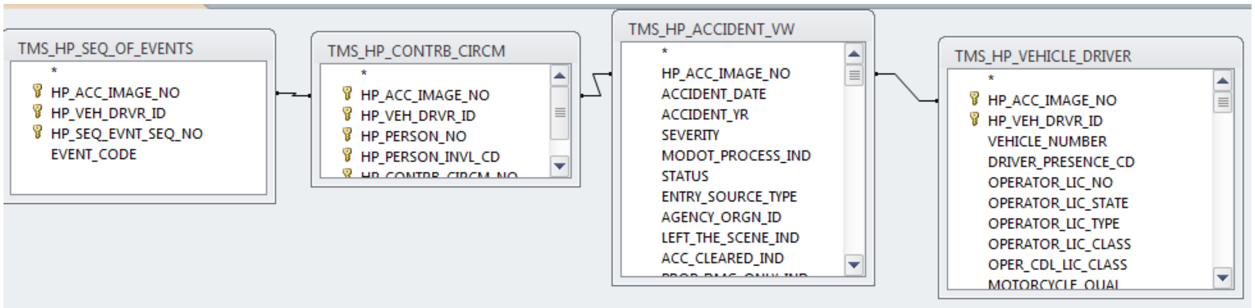

Figure 3.3.3.1 MS Access Design View representation of SQL joins.

Table 3.3.3.2 shows the list of the data queries for this project as well as a brief description of the data. Note that not all the data obtained were presented in this report, because some fields did not contain enough data and some fields did not provide useful results. The data descriptions were taken from the STARS Manual, TMS metadata or both. Table 3.3.3.2 includes 51 fields from the five aforementioned databases. Some of these fields will be discussed further in the data analysis section.

Table 3.3.3.2 TMS Crash Field Descriptions

Field Name	Description	Notes
ACCIDENT_YR	4 digit year of crash	
HP_ACC_IMAGE_NO	unique 10 digit HP crash record identifier, accident image #	
MODOT_COUNTY_NM	county name where crash occurred	
TRAVELWAY_ID	unique travelway (public path) ID by direction, MoDOT designation	used to join separate tables
DESIGNATION	route designation	e.g. IS = interstate US = U.S. highway MO = state numbered RT = state lettered AL = alternate route LP = loop BU = business route SP = spur CST = city street RP = ramp CRD = county road OR = outer road
TRAVELWAY_NAME	"name" of travelway, e.g. numbers, letters	
DIRECTION	direction	N, S, E, W only E is primary for E/W S is primary for N/S
Log	MoDOT continuous log miles	
VEHICLE_NUMBER	sequential number assigned to a vehicle involved in crash	
TRAFFIC_CONTROL_ZN	MUCR §21 traffic control	1 = construction zone 2 = other work zone (e.g. utility, striping, mowing)
PRIMARY_IND	primary travelway identifier	e.g. Y
HIGHWAY_CLASS		L, K, A, D
ACCIDENT_DATE	date-month-year format	
SEVERITY	severity of crash	PDO, minor injury, disabling injury, fatality
NUMBER_INJURED	number of persons injured	
NUMBER_KILLED	number of fatalities	
NO_OF_VEHICLES	number of vehicles involved	
ACCIDENT_TIME	time of accident in hour:minute:seconds	a date of 1/1/1901 also appears with each record
MODOT_DISTRICT_NO	MoDOT district	1 = NE 2 = NW 3 = KC (Kansas City) 4 = CD (central) 5 = SL (St. Louis) 6 = SW 7 = SE

Table 3.3.3.2 Continued

Field Name	Description	Notes
ON_LOC_SPD_LMT	posted speed limit	
ONLOC_DIST_FR_FEET	distance to accident scene from nearest intersecting street or landmark in feet	
INTERSECTION_LOC	accident location from intersecting street or landmark	A, B; some missing
AT_LOCATION_STREET	intersecting street or roadway	
AT_LOC_SPEED_LIMIT	posted speed limit on intersecting street	
GPS_LONGITUDE	GPS longitude	mostly missing
GPS_LATITUDE	GPS latitude	mostly missing
ON_OFF_ROADWAY	MUCR §15 accident type	1 = on roadway 2 = off roadway
ACCIDENT_TYPE	MUCR §15 accident type, collision involved, non-collision	1 = animal 2 = pedalcycle 3 = fixed object 4 = other object (moveable) 5 = pedestrian 6 = train 7 = MV in transport 8 = MV on other roadway 9 = parked MV 10 = overturning 11 = other non-collision (e.g. fire)
TWO_VEH_ANALYSIS	MUCR §15 accident type, two vehicle collision	60= head on 61 = read end 62 = sideswipe – meeting 63 = sideswipe – passing 64 = angle 65 = backed into 67 = other
ROAD_ALIGNMENT	MUCR §22 road character	1 = straight 2 = curve
ROAD_PROFILE	MUCR §22 road character	1= level 2 = grade 3 = hillcrest
LIGHT_CONDITION	MUCR §23 light condition	1 = daylight 2 = dark w/ street lights on 3 = dark w/ street lights off 4 = dark – no street lights 5 = indeterminate
WEATHER_COND_1	MUCR §24 weather condition	1 = clear 2 = cloudy 3 = rain 4 = snow 5 = sleet 6 = freezing (temp.) 7 = fog/mist 8 = indeterminate

Table 3.3.3.2 Continued

Field Name	Description	Notes
ROAD_CONDITION_1	MUCR §25 road condition	1 = dry 2 = wet 3 = snow 4 = ice 5 = slush 6 = mud 7 = standing water 8 = moving water 9 = other
ROAD_SURFACE	MUCR §26 road surface	1 = concrete 2 = asphalt 3 = brick 4 = gravel 5 = dirt/sand 6 = multi-surface
HIGWAY_CLASS	highway classification	A, B, L, D, H
EMERGNC_VEH_INVL_NA	MUCR §13 emergency vehicle involvement	1 = police 2 = fire 3 = ambulance 4 = other A = emergency vehicle on emergency run
URBAN_RURAL_CLASS	population area	rural [0,5000) urban [5000, 50000) urbanized [50000, 200000) metropolitan =>200,000
OPERATOR_LIC_TYPE	MO driver license code	1 = operator: E or F 2 = CDL
INSURANCE_IND	proof of vehicle or driver liability insurance as required by law was shown to officer	Y, N, U
OPERATOR_LIC_STATE	driver's state	
VEHICLE_YEAR	vehicle year	
VEHICLE_MAKE	vehicle make	
VEHICLE_MODEL	vehicle model	some missing
VEHICLE_LICENSE_ST	state of vehicle license	e.g. MO
NO_OF_OCCUPANTS	number of occupants in vehicle	
TRAFFIC_CONDITION	MUCR §16 traffic condition	1 = normal 2 = accident ahead 3 = congestion ahead

Table 3.3.3.2 Continued

Field Name	Description	Notes
VISION_OBSCURED	MUCR §20 vision obscured	1 = windshield 2 = load on vehicle 3 = trees/brush 4 = building 5 = embankment 6 = signboards 7 = hillcrest 8 = parked cars 9 = moving cars 10 = glare 11 = other 12 = not obscured
VEHICLE_TYPE	MUCR §12 vehicle body types automobiles/special vehicles	1 = passenger car 2 = station wagon 3 = SUV 4 = limousine 5 = van 6 = small bus 7 = bus 8&9 = school bus 10 = motorcycle 19 = pickup 20 = single-unit truck: 2 axles 21 = single-unit truck: >=2 axles 22-26 tractor trailers
TRAFFIC_CONTROL_ELC_SGNL	MUCR §21 traffic control (second part)	4 = stop sign 5 = electric signal 6 = RR signal/gate 7 = yield sign 8 = officer/flagman 9 = no passing zone 10 = turn restricted 11 = signal on school bus 12 = none
AADT	Average Annual Daily Traffic	

3.4 Historical Data Analysis

3.4.1 General Descriptive Statistics and Cross-Tabulation

A data check was performed by comparing the TMS query results with those reported in the MoDOT Tracker (MoDOT, 2012) and in the Missouri Traffic Safety Compendium (SAC, 2009-2011). The Tracker from July, 2012, was used because crash reporting is not considered stable until approximately sixth months after the completion of the year. Even though there were some differences among the data, the differences were not very significant. One reason for the difference could be due to the highway patrol adjusting crash figures after the July Tracker was developed. The same query commands used for the Tracker were also used in this project.

A pivot table was used for providing general descriptive statistics of the work zone crash data. A pivot table is a tool for quickly sorting, summarizing and presenting data in worksheets or databases. One benefit of a pivot table is that the data manipulation is achieved graphically from prebuilt commands without the need to enter functions or formulas. Cross tabulation of different safety factors was also accomplished using the pivot table.

As shown in Table 3.4.1.1, there were a total of 35 fatal crashes, 182 disabling injury crashes, 59 severe crashes, 1425 minor injury crashes, and 5107 property damage only (PDO) crashes in Missouri work zones from 2009 to 2011. Severe crashes are crashes resulting in either fatalities or disabling injuries, and they are not double-counted in all crashes. The total number of crashes was 6750. Because of the randomness involved with crashes and the fact that not all factors are captured in the MUCR, it is often useful to examine three year averages and confidence intervals instead of annual frequencies. The three year averages were 11.7 fatal crashes, 72.3 severe crashes, and 2250 crashes. The confidence interval was determined at a 5% significance level, and appeared to be tight (narrow) for all severities due to large sample sizes.

Table 3.4.1.1 Work Zone Crash Severity

Severity	Year			Total	Average	Std. Dev.	Confidence		%
	2009	2010	2011				Lower	Upper	
Fatal	11	14	10	35	11.7	2.1	11.0	12.4	0.52
Disabling Injury	48	77	57	182	60.7	14.8	58.5	62.8	2.7
Minor Injury	425	569	431	1425	475	81.5	471	479	21
Property Damage Only	1710	1939	1458	5107	1700	241	1700	1710	76
Severe Crashes	59	91	67	217	72.3	16.7	70.1	74.5	3.2
All Crashes	2194	2599	1957	6750	2250	325	2240	2260	100

In Table 3.4.1.2, the crash severity of work zone crashes is compared with crash severity of all crashes which was obtained by querying the STARS (2013) system. Because the STARS web-based querying tool does not differentiate between disabling and minor injury, only three severities are compared. The percentage of fatal, injury and PDO crashes appear to be very similar for work zone and non-work zone. There is virtually no difference in the percentage of fatal crashes and the difference for injury and PDO crashes are less than one percent. Despite some non-Missouri literature pointing to elevated crash severities for work zone crashes, it does not appear to be the case here in Missouri.

Table 3.4.1.2 Comparison of Work Zone Versus Overall Crash Severity, 2008-2011

Severity	Work Zones	%	All	%	Diff %
Fatal	35	0.52	3125	0.52	0.00
Injury	1607	23.81	148116	24.55	-0.74
PDO	5107	75.67	452038	74.93	0.74
Total	6749	100	603279	100	

Table 3.4.1.3 shows the severity of work zone crashes for all seven MoDOT districts. At first glance, the distribution of crash severities appears to be fairly similar across all districts. In other words, PDO crashes account for approximately three-fourth of the crashes, minor injury crashes for approximately a fifth and severe crashes for less than a tenth. A closer examination reveals that the districts that have large metropolitan areas such as Kansas City, St. Louis and

Springfield have a lower percentage of severe crashes. The percentages in metropolitan areas range between 2.8 and 3.0 while other districts range between 4.1 and 7.1. This apparent difference will be investigated further by comparing urban versus rural crashes. One could examine to see if the number of crashes is correlated with the number of work zones. However, work zones differ significantly in characteristics such as length, duration, nighttime and work intensity. Thus a cursory comparison between the number of work zone crashes and the number of work zones in a district could be counter-productive. Lastly, the total number of crashes is somewhat correlated with the population of the districts. Kansas City (District 3), Central (District 4), St. Louis (District 5) and Southwest (District 6) have more total crashes.

Table 3.4.1.3 Crash Severity by MoDOT District in Percentage

Severity	MoDOT District						
	1	2	3	4	5	6	7
Fatal	2.3	0.6	0.4	0.2	0.5	0.4	1.8
Disabling Injury	4.5	6.5	2.3	4.3	2.6	2.5	2.4
Minor Injury	23.0	20.2	22.4	20.4	19.1	24.3	19.8
Property Damage Only	70.3	72.6	74.8	75.0	77.9	72.9	76.0
Severe Crashes	6.8	7.1	2.8	4.6	3.0	2.9	4.1
Total Crashes	222	168	2241	460	2542	977	338

The effect of lighting on crash severity is examined in Table 3.4.1.4. For each severity, the columns should add up to 100%. As a whole, daytime crashes represent 77.7% of the crashes. Accounting for exposure, this number could simply reflect the higher traffic demand during daytime. The relationship between crash and AADT will be examined later. Looking at the percentage of crashes for different lighting categories for each severity type, there appears to be significant difference between fatal crashes and other types of crashes. Since the sample size of fatal crashes is relatively small, statistical testing is required to verify that this difference is not merely random. The crashes that occurred when dark seem to be overrepresented in fatal crashes, being at 48.7% as opposed to only 21.3% for all crashes. As a result, it is worthwhile to consider strategies for improving nighttime safety such as better lighting, delineation and visibility at nighttime work zones.

Table 3.4.1.4 Crash Severity by Lighting in Percentage

Severity	Daylight	Dark Lt. On	Dark Lt. Off	Dark No Lts.	Indet.
Fatal	48.7	7.7	0.0	41.0	2.6
Disabling Injury	75.3	8.9	1.1	14.7	0.0
Minor Injury	76.5	11.8	0.7	9.9	1.0
Property Damage Only	78.3	10.7	0.8	9.2	1.0
Severe Crashes	70.7	8.7	0.9	19.2	0.4
Total Crash Counts (not percentage)	5398	754	55	673	68
Total	77.7	10.9	0.8	9.7	1.0

According to the STARS Manual (MTRC, 2002) the Accident Type flows from the first harmful event and involves the two major categories of collision and non-collision. A "fixed object" is any object not in motion and attached to the terrain such as trees, embankments, poles, fences, culverts and curbs. A "fixed object" is also any object intentionally placed for an official purpose such as traffic barricades or road machinery. According to this definition, many objects involved in work zones such as temporary traffic control devices and construction equipment are considered "fixed objects". "Other devices" is a catchall category to encompass objects outside the definition of fixed objects such as objects dropped from motor vehicles, and fallen trees or stones. "Collision Involving Motor Vehicles in Transport" involves at least two vehicles in transport on the same roadway or intersection and includes stopped, disabled and abandoned vehicles. "Other Non-Collision" is a non-overturning catchall category and includes accidents such as carbon monoxide poisoning, vehicle breakage, explosions, fires and leaks.

Table 3.4.1.5 presents the severity of the various accident types in work zones from 2009 to 2011. There were a total of 6750 harmful events. Table 3.4.1.6 presents the percentages of the Accident Types. In examining the percentages of different Accident Types, the non-collision categories of "overturning" and "other" total only 3.2% of all crashes. In terms of collision crashes, the two largest groups are "motor vehicles in transport" (74.3%) and "fixed and other objects" (17.8%). When severe crashes are examined, the disparity between "motor vehicles in transport" and "fixed and other objects" is reduced to 55.8% and 28.6%. Nonetheless, there is still over 50% of work zone crashes that involve vehicle interactions, and they point to possible factors such as traffic queues, lane drops or distracted driving. Other MUCR fields will provide more details on the causes of the crashes.

Table 3.4.1.5 Crash by Severity and Accident Type

	Collision Inv. Animal	Collision Inv. Pedalcycle	Collision Ivn. Fixed Object	Collision Inv. Other Object	Collision Inv. Pedestrian	Collision Inv. Motor Vehicle in Transport	Collision Inv. MV on Other Roadway	Collision Inv. Parked MV	Overturning	Other Non-Collision	
Code	**01**	**02**	**03**	**04**	**05**	**07**	**08**	**09**	**10**	**11**	**Total**
Fatal	0	1	10	5	3	15	1	0	0	0	35
Disabling Injury	1	2	36	11	7	106	0	2	16	1	182
Minor Injury	5	9	195	42	29	1066	0	13	52	14	1425
Property Damage Only	55	2	672	230	6	3825	3	173	32	109	5107
Severe Crashes	1	3	46	16	10	121	1	2	16	1	217
Total	**61**	**14**	**913**	**288**	**45**	**5012**	**4**	**189**	**100**	**124**	**6750**

Table 3.4.1.6 Crash by Severity and Accident Type in Percentage

	Collision Inv. Animal	Collision Inv. Pedalcycle	Collision Ivn. Fixed Objecgt	Collision Inv. Other Object	Collision Inv. Pedestrian	Collision Inv. Motor Vehicle in Transport	Collision Inv. MV on Other Roadway	Collision Inv. Parked MV	Overturning	Other Non-Collision
Code	**1**	**2**	**3**	**4**	**5**	**7**	**8**	**9**	**10**	**11**
Fatal	0.0	2.9	28.6	14.3	8.6	42.9	2.9	0.0	0.0	0.0
Disabling Injury	0.5	1.1	19.8	6.0	3.8	58.2	0.0	1.1	8.8	0.5
Minor Injury	0.4	0.6	13.7	2.9	2.0	74.8	0.0	0.9	3.6	1.0
Property Damage Only	1.1	0.0	13.2	4.5	0.1	74.9	0.1	3.4	0.6	2.1
Severe Crashes	0.5	1.4	21.2	7.4	4.6	55.8	0.5	0.9	7.4	0.5
All Crashes	0.9	0.2	13.5	4.3	0.7	74.3	0.1	2.8	1.5	1.8

According to the STARS Manual (MTRC, 2002), two vehicle collisions are further identified by the first harmful event. A “head on” refers to a collision by vehicle front ends or if two vehicles were traveling in opposite direction immediately preceding a collision. A “rear end” refers to a collision where two vehicles were traveling in the same direction, even if the impact was not by the front end of one against the rear end of another. Table 3.4.1.7 shows the number of crashes for each two-vehicle collision type. The percentage of each collision type among the severities is shown in Table 3.4.1.8. Table 3.4.1.8 shows the most common type of two vehicle collision is “rear end” (56.1% for all crashes and 51.6% for severe crashes). This type of collision occurs when the following vehicle is not able to stop in time before contacting the leading vehicle. The failure to stop could be due to a failure of perception/reaction or a failure of braking such as in inclement weather. To gain more insights, the two vehicle collision data will be analyzed with human factors such as inattention or impairment, weather, or congestion.

Even though “head on” collisions only account for 1.2% of all crashes, it disproportionately represents more severe (10.5%) and fatal (31.3%) crashes. As previously discussed in Table 3.2.2, “head on” was also highlighted in the Blueprint and accounted for 11% of fatalities and 8% of serious injuries by crash type. The work zone settings in which opposite direction vehicles could collide can be analyzed in the work zone context. Some possible settings include two-way (head to head), missing or unclear striping, unclear guidance or encroachment on driving lane in one direction. Even though the sideswipe labels were not explained in the previous STARS Manual, the new STARS Manual (MSC, 2012) re-labeled the two categories as opposite and same direction sideswipe. Thus the previous label of “sideswipe – meeting” might have been interpreted as opposite direction sideswipe while “sideswipe – passing” might have been interpreted as same direction sideswipe. “Sideswipe – meeting” could share similar conditions as “head on”. While “sideswipe – passing” could share similar conditions as “angle”. For example in the case of a lane drop, an angle collision could occur at the taper or a sideswipe could occur in anticipation of the taper when changing lanes. If these assumptions are correct, then 12.9% of severe crashes are head on/sideswipe-meeting and 33.9% are angle/sideswipe-passing.

Table 3.4.1.7 Crash by Severity and Two Vehicle Collision Type

	Head On	Rear End	Sideswipe – Meeting	Sideswipe – Passing	Angle	Backed Into	Other	
Code	**60**	**61**	**62**	**63**	**64**	**65**	**67**	**Total**
Fatal	5	6	1	2	2	0	0	16
Disabling Injury	8	58	2	7	31	0	2	108
Minor Injury	26	749	7	48	232	11	6	1079
Property Damage Only	22	2100	90	695	832	179	74	4001
Severe Crashes	13	64	3	9	33	0	2	124
All Crashes	**61**	**2913**	**100**	**753**	**1097**	**190**	**82**	**5205**

Table 3.4.1.8 Crash by Severity and Two Vehicle Collision Type in Percentage

	Head On	Rear End	Sideswipe – Meeting	Sideswipe - Passing	Angle	Backed Into	Other
Code	**60**	**61**	**62**	**63**	**64**	**65**	**67**
Fatal	31.3	37.5	6.3	12.5	12.5	0.0	0.0
Disabling Injury	7.4	53.7	1.9	6.5	28.7	0.0	1.9
Minor Injury	2.4	69.4	0.6	4.4	21.5	1.0	0.6
Property Damage Only	0.6	52.6	2.3	17.4	20.8	4.5	1.9
Severe Crashes	10.5	51.6	2.4	7.3	26.6	0.0	1.6
All Crashes	1.2	56.1	1.9	14.5	21.1	3.7	1.6

According to the STARS Manual (MTRC, 2002), “probable contributing circumstances” are determined by the investigator regardless of an arrest. At least one category is marked, up to four. Examples of vehicle defects include failed brakes and headlights. An example of an improperly stopped vehicle is an abandoned vehicle. When both “speed – exceeded limit” and “too fast for conditions” apply, only the former is marked. The “violation signal/sign” category includes both traffic control devices and officer/flagperson. The “failed to yield” category applies when there are no traffic control devices specifically assigning the right-of-way. The “alcohol” and “drugs” categories refer to instances where the officer decided that alcohol or drugs contributed to the accident, but is not synonymous with intoxication. Examples of “physical impairment” include fatigue, asleep and illness. The “inattention” category could be due to various factors such as cell phones, stereos, other electronic devices, passengers, smoking, eating/drinking, reading, grooming, etc. The category “none” is marked only when the officer decides that there was not enough evidence to determine a cause.

Table 3.4.1.9 shows counts and Table 3.4.1.10 shows the percentage of crashes for different severities by contributing circumstances. One use of Tables 3.4.1.9 and 3.4.1.10 is to compare the contributing circumstances among the different severities. Before comparing among severities, the last row in Table 3.4.1.10, All Crashes, shows the overall distribution of crashes among the contributing circumstances. This row shows that the last two columns, None and Unknown, represent a large percentage of all vehicle circumstances at 41.3%. As explained in the STARS Manual, the category “none” is marked only when the officer decides that there was not enough evidence to determine a cause. The STARS Manual did not explain what “unknown” meant, although the percentage is relatively small at 1.3%. The next largest categories, Inattention (15.6%), Following Too Close (13.8%), Improper Lane Usage (7.7%), Too Fast for Conditions (6.0%) and Failed to Yield (5.4%), add up to 42.2% of the vehicle circumstances. If only severe crashes were examined, then the order of these categories changes to Inattention (17.3%), Too Fast for Conditions (9.4%), Following Too Close (7.6%), Improper Lane Usage (6.9%), and Failed to Yield (5.8%).

Table 3.4.1.9 Crash Severity by Contributing Circumstances

	Vehicle Defect	Traffic Control Inoperable/Missing	Improperly Stopped	Speed - Exceeded Limit	Too Fast for Conditions	Improper Passing	Violation Signal/Sign	Wrong Side (not passing)	Following Too Close	Improper Signal	Improper Backing	Improper Turn	Improper Lane Usage/Change	Wrong Way (One-Way)	Improper Start From Park	Improperly Parked	Failed to Yield	Alcohol	Drugs	Physical Impairment	Inattention	None	Unknown	
Severity	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**U**	**Total**
Fatal	1	0	0	1	6	2	2	3	5	0	0	0	11	1	0	0	3	8	2	0	10	24	1	80
Disabling Injury	5	0	0	5	35	3	15	4	28	0	0	3	19	0	0	0	22	14	2	11	65	120	3	354
Minor Injury	27	3	9	36	205	21	47	10	404	1	7	24	128	2	2	3	167	50	13	32	452	1021	34	2698
Property Damage Only	109	18	22	62	463	106	105	28	1177	6	75	97	741	12	6	3	436	116	18	55	1309	3527	113	8604
Severe Crashes	6	0	0	6	41	5	17	7	33	0	0	3	30	1	0	0	25	22	4	11	75	144	4	434
All Crashes*	**142**	**21**	**31**	**104**	**709**	**132**	**169**	**45**	**1614**	**7**	**82**	**124**	**899**	**15**	**8**	**6**	**628**	**188**	**35**	**98**	**1836**	**4692**	**151**	**11736**

* The totals row does not double count severe crashes.

Table 3.4.1.10 Crash Severity by Contributing Circumstances in Percentage

	Vehicle Defect	Traffic Control Inoperable/Missing	Improperly Stopped	Speed - Exceeded Limit	Too Fast for Conditions	Improper Passing	Violation Signal/Sign	Wrong Side (not passing)	Following Too Close	Improper Signal	Improper Backing	Improper Turn	Improper Lane Usage/Change	Wrong Way (One-Way)	Improper Start From Park	Improperly Parked	Failed to Yield	Alcohol	Drugs	Physical Impairment	Inattention	None	Unknown
Severity	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**U**
Fatal	1.3	0.0	0.0	1.3	7.5	2.5	2.5	3.8	6.3	0.0	0.0	0.0	13.8	1.3	0.0	0.0	3.8	10.0	2.5	0.0	12.5	30.0	1.3
Disabling Injury	1.4	0.0	0.0	1.4	9.9	0.8	4.2	1.1	7.9	0.0	0.0	0.8	5.4	0.0	0.0	0.0	6.2	4.0	0.6	3.1	18.4	33.9	0.8
Minor Injury	1.0	0.1	0.3	1.3	7.6	0.8	1.7	0.4	15.0	0.0	0.3	0.9	4.7	0.1	0.1	0.1	6.2	1.9	0.5	1.2	16.8	37.8	1.3
Property Damage Only	1.3	0.2	0.3	0.7	5.4	1.2	1.2	0.3	13.7	0.1	0.9	1.1	8.6	0.1	0.1	0.0	5.1	1.3	0.2	0.6	15.2	41.0	1.3
Severe Crashes	1.4	0.0	0.0	1.4	9.4	1.2	3.9	1.6	7.6	0.0	0.0	0.7	6.9	0.2	0.0	0.0	5.8	5.1	0.9	2.5	17.3	33.2	0.9
All Crashes*	1.2	0.2	0.3	0.9	6.0	1.1	1.4	0.4	13.8	0.1	0.7	1.1	7.7	0.1	0.1	0.1	5.4	1.6	0.3	0.8	15.6	40.0	1.3

* The totals row does not double count severe crashes.

Since the None and Unknown categories are not helpful for analysis, only the known contributing circumstances are analyzed further. Also, there are some categories that are closely related and could be corrected by the same countermeasures. These categories are combined for further analysis as was done in the Blueprint. The Aggressive Drivers Involved category includes Speed – Exceeded Limit, Too Fast for Conditions and Following Too Close. Although unexplained in the Blueprint, the Distracted Drivers Involved category is probably equivalent to the MUCR term Inattention. The Substance-Impaired Drivers category includes both Alcohol and Drugs. Table 3.4.1.11 shows the distributions for these categories by adding the applicable percentages in Table 3.4.1.10. Table 3.4.1.11 also compares work zone crashes against all crashes. Because the data for all crashes was generated by the STARS website, only one severity for all injuries was available. In terms of all crashes, Aggressive Drivers and Distracted Drivers appear less in work zone crashes than all crashes. However, the reverse is true if the focus were on injury crashes. In fact, for injury crashes in work zones, these two categories have a much higher percentage than all crashes, 43.1% versus 28.8% for Aggressive Drivers and 35.2% versus 22.6% for Distracted Drivers. Thus these two categories appear to contribute to work zone crashes even more than normal.

For the Distracted Drivers issue, there are engineering counter measures that could be applied. However, for Aggressive Drivers, the solutions are more suitable to educational or legislative efforts. Looking at the related categories of Failed to Yield and Violation Signal/Sign, summed together in the last row of Table 3.4.1.11, it appears that these circumstances appear less in work zone crashes than in all crashes. If the categories of Aggressive Drivers, Distracted Drivers and Failure to Yield/Violation were viewed together, one possible conclusion is that human factors is a much greater contributor than others. This again points to solutions related to education, enforcement and legislation more than engineering. Although engineering solutions might help to provide greater warning. Lastly, Substance-Impaired and Improper Lane Usage circumstances appear to be similar between work zone and all crashes.

Table 3.4.1.11 Comparison of Select Contributing Circumstances in Percentage

Contributing Circumstances	Work Zones Crashes			All Crashes		
	All	Fatal	Injury	All	Fatal	Injury
Aggressive Drivers	20.7	15.1	43.1	28.2	25.8	28.8
Distracted Drivers	15.6	12.5	35.2	24.0	14.3	22.6
Substance-Impaired	1.9	12.5	7	4.4	13.3	6.9
Improper Lane Usage	7.7	13.8	10.1	8.7	12.6	7.7
Failed to Yield	5.4	3.8	12.4	13.3	7.9	15.1
Violation Signal/Sign	1.4	2.5	5.9	3.4	3.2	5.0
Fail Yield + Violation	6.8	6.3	18.3	16.8	11.1	20.2

According to the STARS Manual (2002), up to seven chronological events of each vehicle are recorded in Section 17 of the MUCR. These events start from the first unstabilized event to the final rest. The list of fixed objects (Code 36) include items such as trees, embankments, medians, guardrails, utility/lighting poles, fences, culverts, traffic signs, bridges, curbs, barriers and impact attenuators. Thus these objects could include both permanent road features and temporary ones related to the work zone. Table 3.4.1.12 shows the 18743 crash sequences by severity for work zone crashes from 2009 to 2011.

Table 3.4.1.12 Crash Severity by Vehicle Sequence

	Going Straight	Overtaking	Making Right Turn	Right Turn on Red	Making Left Turn	Making U Turn	Skidding/Sliding	Slowing/Stopping	Start in Traffic	Start from Parked	Backing	Stopped in Traffic	Parked	Changing Lanes	Avoiding	Crossover Median	Crossover Centerline	Crossing Road	Airborne
	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Fatal	32	2	0	0	1	0	16	8	2	0	0	7	1	5	10	1	9	1	3
Disabling Injury	129	11	4	0	13	2	68	44	7	1	1	36	0	10	36	4	26	16	3
Minor Injury	964	44	23	1	78	4	310	525	25	0	5	375	14	145	166	8	79	38	5
Property Damage Only	3158	212	145	7	202	18	593	1535	151	27	78	1053	37	715	527	13	200	50	3
Total	**4283**	**269**	**172**	**8**	**294**	**24**	**987**	**2112**	**185**	**28**	**84**	**1471**	**52**	**875**	**739**	**26**	**314**	**105**	**14**

Table 3.4.1.12 Continued

	Ran Off Road – Right	Ran Off Road - Left	Overturn/Rollover	Fire/Explosion	Immersion	Jackknife	Cargo Loss/Shift	Equipment Failure	Separation of Units	Returned to Road	Collision Inv. Pedestrian	Collision Inv. Pedalcycle	Collision Inv. Animal	Collision Inv. MV in Transport	Collision Inv. Parked Motor Vehicle	Collision Inv. Fixed Object	Collision Inv. Other Object	Other – Non Collision	
	20	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**33**	**34**	**35**	**36**	**37**	**38**	**Grand Total**
Fatal	15	7	5	1	0	0	0	1	1	3	4	1	0	25	1	15	6	0	183
Disabling Injury	50	37	40	1	0	0	1	2	0	15	7	1	1	102	0	50	10	0	728
Minor Injury	155	140	97	1	0	6	4	4	5	55	10	2	3	849	9	209	39	8	4405
Property Damage Only	340	276	51	4	1	11	32	30	10	102	2	0	46	2906	33	610	179	70	13427
Total	**560**	**460**	**193**	**7**	**1**	**17**	**37**	**37**	**16**	**175**	**23**	**4**	**50**	**3882**	**43**	**884**	**234**	**78**	**18743**

Table 3.4.1.13 shows the percentage of each vehicle sequence. Ordered by magnitude, the vehicle sequences with the highest percentages are: going straight (22.9%), collision involving motor vehicle in transport (20.7%), slowing/stopping (11.3%), stopping in traffic (7.8%), skidding/sliding (5.3%), changing lanes (4.7%), collision involving fixed objects (4.7%), avoiding (3.9%), ran off road – right (3.0%) and ran off road – left (2.5%). Since the vehicle sequence categories are not mutually exclusive, there could be many ways of interpreting these percentages to understand the underlying causes of the crashes. One way is to differentiate between on road and off road crashes. All the top vehicle sequences appear to be related to on-road crashes. Thus, going straight, collision involving motor vehicle in transport and slowing/stopping, stopping in traffic add up to 54.9%. While collision involving fixed objects and ran off the road (right and left) add up to only 10.2%. The STARS website does not have an easy way (i.e. pre-built) of querying for vehicle sequences for all crashes, thus the comparison with all crashes will reference the Blueprint. As presented in Table 3.3.2, Ran-Off-Road accounts for 36% of fatalities and 35% of serious injuries resulting from all crashes. Here, only 11.9% of the severe work zone crashes involve Ran-Off-Road. Even though the Blueprint percentage is compiled from individual fatalities or injuries and here the percentage is compiled from crashes, it appears that Ran-Off-Road crashes are much less of an issue at work zones than in other settings. Table 3.4.1.6 (Accident Type) also supports the on road focus since "motor vehicles in transport" accounts for 55.8% of severe work zone crashes and 74.3% of all crash severities. Thus for work zones, safety improvements should be focused on issues that occur on the road itself.

It appears that there is a high percentage of work zone crashes that are related to traffic conditions around the work zone. The vehicle sequence categories of "collision involving motor vehicle in transport", "slowing/stopping", "stopped in traffic", "skidding/sliding" and "avoiding" could all be related to traffic conditions. These categories sum up to 49%. Since these categories are not mutually exclusive, this does not mean that 49% of the crashes could be traffic related. Nonetheless, the 49% does point to engineering and enforcement solutions that deal with advance warning and driver alertness during congestion. And this observation is consistent with national work zone studies as shown in Table 3.2.1 (NCHRP), which pointed to higher number of congestion-related crashes such as multi-vehicle and rear-ends.

The evidence from vehicle sequence data seems to re-affirm the contributing circumstances data. As previously shown in Table 3.4.1.9, the largest known circumstances include inattention, following too close and too fast for conditions. The data suggests that there are a significant number of drivers who are not careful near work zones and who are surprised by work zone-related congestion. This evidence also re-affirms the Blueprint's emphasis on aggressive and distracted drivers.

Table 3.4.1.13 Crash Severity by Vehicle Sequence in Percentage

	Going Straight	Overtaking	Making Right Turn	Right Turn on Red	Making Left Turn	Making U Turn	Skidding/Sliding	Slowing/Stopping	Start in Traffic	Start from Parked	Backing	Stopped in Traffic	Parked	Changing Lanes	Avoiding	Crossover Median	Crossover Centerline	Crossing Road	Airborne
Row Labels	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Fatal	17.5	1.1	0.0	0.0	0.5	0.0	8.7	4.4	1.1	0.0	0.0	3.8	0.5	2.7	5.5	0.5	4.9	0.5	1.6
Disabling Injury	17.7	1.5	0.5	0.0	1.8	0.3	9.3	6.0	1.0	0.1	0.1	4.9	0.0	1.4	4.9	0.5	3.6	2.2	0.4
Minor Injury	21.9	1.0	0.5	0.0	1.8	0.1	7.0	11.9	0.6	0.0	0.1	8.5	0.3	3.3	3.8	0.2	1.8	0.9	0.1
Property Damage Only	23.5	1.6	1.1	0.1	1.5	0.1	4.4	11.4	1.1	0.2	0.6	7.8	0.3	5.3	3.9	0.1	1.5	0.4	0.0
Severe Crashes	17.7	1.4	0.4	0.0	1.5	0.2	9.2	5.7	1.0	0.1	0.1	4.7	0.1	1.6	5.0	0.5	3.8	1.9	0.7
All Crashes*	22.9	1.4	0.9	0.0	1.6	0.1	5.3	11.3	1.0	0.1	0.4	7.8	0.3	4.7	3.9	0.1	1.7	0.6	0.1

* The All Crashes row does not double count severe crashes.

Table 3.4.1.13 Continued

Row Labels	Ran Off Road - Right 20	Ran Off Road - Left 21	Overturn/Rollover 22	Fire/Explosion 23	Immersion 24	Jackknife 25	Cargo Loss/Shift 26	Equipment Failure 27	Separation of Units 28	Returned to Road 29	Collision Inv. Pedestrian 30	Collision Inv. Pedalcycle 31	Collision Inv. Animal 33	Collision Inv. MV in Transport 34	Collision Inv. Parked Motor Vehicle 35	Collision Inv. Fixed Object 36	Collision Inv. Other Object 37	Other – Non Collision 38
Fatal	8.2	3.8	2.7	0.5	0.0	0.0	0.0	0.5	0.5	1.6	2.2	0.5	0.0	13.7	0.5	8.2	3.3	0.0
Disabling Injury	6.9	5.1	5.5	0.1	0.0	0.0	0.1	0.3	0.0	2.1	1.0	0.1	0.1	14.0	0.0	6.9	1.4	0.0
Minor Injury	3.5	3.2	2.2	0.0	0.0	0.1	0.1	0.1	0.1	1.2	0.2	0.0	0.1	19.3	0.2	4.7	0.9	0.2
Property Damage Only	2.5	2.1	0.4	0.0	0.0	0.1	0.2	0.2	0.1	0.8	0.0	0.0	0.3	21.6	0.2	4.5	1.3	0.5
Severe Crashes	7.1	4.8	4.9	0.2	0.0	0.0	0.1	0.3	0.1	2.0	1.2	0.2	0.1	13.9	0.1	7.1	1.8	0.0
All Crashes*	3.0	2.5	1.0	0.0	0.0	0.1	0.2	0.2	0.1	0.9	0.1	0.0	0.3	20.7	0.2	4.7	1.2	0.4

* The All Crashes row does not double count severe crashes.

As discussed in Table 3.3.3.2, the population of the region where the work zone crash occurred is divided into the classifications of urban, urbanized and rural. The population threshold is 50,000 for urbanized and 5,000 for urban. Table 3.4.1.14 shows that the largest percentage of crashes for each severity occur in urbanized areas, since there is more travel in the urbanized areas thus greater exposure. But there is a clear difference in severity among the population categories as rural disproportionately accounts for a greater percentage of fatal and disabling injury crashes. Rural crashes account for less than 20% of the total crashes, and yet account for 46.2% of fatal and 32.8% of disabling injury crashes. Even though the sample size of fatal and disabling crashes is small compared to PDOs it is still significant at 189 crashes. This pattern of more severe rural crashes is consistent with other reports such as the Missouri Traffic Safety Compendium (MSAC, 2012) which reports that 66.3% of crashes occurred in an urban area versus 33.7% in a rural area, but 70.5% of fatal crashes occurred in a rural area. These results are also consistent with examination of crashes by MoDOT districts as shown in Table 3.4.1.3. Severe work zone crashes are disproportionately represented in the more rural districts versus the more urbanized St. Louis and Kansas City districts.

Table 3.4.1.14 Urban/Rural Classification by Crash Severity in Percentage

Population	Severity				Total
	Fatal	**Disabling Injury**	**Minor Injury**	**PDO**	
Urbanized	46.2	55.6	73.7	72.5	72.1
Urban	7.7	11.6	7.8	8.2	8.2
Rural	46.2	32.8	18.4	19.3	19.7
	100%	100%	100%	100%	100%

Related to the previous discussions on the crash patterns in the urban versus the rural areas is the analysis of the type of facilities within the urban or rural regions. Two informative factors include the speed limit and the functional classification. Table 3.4.1.15 shows the distribution of crashes among different speed limits for each severity, i.e. for each severity, the percentage of crashes falling under each speed limit. As noted in some reports (cf. TRB, 1998), there is generally a relationship between speed and both crash frequency and crash severity. This relationship is fundamentally based on the physics of collision. However, Tables 3.4.1.15 and 3.4.1.16 illustrate a more influential factor and that is the functional classification of the facility. Because design standards among other factors differ among functional classes, these factors could be more important than the speed limit of the facility. As shown in Table 3.4.1.15, interstates, account for 48.6% of the total work zone crashes and 47.2% of the serious crashes. This high frequency is a function of the large amount of demand serviced by interstates. More interestingly, Table 3.4.1.16 shows that the distribution of crash severity differs by functional classification. The percentage of severe crashes on major collectors is 9.4%, much larger than other functional classes. The percentage of severe crashes is also large in expressways at 4.5%. In considering the speed limit together with the functional classification, there appears to be some patterns. First, the highest speed facilities or interstates, do not have severe crashes overrepresented. Second, higher speed facilities do experience more severe crashes but that is probably just due to the larger amount of traffic carried on those facilities. Third, the lower speed facilities such as minor collectors and local roads do not experience severe crashes. Last, the major collector roads have the highest percentage of severe crashes at 9.4%, which is more than twice the percentage of the next roadway type, expressways.

Table 3.4.1.15 Crash Severity by Speed Limit

Severity	Speed Limit (mph)													
	05	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
Fatal	0.0	0.5	0.0	0.5	3.2	6.3	10.1	3.7	20.1	9.0	11.6	19.0	6.9	7.9
Disabling Injury	0.0	0.0	0.0	0.0	0.0	2.6	2.6	2.6	12.8	12.8	15.4	25.6	10.3	12.8
Minor Injury	0.1	0.1	0.0	0.4	5.0	5.8	17.1	8.2	18.6	4.0	11.7	16.3	4.5	3.9
Property Damage Only	0.0	0.1	0.4	1.6	8.3	6.5	15.8	7.2	16.2	5.6	10.3	13.1	4.9	4.4

Table 3.4.1.16 Crash Severity by Functional Classification

Severity	Functional Classification								
	IS	**Fwy.**	**Expr.**	**Pr. Art.**	**Min. Art.**	**Maj. Col.**	**Col.**	**Min. Col.**	**Local**
Fatal	27	5	8	9		2			
Disabling Injury	93	23	16	44	13	11	3		
Minor Injury	706	254	147	287	90	17	12	6	8
Property Damage Only	2569	724	357	1020	330	108	68	11	13
Severe Crashes	120	28	24	53	13	13	3	0	0
Total	3395	1006	528	1360	433	138	83	17	21

Table 3.4.1.17 Crash Severity by Functional Classification in Percentage

Severity	Functional Classification								
	IS	**Fwy.**	**Expr.**	**Pr. Art.**	**Min. Art.**	**Maj. Col.**	**Col.**	**Min. Col.**	**Local**
Fatal	0.8	0.5	1.5	0.7	0.0	1.4	0.0	0.0	0.0
Disabling Injury	2.7	2.3	3.0	3.2	3.0	8.0	3.6	0.0	0.0
Minor Injury	20.8	25.2	27.8	21.1	20.8	12.3	14.5	35.3	38.1
Property Damage Only	75.7	72.0	67.6	75.0	76.2	78.3	81.9	64.7	61.9
Severe Crashes	3.5	2.8	4.5	3.9	3.0	9.4	3.6	0.0	0.0

The traffic condition for each crash is divided into three categories. One is normal, two is accident ahead and three is congestion ahead. There were crashes for which the traffic condition was unknown. Because this field is determined by the officer at the scene, some of the congestion ahead conditions could actually be accident ahead as the cause of the congestion might not be evident. And the congestion could have dissipated after the officer arrived. Table 3.4.1.18 shows that 35.7% of all work zone crashes are not under normal traffic conditions. This percentage appears to be high; although this can be verified by comparing against the percentage of traffic conditions for all crashes. As discussed previously, the analysis of vehicle sequences and two-vehicle collision types also seem to suggest that congestion plays a significant part in work zone crashes.

Table 3.4.1.18 Crash Severity by Traffic Condition

	Traffic Condition			
Severity	**1**	**2**	**3**	**U**
Fatal	30	2	6	1
Disabling Injury	135	4	48	2
Minor Injury	884	33	530	20
Property Damage Only	3327	74	1781	56
Serious Crashes	165	6	54	3
Total	4377	113	2365	79
%	63.1	1.6	34.1	1.1

Table 3.4.1.19 shows the percentage of crash severities within each traffic condition. The percentage of PDO crashes is the highest for the normal traffic condition at 76%. The accident ahead condition has the percentages shifted towards the more severe crashes, thus it has the highest fatal, disabling and minor injury crash percentages among all traffic conditions. This shows the safety concern associated with secondary crashes, since they tend to be more severe. The congested traffic condition seems to reflect some conflicting results. On the one hand, it has a slightly smaller PDO percentage than normal traffic condition. On the other, the percentage of severe crashes (2.3%) is smaller than under normal traffic conditions (3.8%). The less severe crashes could be the result of minor read-end crashes. Rear-end crashes were examined previously under two-vehicle collision types (Tables 3.4.1.7 and 3.4.1.8).

Table 3.4.1.19 Crash Severity by Traffic Condition in Percentage

	Traffic Condition			
Severity	**1**	**2**	**3**	**U**
Fatal	0.7	1.8	0.3	1.3
Disabling Injury	3.1	3.5	2.0	2.5
Minor Injury	20.2	29.2	22.4	25.3
Property Damage Only	76.0	65.5	75.3	70.9
Serious Crashes	3.8	5.3	2.3	3.8

The differences in AADT distribution is examined for each severity type. Thus for each severity (row), the percentage of crashes that occur under each AADT range (column) is shown in Table 3.4.1.20. The percentages should add up to 100% across each row. Table 3.4.1.20 or the companion Figure 3.4.1.1, shows some possible differences between the more severe and the less severe crashes. It appears that the low AADTs are overrepresented for more severe crashes, especially for fatal crashes. This possible trend appears to reinforce the previous discussions on urban versus rural and functional classification: that severe crashes are over-represented in rural areas and on major collectors.

Table 3.4.1.20 Percentage Distribution of Crash Severities Among AADT

	AADT Categories										
Severity	0-1k	1k-2k	2k-3k	3k-4k	4k-5k	5k-6k	6k-7k	7k-8k	8k-9k	9k-10k	>10k
Fatal	24.4	33.3	22.2	13.3	2.2	2.2	0.0	2.2	0.0	0.0	0.0
Disabling Injury	31.8	32.3	13.9	8.1	2.2	4.9	2.7	0.9	1.3	1.8	0.0
Minor Injury	19.4	29.4	14.2	13.5	7.7	4.3	3.2	3.5	2.3	1.5	1.1
Property Damage Only	19.9	31.0	13.8	13.1	7.4	4.9	2.5	2.9	2.1	1.7	0.8

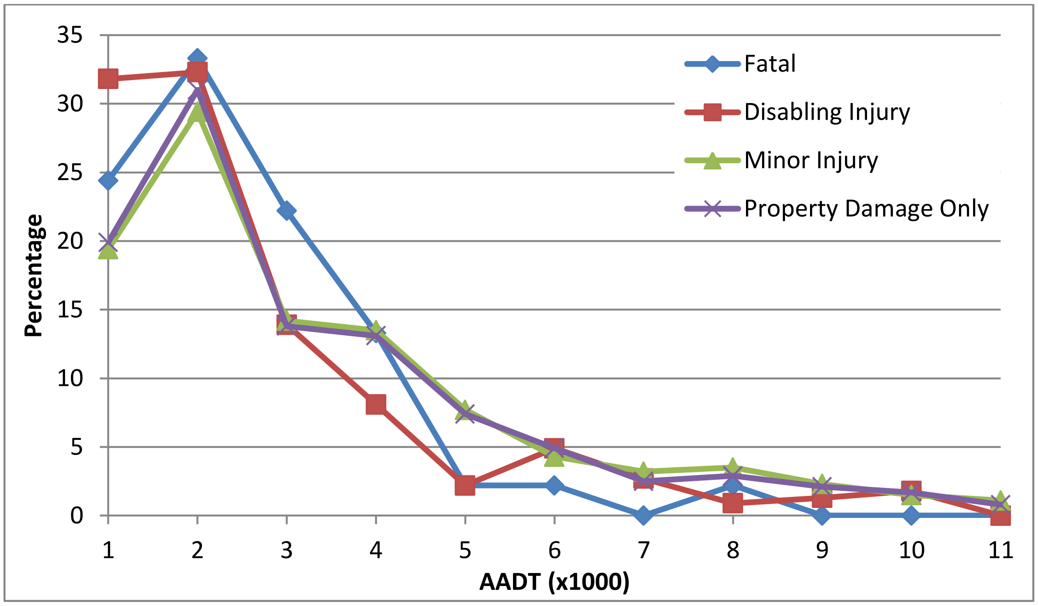

Figure 3.4.1.1 Percentage Distribution of Crash Severities Among AADT

3.5 Chapter Conclusions

The percentage of crashes in the fatal, injury, and PDO categories between work zones and non-work zones differed by less than one. Thus unlike some other studies, the examination of Missouri work zone crashes shows no elevated risk in work zones. Crashes that occurred when dark seemed to be overrepresented in fatal and severe crashes. Therefore it might be useful to consider strategies for improving nighttime safety such as better lighting, delineation, and visibility at nighttime work zones. In terms of accident type, a large number of work zone crashes involved vehicle interactions. These crashes point to possible factors such as traffic queues, lane drops or distracted driving. Of the two-vehicle collisions, rear-end crashes are the most significant, and they tend to be more severe. The failure to stop could be due to a failure of perception/reaction or a failure to brake. Countermeasures that increase driver attention and compliance such as enforcement, larger fines, and education could be useful in reducing two-vehicle and read-end crashes. If the contributing circumstances categories of aggressive drivers, distracted drivers and failure to yield/violation were viewed together, it implies that human factors are a great contributing factor to crashes. This fact again points to solutions related to education, enforcement, and legislation more than just engineering.

In contrast to all crashes, work zone crashes involved fewer ran-off-road and more on-road crashes. In terms of traffic conditions, accident ahead was overrepresented which means congestion and lane drops at work zones could be significant factors. For probable contributing circumstances, aggressive and distracted driving are major problems. The examination of the crash distribution of MoDOT districts, urban versus rural, functional classification, speed limit, and AADT shows rural crashes are disproportionally more severe. Major collectors experience the highest percentage of severe crashes, almost three times as much as interstates and freeways. Low AADT routes are overrepresented in more severe crashes. And rural fatal and disabling injury crashes occur at a higher proportion than in urban or urbanized regions.

The following are a list of possible countermeasures. The first list echoes the conclusions from the Missouri Blueprint:

- Better training all around
- Surveying and educating the public
- Quick incident clearance
- Visible apparel for workers
- Increased enforcement
- Proper work zone setup, planning/prediction of impacts
- Minimizing work zone traffic impacts
- Contractor worker and traffic safety plans, and reviews
- Increasing nighttime visibility
- Dynamic queue monitoring
- Banning handheld cell phones and texting through work zones

In addition, the following suggestions are recommended.

- Advocate for educational solutions such as a news release for this report
- Suggest the use of this report to help with work zone safety legislative efforts such as increasing speeding fines at work zones and greater enforcement

Follow up research to this project could involve a comparison of HSM-type crash prediction versus the actual crashes. This is currently not feasible as there is very little information in the HSM on work zone crash prediction. A more detailed comparison between work zone crashes and crashes on other facilities could help to better assess work zone risk. And a detailed analysis of crash narratives for fatal and injury crashes, including crash diagrams, could help to reveal greater insights into contributing factors.

4. Statistical Analysis of Work Zone Crash Data

The crash data discussed in the previous chapter was further analysed using statistical methods. This verifies that trends observed in the data are systematic and not due to natural randomness.

There is a wide range of literature available on work zones in the US. This literature provides important usable information on different aspects of work zone crashes and modeling information. According to the Fatality Analysis Reporting System (FARS) maintained by the National Highway Traffic Safety Administration (NHTSA), the number of fatal motor vehicle traffic crashes in the state of Missouri in 2012 was 826 of which 7 of them took place in work zones. According to Federal Highway Administration (FHWA), Motor vehicle fatal injuries in work zones average around 900 persons every year and fatalities increased more than 50 percent in a span of 5 years.

The Federal Highway Department's facts show that work zones lead to increases in traffic congestion that leads to increases in crash rates (FHWA, 1998). Congestion and crashes are closely tied. Congestion leads to crashes and crashes lead to congestion. Work zones are estimated to cause about 10% of nationwide traffic congestion which leads to an annual fuel loss of about $0.714 billion. Most work zones have Temporary Traffic Control (TTC) zones. Most TTC zones are divided into four areas. They are the advance warning area, the transition area, the activity area, and the termination area (FHWA, 2009).

The advance warning area is where road users are warned of an upcoming work zone. The transition area is the zone where the road users are redirected from their regular path. The activity area is where the construction activity takes place. Activity area can be further divided into workspace, traffic space and buffer space. The workspace is closed to road users and has the workers, equipment, construction vehicles and construction activity. It is not stationery and may move as the work progresses. There may be multiple workspaces in an activity area. The traffic space is where the regular traffic is directed through a work zone. The buffer space is the area which separates the workspace and the traffic space. It may also provide some recovery space for errant vehicles. The termination area is where the activity area ends and the road users can transition from the temporary path to the normal path (FHWA, 2009). An analysis of crashes in Kentucky shows that 80% of the crashes occur in the work- area (Pigman and Agent). Garber and Zhou also stated that most of the crashes are found in the activity area (Garber and Zhou, 2002).

An analysis of freeway work zones shows that the advance-warning area is unsafe during peak traffic conditions and during bad weather. Exit area is also unsafe particularly during the off-peak periods. Queuing crashes are more likely to involve two or more vehicles and tend to be rear-end crashes. Research also shows that queuing crashes are likely to be more severe when compared to regular work-zone crashes (Srinivasan, 2008).Washburn and Carrick point out that the crash reports of most of the states do not have data elements to capture adequate details about the work zone in which a crash may have occurred (Washburn, 2006).

79% of work zone crashes occurred in daylight conditions and 58.4% of crashes occurred in clear weather conditions (Akepati, 2010). Inattentive driving and following too closely are two major factors of crash causes. Most crashes are Property Damage Only (PDO) type. In a study of 5 states, 72.2% of them were PDO (Dissanayake and Akepati, 2007). 82% of injury crashes were due to driver error. Rear end collision was the most common cause for crash injuries and head-on collision was the most common cause for fatal work zone accidents (Bai and Li, 2007). FHWA facts show that rear end collisions are the most common type of crashes in work zones. Research suggests that following too close, failure to control and improper lane change/improper passing accounted for 71% of all fatal and injury crashes at interstate freeways in Ohio work zones (Salem, 2007). From 2003-2007, around 70% of the accidents occurred between 8 AM to 4:59 PM (Pegula, 2010). Bai and Li (2007b) conducted research on fatal and injury crashes on Kansas Highway work zones from 1992 to 2004. Their research shows that day time non-peak hours between (10 AM to 4 PM) have the highest crash injuries (42%) and second highest number of fatal injuries (32%). A large percentage of fatal injuries (37%) occur in night time between 8 PM to 6 AM. Most of the fatal work zone crashes occur on roads with speed limits greater than 50 mph (FHWA).

The number of fatalities in work zone crashes involving trucks has been increasing. From 2000-2008, 25% of work zone MV fatalities involved trucks. 65% of the fatal crashes occurred during the day. Angle, Rear-End and Head-On are the most common types of crashes involving large trucks in work zones (FHWA).

4.1 Methodology

Data analysis is the process of observing the data, transforming it, and modeling it to obtain useful information. This modeling process allows the identification of statistically significant factors that contribute to work zone crashes. The methodology used to model the data was Multinomial Logistic Regression (MLR). The raw data set consists of values which are ordinal and nominal. Multinomial Regression is used when the dependant variable is nominal and for which the number of categories are more than two. There is no natural ordering in the independent variables. One of the assumptions of MLR is that the dependent variable cannot be perfectly predicted by the independent variables for any case. It is an extension of the Binomial Logit model. Multinomial Regression uses the maximum likelihood ratio to determine the probability of the categorical membership of the dependent variable. One of the reasons why Multinomial Logistic Regression is a good choice for this data is that it does not assume normality, linearity, or homoscedasticity (Starkweather, 2011).

There are multiple ways to mathematically model the Multinomial Logistic Regression. But the concept behind all of them is to construct a linear predictor function which constructs a score from a set of weights that are linearly combined with independent or explanatory variables using a dot product.

Score $(X_i, k) = \beta_k \cdot X_i$,

Where X_i is the Vector of independent variables of the observation i

β_k is the vector of regression co-efficients corresponding to outcome k

and Score (X_i, k) is the score associated with assigning observation i to category k.

It is assumed that there are *N* data points. Each data point has m independent variables and a dependant variable *Y* which can take on one of *K* possible values. The goal of the multinomial logistic regression is to construct a model that explains the relationship between the independent variables and the dependent variable. When using this regression, one category of the dependent variable is selected as the reference category. Separate odds ratios, the odds of an event occurring given some factor compared to the odds of an event occurring in the absence of that factor, are determined for all independent variables for each category of the dependent variable with the exception of the reference category, which is omitted.

4.2 Modeling the Data

The data used for the Multi Logit Model is from the Missouri Transportation Management System (TMS). The data is for the years 2009-2011. For modeling the data, we choose the independent variables which might have significance on the severity of crash and we convert them, coding it to our convenience. Accident Severity is our dependent variable. The original data has four categories of Severity. They are Property Damage Only (PDO), Minor Injury (MI), Disabling Injury (DI) and Fatal. For our research we combine Disabling Injury and Fatal as one independent variable. Table 4.2.1 displays the three dependent variables modeled. The nine independent variables, their categories and codes used in the regression are presented in Table 4.2.2.

Table 4.2.1 Dependent Variables

Severity	**Code**
Property Damage Only (PDO)	1
Minor Injury (MI)	2
Disabling Injury (DI) and Fatal	4

Table 4.2.2 Independent Variables

Variable Name	Categories	Code
Accident Type	Animal	1
	Pedalcycle	2
	Fixed object	3
	Other object (moveable)	4
	Pedestrian	5
	Train	6
	MV in transport	7
	MV on other roadway	8
	Parked MV	9
	Overturning	10
	Other non-collision (Eg: Fire)	11
Two Vehicle Analysis	Head on	60
	Rear end	61
	Sideswipe- meeting	62
	Sideswipe-passing	63
	Angle	64
	Backed into	65
	Other	67
Road Alignment	Straight	1
	Curve	2
Road profile	Level	1
	Grade	2
	Hillcrest	3
Light conditions	Daylight	1
	Dark with streetlights on	2
	Dark with streetlights off	3
	Dark with no streetlights	4
	Indeterminate	5
Weather	Clear	1
	Cloudy	2
	Rain	3
	Snow	4
	Sleet	5
	Freezing (temp)	6
	Fog/mist	7
	Indeterminate	8
Road Condition	Dry	1
	Wet	2
	Snow	3
	Ice	4
	Slush	5
	Mud	6
	Standing water	7
	Moving water	8
	Other	9

Table 4.2.2 Continued

Variable Name	**Categories**	**Code**
Vision Obscurity	Windshield	1
	Load on vehicle	2
	Tree/bush	3
	Building	4
	Embankment	5
	Signboards	6
	Hillcrest	7
	Parked cars	8
	Moving cars	9
	Glare	10
	Other	11
	Not-obscured	12
Traffic Control	Normal	1
	Accident ahead	2
	Congestion ahead	3

The analysis of the model uses three performance measures:

1) P value : This is a significance test. It is normally tested at a threshold value of 5% or 1%. If the p-value is less than the threshold value, we reject the null hypothesis and accept the test hypothesis to be valid. For our model, we test at a 5% level. Therefore, if the p-value is less than 0.05, we can conclude that it is statistically valid.
2) ß value : The beta coefficients show the effect of the independent variables on the dependent variable. A positive coefficient for B, shows a positive impact while a negative coefficient shows a negative impact. For our analysis, a positive B value shows that the category is more likely to impact category of dependent variable with respect to the reference category. If $B > 0$, it is more likely to impact the dependent variable. If $B < 0$, it is less likely to impact the dependent variable. If $B=0$, the particular category and the reference category are equally likely to impact the dependent variable.
3) Exponential Beta value: This value gives us the odds ratio for the independent variables. It is an exponentiation of the regression coefficients (B). The odds ratio shows the change in odds of the dependent variable being in a particular category compared to the reference category, corresponding to one unit change of independent variable. An odds ratio > 1 indicates that the risk of the outcome falling in the comparison group relative to the risk of the outcome falling in the referent group increases as the variable increases. So it is more likely to fall in the comparison group. An odds ratio < 1 indicates that the risk of the outcome falling in the comparison group relative to the risk of the outcome falling in the referent group decreases as the variable increases. In general, if the odds ratio < 1, the outcome is more likely to be in the referent group.

Table 4.2.3 presents the descriptive statistics of the data set. The descriptive statistics display the quantitative features of the sub-groups in the sample. The data set contains a total of 225,383 observations. Of these, 198,836 are valid and 26,547 were missing or blank. Valid observations are those observations in the data set which do not have any of the dependent or independent variables missing. The missing observations are observations in which data is missing from either the dependent or independent variables or both.

N- This gives us the total number of observations corresponding to a particular category. For example, the first three values in the table can be interpreted as, among the 198,836 crashes, 129,032 were PDO, 60,646 were MI and 9,158 were DI and Fatal.

Marginal Percentage: This gives an estimate of the proportion of valid observations found in the dependent variable's group. For example, going back to the first three values in the group, among all the crashes, 64.9% were PDO, 30.5% were MI and 4.6% were DI and Fatal.

Table 4.2.3 Independent Variable Descriptive Statistics

Variable and code		N	Marginal Percentage
SEVERITY	1	129032	64.90%
	2	60646	30.50%
	4	9158	4.60%
ACCIDENT_TYPE	7	195936	98.50%
	8	136	0.10%
	9	2764	1.40%
TWO_VEH_ANALYSIS	60	2486	1.30%
	61	137725	69.30%
	62	2928	1.50%
	63	20277	10.20%
	64	28080	14.10%
	65	3954	2.00%
	66	120	0.10%
	67	3266	1.60%
ROAD_ALIGNMENT	1	180460	90.80%
	2	18376	9.20%
ROAD_PROFILE	1	123829	62.30%
	2	71276	35.80%
	3	3731	1.90%
LIGHT_CONDITION	1	164568	82.80%
	2	16768	8.40%
	3	1037	0.50%
	4	15417	7.80%
	5	1046	0.50%
WEATHER	1	145960	73.40%
	2	45072	22.70%
	3	6169	3.10%
	4	455	0.20%
	5	20	0.00%
	6	392	0.20%
	7	620	0.30%
	8	148	0.10%
ROAD_CONDITION	1	178752	89.90%
	2	18274	9.20%
	3	571	0.30%
	4	382	0.20%
	5	76	0.00%
	6	24	0.00%
	7	12	0.00%
	9	745	0.40%

Table 4.2.3 Continued

VISION_OBSCURITY	1	301	0.20%
	2	400	0.20%
	3	87	0.00%
	4	40	0.00%
	5	62	0.00%
	6	52	0.00%
	7	687	0.30%
	8	483	0.20%
	9	2372	1.20%
	10	919	0.50%
	11	2288	1.20%
	12	191145	96.10%
TC	1	90619	45.60%
	2	7222	3.60%
	3	100995	50.80%

4.3 Analysis

Table 4.3.1 displays the results of the model analysis. The reference category of the dependent variable is 1 which is Property Damage Only. The model compares PDO with Minor Injuries and PDO with DI and Fatal crashes. All these results are based on the P-values, Beta Coefficients and the Exponential Beta Coefficients. PDO is treated as the reference group and therefore models are estimated for MI relative to PDO and a model for DI and Fatal to PDO. Since the last category of each independent variable is used as the reference category, its β value is denoted as 0b.

Table 4.3.1 Model Results

SEVERITYa	ß	Df	Sig.	Exp(ß)
2 Intercept	-4.474	1	0.000	
[ACCIDENT_TYPE=7]	0.642	1	0.000	1.901
[ACCIDENT_TYPE=8]	-1.289	1	0.431	0.276
[ACCIDENT_TYPE=9]	0b	0	.	.
[TWO_VEH_ANALYSIS=60]	2.964	1	0.000	19.379
[TWO_VEH_ANALYSIS=61]	1.624	1	0.000	5.073
[TWO_VEH_ANALYSIS=62]	1.146	1	0.000	3.144
[TWO_VEH_ANALYSIS=63]	0.518	1	0.000	1.678
[TWO_VEH_ANALYSIS=64]	1.498	1	0.000	4.474
[TWO_VEH_ANALYSIS=65]	0.490	1	0.000	1.632
[TWO_VEH_ANALYSIS=66]	0.177	1	0.597	1.193
[TWO_VEH_ANALYSIS=67]	0b	0	.	.
[ROAD_ALIGNMENT=1]	0.377	1	0.000	1.458
[ROAD_ALIGNMENT=2]	0b	0	.	.
[ROAD_PROFILE=1]	0.622	1	0.000	1.863
[ROAD_PROFILE=2]	0.565	1	0.000	1.759
[ROAD_PROFILE=3]	0b	0	.	.
[LIGHT_CONDITION=1]	-0.726	1	0.000	0.484
[LIGHT_CONDITION=2]	-0.757	1	0.000	0.469
[LIGHT_CONDITION=3]	-0.745	1	0.000	0.475
[LIGHT_CONDITION=4]	-0.293	1	0.000	0.746
[LIGHT_CONDITION=5]	0b	0	.	.
[WEATHER=1]	0.629	1	0.005	1.875
[WEATHER=2]	0.801	1	0.000	2.228
[WEATHER=3]	0.795	1	0.000	2.214
[WEATHER=4]	0.984	1	0.000	2.676
[WEATHER=5]	4.664	1	0.000	106.051
[WEATHER=6]	0.397	1	0.135	1.487
[WEATHER=7]	1.611	1	0.000	5.008
[WEATHER=8]	0b	0	.	.
[ROAD_CONDITION=1]	0.828	1	0.000	2.288
[ROAD_CONDITION=2]	0.265	1	0.008	1.303
[ROAD_CONDITION=3]	0.420	1	0.016	1.522
[ROAD_CONDITION=4]	-0.610	1	0.002	0.543
[ROAD_CONDITION=5]	-0.600	1	0.214	0.549
[ROAD_CONDITION=6]	-0.128	1	0.862	0.880
[ROAD_CONDITION=7]	-0.727	1	0.491	0.484
[ROAD_CONDITION=9]	0b	0	.	.

Table 4.3.1 Continued

SEVERITYa	ß	Df	Sig.	Exp(ß)
[VISION_OBSCURITY=1]	0.022	1	0.881	1.022
[VISION_OBSCURITY=2]	0.004	1	0.976	1.004
[VISION_OBSCURITY=3]	-0.460	1	0.132	0.631
[VISION_OBSCURITY=4]	-53.407	1	.	.
[VISION_OBSCURITY=5]	-1.668	1	0.000	0.189
[VISION_OBSCURITY=6]	-0.362	1	0.275	0.696
[VISION_OBSCURITY=7]	0.052	1	0.587	1.053
[VISION_OBSCURITY=8]	-0.105	1	0.328	0.900
[VISION_OBSCURITY=9]	0.800	1	0.000	2.226
[VISION_OBSCURITY=10]	-0.551	1	0.000	0.577
[VISION_OBSCURITY=11]	-0.405	1	0.000	0.667
[VISION_OBSCURITY=12]	0b	0	.	.
[TC=1]	-0.138	1	0.000	0.871
[TC=2]	0.139	1	0.000	1.149
[TC=3]	0b	0	.	.
4 Intercept	-7.393	1	0.000	
[ACCIDENT_TYPE=7]	0.621	1	0.000	1.861
[ACCIDENT_TYPE=8]	5.698	1	0.000	298.406
[ACCIDENT_TYPE=9]	0b	0	.	.
[TWO_VEH_ANALYSIS=60]	6.124	1	0.000	456.675
[TWO_VEH_ANALYSIS=61]	0.853	1	0.000	2.348
[TWO_VEH_ANALYSIS=62]	2.281	1	0.000	9.789
[TWO_VEH_ANALYSIS=63]	1.329	1	0.000	3.778
[TWO_VEH_ANALYSIS=64]	0.781	1	0.000	2.183
[TWO_VEH_ANALYSIS=65]	-0.235	1	0.120	0.790
[TWO_VEH_ANALYSIS=66]	-0.137	1	0.826	0.872
[TWO_VEH_ANALYSIS=67]	0b	0	.	.
[ROAD_ALIGNMENT=1]	0.647	1	0.000	1.910
[ROAD_ALIGNMENT=2]	0b	0	.	.
[ROAD_PROFILE=1]	0.237	1	0.031	1.268
[ROAD_PROFILE=2]	1.183	1	0.000	3.263
[ROAD_PROFILE=3]	0b	0	.	.
[LIGHT_CONDITION=1]	0.408	1	0.020	1.504
[LIGHT_CONDITION=2]	0.205	1	0.256	1.227
[LIGHT_CONDITION=3]	0.305	1	0.219	1.357
[LIGHT_CONDITION=4]	3.313	1	0.000	27.467
[LIGHT_CONDITION=5]	0b	0	.	.

Table 4.3.1 Continued

SEVERITYa	ß	Df	Sig.	Exp(ß)
[WEATHER=1]	0.426	1	0.522	1.531
[WEATHER=2]	0.831	1	0.211	2.295
[WEATHER=3]	-0.599	1	0.370	0.549
[WEATHER=4]	1.241	1	0.071	3.460
[WEATHER=5]	2.523	1	0.472	12.472
[WEATHER=6]	-0.371	1	0.595	0.690
[WEATHER=7]	-2.522	1	0.000	0.080
[WEATHER=8]	0b	0	.	.
[ROAD_CONDITION=1]	0.836	1	0.003	2.307
[ROAD_CONDITION=2]	0.890	1	0.002	2.434
[ROAD_CONDITION=3]	1.809	1	0.000	6.107
[ROAD_CONDITION=4]	0.475	1	0.149	1.608
[ROAD_CONDITION=5]	-0.256	1	0.805	0.774
[ROAD_CONDITION=6]	0.363	1	0.842	1.437
[ROAD_CONDITION=7]	3.983	1	0.126	53.693
[ROAD_CONDITION=9]	0b	0	.	.
[VISION_OBSCURITY=1]	-2.192	1	0.000	0.112
[VISION_OBSCURITY=2]	-0.888	1	0.007	0.411
[VISION_OBSCURITY=3]	-0.950	1	0.293	0.387
[VISION_OBSCURITY=4]	-42.294	1	.	1.000E-013
[VISION_OBSCURITY=5]	-1.669	1	0.134	0.189
[VISION_OBSCURITY=6]	-0.449	1	0.658	0.638
[VISION_OBSCURITY=7]	-2.701	1	0.000	0.067
[VISION_OBSCURITY=8]	-0.144	1	0.571	0.866
[VISION_OBSCURITY=9]	-0.758	1	0.000	0.469
[VISION_OBSCURITY=10]	-0.466	1	0.008	0.627
[VISION_OBSCURITY=11]	-0.890	1	0.000	0.411
[VISION_OBSCURITY=12]	0b	0	.	.
[TC=1]	0.194	1	0.000	1.214
[TC=2]	0.788	1	0.000	2.199
[TC=3]	0b	0	.	.

Minor Injuries versus PDO

- Motor Vehicle (MV) in transport is more likely to cause a MI than a parked MV. It has a B value of 0.642. This is the multinomial logit estimate comparing MV in transport to parked MV for MI relative to PDO given the other variables in the model are held constant. The multinomial logit for MV in transport relative to parked MV is 0.817 units higher for MI relative to PDO given all other independent variables in the model are held constant. So, MV in transport are more likely than parked MV to cause MI than PDO.
  It has an Odds-Ratio of 1.901. This is the relative risk ratio comparing MV in transport to parked MV for MI relative to PDO given that the other variables in the model are held constant. For MV in transport relative to parked MV, the relative risk of being involved in a MI relative to PDO would be expected to increase by a factor of 2.263 given the

other variables in the model are held constant. In other words, MV in transport is more likely than parked MV to be in a MI over PDO. MV in other roadway is not a statistically significant factor.

- Similarly, Two vehicle analysis shows that head-on, rear-end, sideswipe (meeting and passing), angle and backed into were all more likely to cause a MI when compared to other type of collisions. Most likely factor was head on collision. It has a B value of 2.964 and an odds ratio of 19.379.
- Straight roads are more likely to cause MI than a curved road.
- Level and grade roads are more likely to cause MI than a hill-crest.
- Light conditions: Daylight, dark with streetlights on and ark with streetlights off and dark with no streetlights are all less likely to cause MI than indeterminate conditions.
- Weather: Clear, cloudy, rain, snow, sleet and fog are most likely to cause a MI. Of the above conditions, Sleet the biggest positive regression coefficient and has the highest odd's ratio and so is more likely to cause MI than a PDO.
- Road Conditions: Dry, wet and snow are more likely to cause a MI with dry Condition being the most likely. Ice is less likely to cause a MI.
- Vision obscured by Embankment, glare and other factors were less likely to cause a MI. Vision obscured by moving cars are more likely to be involved in a MI. Other categories are not statistically significant.
- MI is less likely to happen under normal conditions and more likely to occur when there is an accident ahead when compared to congested traffic conditions.

Fatal and Disabling Injuries Vs PDO:

- MV in transport and MV on other roadway are more likely to cause a DI and/or Fatal accident than a parked MV. Of the two, MV on other roadways has a higher odds ratio. This interprets as the there is a much higher possibility of an MV on other roadway causing a DI and/or Fatal accident than a parked MV when compared to the reference category of PDO.
- Head-on, Rear end, angle and Sideswipe collision (Meeting and passing) categories of two vehicle analyses are more likely to cause a DI and/or Fatal accident. Head on was the most likely cause of a fatal/Disabling injury with a regression coefficient of 6.124.
- A straight road was more likely to cause a DI and/or Fatal accident than a curved road.
- Level and graded roads are more likely to cause DI and/or fatal accidents compared to a hill crest. Of the two, grade roads are more likely than level. It has an odds ratio of 3.263.
- Light Conditions: Daylight and dark with no streetlights are the most likely light conditions in which DI and/or Fatal accidents occur. Dark with no streetlights has the highest odds ratio of 27.467.
- Fog/Mist is less likely to cause a DI and/or Fatal accident compared to indeterminate weather conditions. Sleet is most likely to cause a DI and Fatal accident. However it is not statistically significant
- Dry, wet and snowy road conditions are more likely conditions for a DI and/or Fatal Accident. Snow has the highest odds ratio of 6.107. Standing water is also highly likely to cause a DI and Fatal accident. However, it is not statistically significant.

- Vision obscured by windshield, load on vehicle, glare, hillcrest, moving cars and other factors were less likely to cause a DI and/or Fatal accident. All other categories under vision obscurity are not statistically significant.
- Normal traffic conditions and accident ahead are more likely to cause a DI and/or Fatal accident when compared with congested traffic conditions.

4.4 Chapter Conclusions

The objective of this study was to perform a statistical data analysis on work zone crash data for Missouri Work zones and identify attributes associated with severity of crashes. Crash Data from the Transportation Management System for the years 2009 to 2011 was used. Statistical models using Multinomial Logistic Regression were developed to analyze the influence of Light Conditions, Road Conditions, Traffic Conditions, Weather Conditions, Road Profile, Road Alignment and Two-Vehicle Analysis on Severity of the crash. The model gives us the descriptive statistics of the features of the crashes and a comparison of attributes of Crashes with severity MI relative to PDO and DI/Fatal relative to PDO.

- Majority of the crashes were PDO with a percentage of 64.9%.
- Rear-end collision was the most common type of crash with a percentage of 69.3%.
- Two vehicle analysis showed that Head-on collision was the most likely factor to cause MI relative to PDO.
- Clear, cloudy, rain, snow, sleet and fog are more likely to cause a MI. Dry, Wet and Snow on the road are more likely to cause an MI.
- MV in transport and MV on other roadway are both more likely to cause DI and Fatal accidents.
- Head-On collision is the most likely factor for DI and Fatal crashes.
- Daylight and Dark with no streetlights ON are more likely factors for DI and Fatal crashes.
- Snow on road is more likely to be associated with DI and Fatal crashes than PDO crashes.
- Accident ahead and normal traffic conditions are also associated with DI and Fatal accidents.
- There are some limitations with the data set like errors in data collection and missing data. Some variables can also interact with each other.
- Careful driving and paying attention can greatly increase safety in work zones.

Seat belts are extremely important. Lack of Seat-belt use was a factor in 383 of the 720 work zone fatal accidents in 2008 (FHWA).

5. Conclusions

The scope of the current project focused on worker safety culture, thus the analysis and discussions on work zone crashes were limited. There were many related issues that were not analyzed in detail. For example, the comparison of work zone and non-work zone crashes was brief. No Highway Safety Manual (HSM) style statistical analysis was conducted. Specifically, HSM-type analysis involving Safety Performance Functions or Crash Modification Factors was not utilized. And a review of crash diagram and narratives for the most severe crashes could reveal more insights into crash causes and potential countermeasures.

Crashes occurring on Missouri work zones from 2009 to 2011 were analyzed in this project. There were approximately 6750 crashes composed of 35 fatal crashes, 182 disabling injury crashes, 1425 minor injury crashes, and 5107 property damage only crashes. This review of historical work zone crash data and comparison with all crashes revealed some possible Missouri trends. First, Missouri work zones do not appear to have an elevated risk in contrast to some other states. Second, low AADT routes are overrepresented in more severe crashes, and rural fatal and disabling injury crashes occur at a higher proportion than in urban or urbanized regions. Third, crashes occurring when dark seemed to be overrepresented in severe crashes. Fourth, vehicle-interaction crashes were much more prevalent than single vehicle crashes, and rear-end crashes were the more significant and severe. These two facts point to a potential issue with queuing and perception/reaction times which could be countered via enforcement, education, and improved warning. Last, human factors seem to dominate in work zone crashes. Aggressive driving and distracted driving are primary factors in work zone crashes, thus changing traveler safety culture could help reduce crashes. As suggested by the survey results in Chapter 2, the general public could improve in its knowledge and compliance of work zone laws and regulations.

Statistical models using Multinomial Logistic Regression were developed to analyze the influence of Light Conditions, Road Conditions, Traffic Conditions, Weather Conditions, Road Profile, Road Alignment and Two-Vehicle Analysis on severity of the crash, utilizing crash data from the Transportation Management System for the years 2009 to 2011. The models provide the descriptive statistics of the features of the crashes and a comparison of attributes of crashes with severity level of Minor Injury relative to Property Damage Only and Disabling Injury/Fatal relative to Property Damage Only. The majority of the crashes were Property Damage Only with a percentage of 64.9%. Rear-end collision was the most common type of crash with a percentage of 69.3%. Two vehicle analysis showed that head-on collision was the most likely factor to cause Minor Injury relative to Property Damage Only. Clear, cloudy, rain, snow, sleet and fog are more likely to cause a Minor Injury. Dry, Wet and Snow road conditions are more likely to cause a Minor Injury. Head-On collision is the most likely factor for Disabling Injury and Fatal crashes. Daylight and Dark with no streetlights are more likely factors for Disabling Injuries and Fatal crashes. Snow on the roadway is more likely to be associated with Disabling Injuries and Fatal crashes than Property Damage Only crashes.

The effectiveness of existing MoDOT Work Zone Rating survey in measuring the perceived safety of work zone warning signs was evaluated. An extension on the survey to collect more data was incorporated and administered concurrently with MoDOT Work Zone Rating survey. The result shows that there are differences in responses by MoDOT employees and the general public. The possible contributing factors to the difference between MoDOT employees and the general public rating are: the general public's lacked safety awareness and knowledge of existing protocols and SOP for work zones; existing SOP and protocols were insufficient for certain work zone locations due to geometrics, terrain, and other challenges of the terrain; under the influence of organization culture and knowledge, rather than evaluating the effectiveness of the warning signage on a case by case basis, MoDOT employees subconsciously seek confirmation and rate the work zone based on the existence of warning signage according to protocol when they pass through a work zone rather than the effectiveness of the signage. Since most of the workers in the work zone are contractors and non-MoDOT employees, changing the culture in MoDOT will not likely have a significant effect. To improve work zone safety from the behavior aspect, MoDOT employees will need to rate the work zone safety case by case, rather than strictly adhering to the protocols; updating the protocols related to MoDOT contractors may be necessary.

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Appendix A: MoDOT Existing Work Zone Rating Survey

Your Name:

MoDOT strives to provide excellent customer service. If you wish to be contacted with regards to any comments/questions you provide with this survey, please submit your phone number and/or email allowing a staff member to respond.

Phone Number:

Email Address:

Are you a MoDOT Employee? YES ○ NO ○

County: Select county

If county is unknown, type Unknown in the field above.

Road/Highway Name & Direction:

Nearest Intersection:

Date Traveled: Time: AM ○ PM ○

1. Did you have enough warning before entering this work zone?
   YES ○ NO ○

2. Did the signs provide clear instructions?
   YES ○ NO ○

3. Did the cones, barrels, or striping guide you through the work zone?
   YES ○ NO ○ None Present ○

4. Did you make it through the work zone in a timely manner?
   YES ○ NO ○

   If no, please explain: (2000 character max)

5. Were you able to travel safely in the work zone?
   YES ○ NO ○

   If no, please explain: (2000 character max)

Additional Comments:

(Maximum characters: 2000): You have 2000 characters left.

Appendix B: Data from MoDOT existing survey, May 1 – June 13, 2013.

Data Breakdown by Count and Percentages

Question 1: Enough warning	Respondents that answered:				Total	
	Yes		No			
Responses by Group:	Count	%	Count	%	Count	%
All Respondents	465	96.47%	17	3.53%	482	100%
MoDOT Employees	421	99.76%	1	0.24%	422	100%
General Public	44	73.33%	16	26.67%	60	100%

Question 2: Signs provide clear instructions	Respondents that answered:				Total	
	Yes		No			
Responses by Group:	Count	%	Count	%	Count	%
All Respondents	460	95.04%	24	4.96%	484	100%
MoDOT Employees	423	99.53%	2	0.47%	425	100%
General Public	37	62.71%	22	37.29%	59	100%

Question 3: Cones guide through work zone	Respondents that answered:						Total	
	Yes		No		None Present			
Responses by Group:	Count	%	Count	%	Count	%	Count	%
All Respondents	408	85.71%	10	2.10%	58	12.18%	476	100%
MoDOT Employees	365	87.32%	1	0.24%	52	12.44%	418	100%
General Public	43	74.14%	9	15.52%	6	10.34%	58	100%

Question 4: Through in a timely manner	Respondents that answered:				Total	
	Yes		No			
Responses by Group:	Count	%	Count	%	Count	%
All Respondents	457	94.23%	28	5.77%	485	100%
MoDOT Employees	422	99.29%	3	0.71%	425	100%
General Public	35	58.33%	25	41.67%	60	100%

Question 5: Able to travel safely	Respondents that answered:				Total	
	Yes		No			
Responses by Group:	Count	%	Count	%	Count	%
All Respondents	455	95.39%	22	4.61%	477	100%
MoDOT Employees	418	100.00%	0	0.00%	418	100%
General Public	37	62.71%	22	37.29%	59	100%

Appendix C: Expanded Work Zone Rating Survey

Note: This survey was launched online only and is not available in post card form as the original survey. The logic to display hidden question is highlight in Purple Box.

MoDOT Traffic and Highway Safety Division: WZ Rating Extension Survey

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Please bear with us...

We appreciate you taking additional time to complete this second portion of the survey. You will notice that a number of questions are similar to the survey you have just completed on MoDOT website.

This is an extension on the MoDOT survey. If you answered "No" to any of the question in previous survey, your response to this survey will be valuable to us. Your opinion on the "No" rating will give us idea on how to improve our work zone.

This is an initial study to find out how can we improve our current work zone survey that will allow MoDOT to collect more information. At the end of this survey, we will ask you to tell us how you feel about this survey. Please feel free to comment.

Thank you again for your patience.

This study is performed in partnership with Missouri University of Science & Technology, and University of Missouri, Columbia.

Work Zone Information

Your Name (Optional) ____

MoDOT strives to provide excellent customer service. If you wish to be contacted with regards to any comments/questions you provide with this survey, please submit your phone number and/or email allowing a staff member to respond.

Phone Number: ____

Email Address: ____

Are you a MoDOT Employee?*

( ) Yes ( ) No

County of the work zone ***[Select from a dropdown menu containing all counties in MO]***
If county is unknown, select 'Unknown' from the list.*

Please let us know the details of work zone you travel through:*

Roadway/Highway Name & Direction: ____

Nearest Intersection/Mile Marker/City Street/County Road:____________________________

Date Traveled: ____

Time: ____

AM or PM: ____

Work Zone Warning

1) When did you first notice the warning sign while approaching the work zone? Please provide the distance listed on the warning sign.*

( ) 3 miles out

( ) 2 miles out

( ) 1 mile out

( ) 1/2 mile out

( ) 1/8 mile out

( ) Don't know

( ) Did not see

Did you have enough warning before entering this work zone?*

( ) Yes ( ) No

2) Did the signs provide clear instructions?*

( ) Yes ( ) No

Warning Signs, Cones, Barrels, and Striping

Logic: Hidden unless: Question #2 = ("No")

Please let us know the issues with the signs. Please check all that applies.*

[ ] Confusing symbol
[ ] Confusing message
[ ] Message too long
[ ] Words too small
[ ] Better locations

[ ] More visible signs
[ ] Other (Please provide more information):____*

3) Did the cones, barrels, or striping adequately guide you through the work zone?*

( ) Yes ( ) No ( ) None present

Cones, Barrels, Striping, and Safety

Logic: Hidden unless: Question #3 = ("No")

Why were the cones, barrels or striping inadequate? Please check all that applies.*

[ ] Wrong locations

[ ] Too few/missing

[ ] Confusing

[ ] Not visible

[ ] Other (Please provide more information): ____*

4) How long did it take you to make it through the work zone?*

( ) 1 to 9 minutes

( ) 10 to 15 minutes

( ) 16 to 30 minutes

( ) More than 30 minutes

5) Were you able to travel safely in the work zone?*

( ) Yes ( ) No

General Information

Logic: Hidden unless: Question #5 = ("No")

Please let us know the issues. Please check all that applies.*

[ ] Roadway too narrow

[ ] Worker's proximity to the roadway

[ ] Speed limit at work zone was too high

[ ] Stopped traffic or traffic backups

[ ] Other (Please provide more information): ____*

Weather

( ) Clear	( ) Cloudy	( ) Rain
( ) Snow	( ) Ice	( ) Windy

Vehicle

( ) Car/Pickup	( ) Recreational	( ) Commercial

How did you learn of our survey?

( ) MoDOT Website	( ) Media
( ) Work Zone message sign	( ) Provided by MoDOT staff/flagger
( ) Received by mail	( ) Postcard

( ) Other (Please explain): ____

Other comments on MoDOT Work Zone: _________________________________

Approximately how long did it take you to complete this survey?

( ) Less than 5 minutes

( ) 5 to 10 minutes

( ) More than 10 minutes

( ) I don't remember, but it felt like it took a long time.

( ) I don't remember, but it felt like it took a short time.

( ) Other:

What do you think about this expanded version of the MoDOT Work Zone Rating survey?

____

Thank You!

Appendix D: Data from Expanded Survey, May 1 – December 31, 2013

Data Breakdown by Count and Percentages

Question 1: **Enough warning**	Respondents that answered: Yes		No		Total	
Responses by Group:	Count	%	Count	%	Count	%
All Respondents	146	82.95%	30	17.05%	176	100%
MoDOT Employees	88	98.88%	1	1.12%	89	100%
General Public	58	66.67%	29	33.33%	87	100%

Question 2: **Signs provide clear instructions**	Respondents that answered: Yes		No		Total	
Responses by Group:	Count	%	Count	%	Count	%
All Respondents	137	77.84%	39	22.16%	176	100%
MoDOT Employees	88	98.88%	1	1.12%	89	100%
General Public	49	56.32%	38	43.68%	87	100%

Question 3: **Cones guide through work zone**	Respondents that answered: Yes		No		None Present		Total	
Responses by Group:	Count	%	Count	%	Count	%	Count	%
All Respondents	123	69.89%	16	9.09%	37	21.02%	176	100%
MoDOT Employees	63	70.79%	0	0.00%	26	29.21%	89	100%
General Public	60	68.97%	16	18.39%	11	12.64%	87	100%

Question 5: **Able to travel safely**	Respondents that answered: Yes		No		Total	
Responses by Group:	Count	%	Count	%	Count	%
All Respondents	146	82.95%	30	17.05%	176	100%
MoDOT Employees	88	98.88%	1	1.12%	89	100%
General Public	58	66.67%	29	33.33%	87	100%

Appendix E: Breakdown on the Reasons for Negative Rating

Question 2: Did the signs provide clear instructions?		
Yes	137	
No	39	
Reasons for "No" Rating		
7	Confusing message	
9	Better locations	
10	More visible signs	
27	Other	Comments
		No sign that said what was going on, just a road work ahead sign on the ramp
		No warning that metal plates are on the roadway
		no information that the exit was still closed past the announced time
		There were no signs informing motorists of the new traffic pattern ahead of them and no information on how to navigate. I.E. Supplementary warning signs with symbols, a message
		No signs whatsoever
		If signs were in place, blended in with the other construction signs
		Signs were wrong
		Pertinent one missing
		Clearer direction/lane blockage
		You leave signs up all the time. Not sure when you are working.
		There were no advanced warning signs prior to complete stop in the work zone
		CARS & TRUCKS SPEEDING AND CHANGING LANES
		did not warn about bumps to exit
		No warning about stopping
		no signs in advance, just cones and arrow at the start of work zone
		Too general
		Wrong Directional arrows
		work started before 8:00 a.m. as sign indicated
		wrong dates on the sign & didn't say the road was actually CLOSED to through traffic 3 miles ahead, just warned of upcoming work on E Hwy
		uneven
		saw stopped cars before work zone sign
		there were no signs stating that a lane was closed
		No signs on ramps
		not warned of drop off
		No detour posted
		just said prepare to stop, no info on work zone

Question 3: Did the cones, barrels, or striping adequately guide you through the work zone?		
Yes	123	
No	16	
Reasons for "No" Rating		
1	Wrong location	
3	Too few/missing	
7	Confusing	
1	Not visible	
11	Other	Comments:
		Incorrectly placed
		busy
		no warning metal plates on the roadway
		they make you swith lanes multiple times and when its wet outside the construction zones seem to be slicker then the old highway!
		too close to lane squeezing cars close to middle striped lane markers
		no clear access left to travel south on U from 60 east
		Moved frequently
		Should have been reduced to 1 lane much earlier
		to far over
		they were on the shoulder of the road - it was not clear which lane we were supposed to drive is as neither was blocked off
		sign stated one lane, the cones took two lanes, and i used the turn lane which had the drop off as well, granted it wasnt the big ditch that they are working on , but a little gravel would of been nice

Question 5: Were you able to travel safely in the work zone?		
Yes	143	
No	33	
Reasons for "No" Rating		
7	Roadway too narrow	
8	Worker's proximity to the roadway	
2	Speed limit at work zone was too high	
11	Stopped traffic or traffic backups	
23	Others	Comments:
		signs in road
		Problems with the ramp entering I-35
		Metal plates on road, no reduction in speed or signs warning about metal plates on the roadway
		could not enter work zone
		Merging traffic
		POTHOLE IN CENTER LANE
		Exit blocked without warning
		road suface damaged in detour(s)
		SPEEDING
		contractor out in driving lane setting tabs vest dirty
		the roads are horrible and never seem to actually get done they put more down and dig it back up.
		uneven lanes for 3 months
		Not enough warnings
		access to intersecting road blocked with no arning, no detour and no direction as to how to move through the intersection
		Wrong Directions given and cones in the middle of nowhere blocking about 200' of lane with no one around or any warning signs letting one know the lane was closed
		cone placement
		rocks left all over the road
		lead truck was careless
		to much gravel on road
		they did not have the lane marked as being closed so you had to try and get back into the driving lane from the turn lane
		drop off in pavement took the steering wheel out of my hand and i was going lower than the speed limit because it said one lane ahead, which it really meant there is a drop off no matter where you drive here
		No painted lines

Appendix F: Existing WZ Rating Survey – Comments by Participants

Question 5: Were you able to travel safely in the work zone?

Yes	455
No	22

Comments on “No” rating:

1	Trying to obey the speed limit of 35MPH every morning is causing a lot of pissed off drivers to tailgate and honk. People believe (including me but I do not wish to take a chance on getting a ticket) that if there is not a speed limit sign present every 150 feet or so during a work zone that the old speed limit prevails. Please correct this fast.
2	Road work sign no work
3	Signage needs to be placed further in advance of a detour for tall vehicles to avoid "dead ends" and having to jackknife in the middle of a highway to turn around.
4	There were no signs on side streets/roads that said wait for pilot car. This resulted in many cars driving towards the pilot car and having to turn around or were forced to drive on the shoulder/grass to avoid colliding into pilot car and cars following it.
5	Massive amounts of people trying to get over for cones when there were no workers present
6	Need more law enforcement of the speed limit in this work zone.PLEASE!!!
7	With the rest stop on the highway between the exit for Dearborn, Missouri and the exit for Camden Point; I was run off the road by a tractor trailer trying to enter the road from the rest stop. This involved the semi driver yelling profanity at me, riding me to the shoulder, and staying on my tail all the way through the construction zone. It isn't my fault that he couldn't get over due to his size, and as a personal driver, I'm tired of being bullied by tractor trailers on the road; primarily on Interstate 29 between St. Joseph and Kansas City.
8	I made it through safely but did not feel safe while I was driving.
9	Because there were no signs there were cars swerving in and out of the cones. It was not safe. The cones seemed to be placed too far into the lane we were supposed to be using.
10	two road signs were out in the exit lane i attempted to avoid them but hit each one after the car in front of me i had my truck check out the tires and front end was ok the only damage was a small dent in my bumper the reason i'm letting you know is neither sign was sandbagged and if would have tried to avoid them it could have been worse because of cars to my side and behind me so a reminder to the contractor to secure signs would be appreciated thank you
11	This zone is incredibly poorly marked. Speed limit signs contradict each other daily, there is zero indication that you have entered the zone and zero indication you are through or that the zone is ended. All of these indicators ate required by law. Fix it before someone is hurt, its ridiculous on your part.
12	i needed information but wasn't able to get it due to the problems with your website.
13	This should be a yes and no answer as I remained stopped, but several drivers did not.
14	To long periods waiting on pilot car
15	Contractor's work zone(chester bros), unorganized work zone
16	There are metal plates on the road, no warning ahead of time that plates are on the roadway. Only a bump sign on one side of the three lane interstate.
17	Metal plates in the road, no advance warning, sticking above the pavement at least an inch
18	When making a turn onto southbound Hwy 7 from Muddy River Road, the driver has no choice but to turn wide, crossing over the median into oncoming traffic, which is frequently traveling above the recommended speed.
19	Excessive traffic back-up on highway W due to poor timing on temporary lights