Safety Evaluation of Work Zone Practices in Utah

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ABSTRACT

Safety Evaluation of Work Zone Practices in Utah

by

Tomás Ernesto Lindheimer, Master of Science
Utah State University, 2010

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Department: Civil and Environmental Engineering

Work zones present a risk to drivers and to personnel constructing the roadway. In 2005 work zones accounted for 2.5% of fatalities nationwide, 3.5% for the state of Utah. The goal of this research is to make work zones safer by quantifying the risk that they present to drivers. The approach of this research has been to review part 6 of the Manual of Uniform Traffic Control Devices (MUTCD) and compare the differences from the 2003 and 2009 editions, conduct field studies of Utah work zones, and develop a tool for measuring risk in work zones. In the 2009 MUTCD an effort is made to provide additional safety measures to disabled pedestrians. Also, guidelines are set for the use of new technology for work zones, flagger procedures, and incident management. Research was done to ascertain what several states are doing to promote safety around work zones. The states that are highlighted in this report are Arkansas, North Carolina, Illinois, Pennsylvania, New Mexico, Minnesota, and Virginia. These methods include integration of a Smart Work Zone system, late lane merge, investigation of higher quality traffic control devices, and application of other technologies to make drivers aware of work
zone conditions. Discussion about the various technologies available and their effects on traffic found through research is also provided in this thesis. Research for safety and safety regulations continues.

An audit process developed at Utah State University and the Illinois Institute of Technology was used to conduct an evaluation of work zones in Utah. The audit was instrumental in evaluating the measures being used on highway and interstate roads work sites. The results and observations of this research were utilized to make standards concerning conditions of signs and delineation devices. Also observations were used to determine risk factors pertaining to a work zone. These factors were implemented in a spreadsheet that served as an analysis tool for quantification of risk in a work zone. Eleven projects in highways and arterials were audited and analyzed with the analysis tool developed. The risk scores attained from this tool range in value, and though the values may not be an exact value of the present risk, the tool still proved to be effective as an estimation device for auditors and contractors alike. The tool also proved efficient in quickly identifying the areas of concern in the work zone, and giving an estimate on the impact that improvements will have on the safety of workers and drivers. For the 11 work zones audited, the recommendations were enforcement of speed limit, improvement of signs in the work zone, and use of positive protection, among others.
DEDICATION

This thesis is dedicated to my family, friends, and Maté. To my family and friends for their support and patience through this educational process. I couldn’t have done it without you. To Maté for keeping me awake and relaxed during long nights of writing, reading, and studying.
ACKNOWLEDGMENTS

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Tomás E. Lindheimer
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CHAPTER 1
INTRODUCTION

1.1 Background

Road construction affects the safety and mobility of roadways. Work zones reduce the capacity, present the driver with merging movements, and reduce the speed at the activity area. Reduction in speed, capacity, combined with exposing the driver to an unfamiliar environment, cause a reduction in mobility and an increase in safety risk. According to the Federal Highway Administration (FHWA) from 1997 to 2005 there was an increase of nearly 40% in work zone fatalities (USDOT 2007). There were a total of 1074 work zone fatalities in 2005, which accounts for 2.5% of all fatalities. Utah reported that in 2005 work zones accounted for 3.5% of fatalities state wide, surpassing the national trend.

1.2 Necessity for Research

Work zones present drivers with an unexpected change in roadway and a reduction in capacity. These events attribute to an increase in crash severity, and frequency. Research supports the notion of work zones being a safety risk to all exposed.

Analysis of crash data has shown that work zones present a danger to drivers and increase the probability of crashes. The Georgia Department of Transportation (GDOT) performed a study on the manner of collision, location and type of construction associated with fatal crashes. Data was gathered from three different work zones, fatal crashes within work zones were compared to non-fatal crashes within the work zone, and then the fatal crash activity was analyzed in order to determine the influence of work zones on the frequency of fatal crashes. The study showed that most fatal crashes
occurred on construction work zones rather than maintenance work zones. Fatal crashes in work zones involve other cars more often, and a higher percent of crashes in work zones involve trucks. Fatal crashes in dark conditions occur more often in work zones than non-work zone environment, and within the work zone most crashes in dark conditions are fatal as compared to non-fatal. Overall the presence of a work zone does influence the type of collision, truck involvement, light conditions and roadway functional classification where fatal crashes occur (Daniel et al. 2000).

Similar results were found in an analysis of California crash data. The rate of crashes on limited-access roadways before and during road construction was compared. Also, a comparison and estimate of the effects of duration, length and traffic was performed. This required data about the start and the end of work zones, location of work zones, crashes, and ADT. Thirty-six sites were analyzed using data from 1992 and 1993. The study found that the rate of overall crashes is 21.5% higher than pre-work crash rate. Most crashes, however, are non-injury. The results also showed that the frequency of crashes depends on ADT, work zone duration, and work zone length (Khattak et al. 1999).

Work zone crashes can be reduced if proper safety countermeasures are employed and if the standards set by the Manual of Uniform Traffic Control Devices (MUTCD) are followed. In 2009 the MUTCD provided new provisions for use of technologies, new guidelines for work zone set up, and new procedures and regulations. Also states around the country are using new technologies to enhance the safety of work zones and reduce the amount of congestion that work zones cause. Reducing congestion in work zones is also significant since the American Traffic Safety Services Association (ATSSA) reports
that 37% of fatalities in work zones are due to secondary crashes. The changes in the MUTCD compiled with the new strategies that states are adopting show that work zone safety is of concern. Research on how to make work zone safer is still on-going.

1.3 Research Questions

The main question of this research is “how to use a road safety audit to quantify risk in work zones?” Addressing this question requires a standard safety audit procedure and an effective tool to quantify the risk. A safety audit procedure needs to be developed for this research. The audit should show whether work zones are following current standards, and if new technologies or procedures are used to address traffic concerns. Type of signs, delineators, and condition of such should be considered. The kind of safety measures, technological advances, and the driver reaction should be observed during the audit process. The audit can also be used to determine driver reaction to the traffic controls and to the set up of the work zone overall.

After the audits are conducted for different work zones risk factors can be used to quantify the total risk that work zones present. After the total risk has been calculated, improvements can be made to the sections of the work zone that have the most risk. Risk mitigation factors can be used to measure the impact of improvements on the work zone, and how much risk is reduced. There are risk reduction factors for road improvements and signals, but there are no risk factors or risk reduction factors specific to work zones. To come up with risk factors, crash data can be analyzed, and reduction factors can be estimated.

Simulation software can make such evaluations quick and simple. This software should take into account the crash risk, the condition of work zone devices, give accurate
results when it comes to total risk and total risk reduction due to improvements. Such simulation software for work zones is not available right now.

### 1.4 Research Approach

Developing a software tool that can effectively and accurately quantify risk and risk reduction requires an extensive literature review. There is research that measures the amount of influence that different safety countermeasures have on drivers. This can provide a more accurate assessment when coming up with risk factors for different improvements. Also, reviewing past research can assist in developing a safety audit procedure. Factors of main concern when researching work zones can be useful when determining what to take into account when developing a safety audit.

The safety audit will require four phases: pre-audit, site selection, field audit, and analysis of findings. The pre-audit of project being performed helps develop a criterion that is based on AADT, location, and type of work zone. It is important to audit work zones in different regions of the states, so that regional differences between projects can be recognized. Also, duration of the project must be taken into account because driver behavior may change by the amount of time that drivers have been exposed to the work zone.

Once the work zones are selected, a field audit is performed by a team of three student engineers. The field audit will be composed of the following elements:

1. Careful documentation of signs used
2. Delineator used
3. Overall set up
4. Driver Response to set up
5. Amount of time to drive through the work zone

Driver response to the work zone is filmed by a camera that is set up at locations in the work zone where drivers have to make adjusting maneuvers. Surveying equipment will be used when possible to measure the distance between signs, barrels and the length of tapers in the work zone. Construction activities are observed to see if worker behavior and construction practices are of safety concern. Driving through of the work zone can provide the time to get to the end of the work zone, document the experience of traveling a work zone, and show if the set up of the work zone is confusing to motorists.

The analysis of work zones comprises of individually assessing the condition and set up of the work zones. The film of the drive through and driver conditions will be reviewed. Pictures and measurements will be documented. A write up of each work zone will be made, and after the write ups are completed the findings can be compared to part 6 of the 2009 MUTCD. Out of the comparisons signs and devices can be placed in the following categories: High, medium, or low. Comparisons can also show generalities about problems and good practices in work zones.

After the comparisons and categories are made, a risk assessment can be made about each work zone. The risks associated with poor conditions can be plotted, and a measurement of impact of improvements can be estimated. Crash data obtained from the Utah Department of Transportation can be analyzed to locate sections of concern for work zones in Utah. These results can be programmed in an excel spreadsheet to make the analysis of each work zone quicker.
1.5 Anticipated Contributions

This research will provide a standard method of evaluation of work zones. The observations gathered in the field can be given to the local Department of Transportation, for further evaluation. Also the review of current technologies and other state policies can be given for further consideration to the DOT. The risk results can be used to create a spreadsheet that can estimate the risk associated with the work zone.

1.6 Thesis Organization

The research conducted from May 2010 till August 2010 is presented in this thesis paper. Chapters three and four show the results of the audits and the analysis performed. The remaining chapters are organized as follows.

Chapter 2 – Literature Review

Chapter 3 – Data Collection and findings

Chapter 4 – Risk Analysis

Chapter 5 – Conclusions
CHAPTER 2
LITERATURE REVIEW

2.1 Differences Between the 2009 and 2003 MUTCD

This section will outline the differences between the 2009 and 2003 Manual of Uniform Traffic Control Devices (MUTCD). Also, an introduction to standards of work zone set up is introduced in this section. The MUTCD is a lawful document that provides the minimum requirements for work zones. Contractors and Departments of Transportation are encouraged to practice countermeasures beyond the minimum requirement, however if minimum requirements provided are not met, penalties and sanctions may apply.

In summary, the 2009 MUTCD emphasizes the safety of pedestrians and workers in the work zone. New guidelines are also given for use of new technology, worker apparel, signage, flagger procedures, and incident management (FHWA 2009). The following sub-sections present in greater detail these changes. Appendix A contains a paragraph by paragraph comparison between the 2003 and 2009 MUTCD.

2.1.1 Taper Length

In order to determine the length of tapers for certain work zones, the MUTCD provides a set of formulas to calculate the total length. According to these formulas, the length of taper depends on the posted speed limit of the roadway. Regardless of speed however, the 2009 MUTCD specifies that tapers should have a minimum of 50 to 100 feet. This same guideline applies to downstream tapers. Figure 2.1 show the formulas provided in the MUTCD, and the taper length criteria.
2.1.2 Personnel Safety

The 2009 MUTCD expands the requirement of high-visibility safety apparel. The requirement of wearing high visibility apparel applies to workers as well as emergency responders, on-scene responders and news media. Firefighters and Law enforcement are exempt of this rule under certain conditions. Also workers within public right-of-way of all federal-aid and non-federal-aid streets should wear high-visibility safety apparel. The FWHA established a target compliance date of Dec. 31, 2011 for flagger apparel on non-federal-aid highways (FHWA 2009).

2.1.3 Automated Flagger Assistance Device (AFAD)

Automated Flagger Assistance Devices were added in section 6E of the 2009 MUTCD. The two types of AFAD’s mentioned use a STOP/SLOW sign, or a RED/YELLOW sign that control the right of way. AFAD’s shall meet crashworthy criteria, shall only be used in situations where there is only one lane of traffic, and shall not be used as a replacement for traffic control signals. The devices shall also be operated by a trained flagger, and they must have a retroreflectorized lever arm. Figure 2.2 show the set up for these devices in the work zones.

2.1.4 Flagger Procedures

The 2009 MUTCD specifies that flaggers should only use a STOP/SLOW paddle, a flag or an AFAD to control traffic. The use of hand signals is for law enforcement or emergency responders only. Also, the STOP/SLOW paddle is the preferred method, and the use of flags should be limited to emergency situations. The option is given that if the
work zone is short enough to provide drivers with adequate sight distance, and located in a low volume street, then traffic may be self-regulated.

Figure 2.1 Taper length formula and length criteria provided in the MUTCD.

Figure 2.2 Type 1 and Type 2 AFAD diagrams.
2.1.5 Signs

Signs were added and deleted from section 6F of the MUTCD in order to emphasize regulations and to decrease driver confusion. The symbolic version of CENTER LANE CLOSED AHEAD (W9-3a) was removed because its meaning was not very clear to motorists. Also a FINES DOUBLE (R2-6aP) and WORK ZONE (G20-5aP) plaque were added. These plaques are to be used with the speed limit sign in order to emphasize a reduction of speed when driving through the work zone. A 2001 study in the state of Utah observed the dancing diamond display versus flashing box display, and other flashing displays. The effectiveness was measured by speed reduction caused by the sign, lane migration, and conflict. Also a driver survey was taken to get the driver’s perception. The field study was done for 2 months, in highways like I-15, I-215, US 6, I-80, US 89, US 189, and SR 92. The work zones were monitored by cameras and speed was reduction was measured. The results yielded that the dancing diamond display caused a more statistical significant reduction in speed, 2 mph, than the other displays. The study also showed that the effects of the dancing diamonds display was lessened as the weeks went by. No significant statistical analysis was found for conflict and merging movements. The driver survey showed that drivers favor the dancing diamond display over the flashing box (Turley et al. 2002). As a result of this and other research, the Alternating Diamond mode was added.

2.1.6 Temporary Channelizing Devices

New guidelines in section 6F were added concerning channelizing devices and temporary pavement markings in work zones. Longitudinal Channelizing Devices, Temporary Lane Separators can be used for cones, drums and barricades. They can also
serve as a pedestrian traffic control device. Temporary Raised Islands should provide a 60-inch pathway for a crossing pedestrian, should only be 4-inches high, and 12-inches wide.

2.1.7 Typical Application Drawings

Changes and recommendations were made to typical application drawings in the 2009 MUTCD. The purpose of these changes is to avoid confusing the driver when approaching the work zone. The changes are:

1. TA 4: Stationary signs may be omitted for mobile work if the work vehicle displays high-intensity strobe lights
2. TA 7: ROAD CLOSED sign eliminated
3. TA 16: Lanes should be at least 10 feet wide
4. TA 41: If an exit is closed, channelizing devices should be placed to physically close the ramp
5. Typical Applications about freeway lane closures (TA 37, 38, 39, 42, and 44) have requirement that arrow panels should be used for all lane closures. A separate arrow board shall be used for each lane closed (FHWA 2009).

2.1.8 Section 6I

Section 6I was added to provide more information about how to control traffic through incident management areas. All on-scene responders, including news media, should wear high visibility apparel. Light sticks may be used in place of flares, and may even be used to supplement channelizing devices once they are installed. Also, an Incident Command System (ICS) is required by the National Incident Command System
(NIMS) to be used at incident sites. Also when an incident is present pink signs with a black border may be used for temporary guidance to the drivers. Figure 2.3 shows the signs that may be used.

2.1.9 Summary

The 2009 MUTCD shows concern for the driver, pedestrian, and worker present at a work zone. The installation of AFAD’s and alternating diamond provisions demonstrate that the MUTCD encourages the use of new technologies to be employed in work zones. The provisions for signs, changes of Typical Application drawings, and Temporary Channelizing device provisions portray a concern to not confuse drivers by clearly informing the driver with what they need to know. The provisions for incident management show that there should be an effort to get traffic through the incident zone as fast as possible, while keeping personnel safe. Overall changes to the standards show that work zone safety is an ongoing process.

2.2 Past Research

Much research has been done concerning the safety of work zones. Many countermeasures have been researched, from regulation to application of different technologies. States around the country are attempting to improve traffic and safety conditions at work zones. States, such as California, have added amendments and change the minimum requirements of the MUTCD to better suit the needs of the state. Illinois started a hire back program, which hires off duty police officers to monitor speeds and issue citations at work sites. Virginia adopted strategies to reduce motorist exposure to
work zones. The Pennsylvania Department of Transportation (PennDOT) developed a static late merge method, which reduces queue length upstream. For large projects, New Mexico and Minnesota chose to implement Intelligent Transportation Systems (ITS) in order to keep drivers informed of traffic conditions and incidents. A thorough knowledge of the results obtained from the research can help in making a more accurate risk factor for the tool developed through this research. In addition, knowledge of such countermeasures and policies can assist in the creativity of possible solutions to problems found during the field audit.

2.2.1 Variable Message Signs

Variable Message Signs (VMS), or Changeable Message Signs (CMS), can be used to reduce the speed of traffic or divert drivers from the work zone in peak conditions. The influence of CMS was studied in Virginia, along with the effectiveness of exposure over time. Data was collected from sites that were 1500 feet long or more, free flow traffic was at least 30 percent of the total traffic, a high percentage of drivers was repeat drivers, and safety conditions are met. Instrumentation for data collection was tubes that recorded...
vehicle speeds and volumes and were located at the beginning of the work zone, within the work zone, and just before the end of the work zone. Overall, observations were made and data was collected for the duration of 7 weeks. The results showed that the CMS is a very effective method of reducing speed, even for prolonged periods of time. Also, CMS reduced the variance of speed variance, and there was no evidence that the CMS is more or less effective for drivers in different types of vehicles (Garber and Srinivasan 1998). Researchers at the University of Purdue conducted a survey to measure the importance and impact of the messages displayed on VMS signs. The survey asked survey takers about their socioeconomic characteristics, attitudes towards traffic information displayed through VMS, and diversion intentions under generic descriptions of VMS. The responses to the last part were recorded in a Likert scale (1-5) where 1 is low willingness to divert, and 5 meant high willingness to divert. There were a total of 248 respondents, 116 truck drivers and 132 non-truck drivers. The study showed a strong correlation between message type and driver response, meaning the message content is an important control variable for improving system performance (Peeta et al. 1999).

Variable Message signs can also be used to give information to the driver. The information transmitted can be used to present the driver with an alternative route if conditions at the work zone become too congested. The effectiveness of this method was tested in Milwaukee. The work zone was 12 miles long, located in a rural area in Milwaukee-Racine county line. The speed limit was reduced to 55 miles an hour, and the expected delays were 32 minutes. The purpose of the signs was to provide drivers with information of traffic conditions and possible diverting routes. This could make drivers
aware of possible alternate routes. The system used five microwave detectors and four signs. Overall, not many drivers diverted to a different route, unless the message signs displayed a high delay time (Horowitz et al. 2003).

2.2.2 Work Zone Configuration, Duration

How long road construction is performed at a site can have an effect on safety. Certain studies suggest that if drivers are exposed to a work zone for a long period of time, the higher the frequency of crashes (Khattak et al. 1999). The State of Maryland performed a study focused on optimizing resurfacing projects on two lane highways by presenting models that optimize work plans, including zone lengths, work durations, starting times, pausing times, control cycle times, alternative selection and diverted fractions. The four alternatives proposed are traffic flow both directions alternate on one lane (alt. 1), all traffic in one direction is directed to an alternative route (alt. 3) while the other lane is used as usual, a combination of alternative 1 and 3 (alt. 2), and both lanes are closed for resurfacing and divert the traffic onto an alternative route (alt.4). The values used in the models were obtained from the Maryland State Highway Administration. The models showed that full diversion (alt. 3) is preferable when specifying uniform alternatives along a road. Full-diversion (alt. 4) can be used when considering a speed-up in re-surfacing time per kilometer. If using mixed alternatives along a road, partial or no diversion is best during the day, and full diversion is best during the night because vehicles will have to spend less time in the alternate road during the night than the day (Chen and Schonfeld 2003).

Another study in Iowa supports the notion that full diversion or decreasing exposure to the work zone is a very effective way to increase safety. Due to the increase in traffic
levels on I-80 in Iowa, this study developed a method to evaluate the cost-effectiveness of alternative work zone traffic management plans, and determine the effectiveness of past work zone methodology. A case study was made out of a work zone that was 10.9 miles long, the speed was reduced from 65 mph to 55 mph, and changed the highway operation into a two way, two lane highways. The duration of the work zone was 4 months, CMS signs and highway advisory radios were used at the site. Four alternative traffic plans were created and modeled for this work zone. The software used for modeling was Traffic Software Integrated System 4.2 and the alternatives that were modeled are do nothing, non-stop work, four traffic lanes through the work zone, diversion route. This research found that non-stop work, where the contractor is required to work 24 hours a day, 7 days a week, had the best benefit to cost ratio. This is due in part because the duration of the project was decreased by an estimated 56 days, and when compared to the do-nothing alternative it decreased the delay by 86 percent. Also, diversion routes modeled presented a good benefit to cost ratio, drawing the conclusion that there are cost-efficient measures to reduce rural highway work zone delay. This research also showed that simulation is an effective tool when evaluating work zone traffic management plans (Schrock and Maze 2000)

2.2.3 Speed Regulation Concerns

Speed patterns are of major concern in work zones. Regulation and enforcement of speed limits in work zones is not very feasible in some instances because shoulders may be unavailable through the activity area. Driving through a work zone requires the driver to pay special attention to their surroundings while having full control of their vehicle.
Since presence of enforcement is difficult, drivers tend to drive fast putting themselves and personnel in danger.

A study at Michigan State University measured the compliance of drivers to different posted driving speeds in work zones and the impact of conditions. Data was collected from sites that fulfilled the following criteria: limited access, overpass where data collection equipment could be placed, low traffic volumes, signs and markings had to meet MUTCD requirements. The Autoscope system was used to gather data. This system videotapes traffic for duration of two hours, a “test” vehicle is driven through the site in order to calibrate speed measurements, and speed data on all lanes, as well as site information, is gathered. Thirty five sites were selected and analyzed. The data analyzed found motorist are responsive to reduced speed limits but only reduce their speed to a fraction (55-75%) of the reduction requested, work presence does not influence traffic speed, speeds are higher when concrete barriers are used instead of barrels. The study also found a high correlation between speed reduction and number of lanes open. The more lanes open, the less reduction in speed (Sisiopiku et al. 1999).

Reduction of lane width on a work zone was researched as an alternative to reducing traffic speed. In the study data was collected from eleven work zones on an interstate road in Illinois. Three of the work zones were short term zones that used cones and barrels, and the remaining zones were long-term which used concrete barriers to guide traffic. The four main categories of data that was collected are general, geometric, traffic and work activity. The study found that lack of shoulder on either side would reduce the speed by 5.6 mph in a work zone with one lane open. The narrower the lanes, the greater the speed reduction, and heavy vehicles are more adversely affected by narrower lanes.
than passenger vehicles. The recommended speed reduction are 10, 7, 4.4, and 2.1 mph for lane widths of 10, 10.5, 11, and 11.5 respectively (Chitturi and Benekohal 2005).

The MUTCD set guidelines for rumble strips as a traffic control device. Orange removable strips offer an alternative to rumble strips that is easier to apply and remove, while improving safety on the roadway. A study evaluates the installation, removal times, as well as effects on vehicle speeds compared to rumble strips. The test site was a rural bridge repair project in Kansas. On this two-lane highway the speed was reduced from 65 mph to 30 mph. Speed data was gathered using pneumatic tubes counters located in 6 different locations along the road. The orange rumble strips was placed between data points 2 and 3, and rumble strips were placed between data points 4 and 5 and 5 and 6. Speeds were measured during two weekdays, only daytime volumes were evaluated because of low volumes during night time, and only records with headway of 5 seconds or greater was considered in order to eliminate the effects of platooning. After installation of the orange strips the reduction of speed for passenger cars was statistically insignificant, while for trucks it was statistically significant at the 99% confidence level, though this change could be attributed to the fact that the construction site was only one mile upstream. The thickness of the strips may not be enough to create an audible warning to the driver, but the color of the strips is sufficient to have an effect. Installation and removal of the strips was relatively easy, and after two weeks the strips showed no noticeable wear (Meyer 2000).

Doubling the fine for speeding could take away motivation from the driver. This policy was adopted in many states, but a study in Texas shows the impact on the work zone double-fine zone is not as influential as hoped. The study was conducted 2 months
prior to the law being implemented and 3 months after it was implemented. Ten different work zones in three different districts were surveyed. The work zones involved two-lane, two-way operations, and the project lengths varied between 3 to 9 miles. Four sites were located on freeways; the remaining six were located in suburban areas. The results of the speed study show that the double-fine law had little effect on traffic speed around work zones (Ullman et al. 1998).

An unmanned radar as a speed control device was tested as a possibility since it is unfeasible to have police presence in some work zones. In a study the effectiveness of this device is measured by compliance to the following criteria: change in mean speed of traffic entering the work zone, change in standard deviation of speed, change in percent of traffic exceeding speed limit, change in 85th percentile speed. The data was collected for trucks and passenger cars separately. Two stations were set up to collect data at the work zone, station 1 was located 3000 feet before traffic enters the radar unit influence zone, and station 2 was located after traffic enters the influence zone. Speed data was measured manually by using time-distance methods. Two markers were placed 250 feet apart, and the distance was divided by the measured time in order to get the space mean speed. Data was collected from 3 different sites on I-81 in Virginia. The results showed reductions in mean speed of .8 mph to 2.3 mph, reduction in standard deviation of speed of .1 mph to .5 mph, 6% to 20% less of traffic exceed the speed limit, and reductions in 85th varied between 1.1 mph to 3.9 mph. Short term work zones, and sites where police presence is not common experienced a greater impact in speed patterns (Turochy and Sivanandan 1998).
The effect of police presence in work zones was studied in Michigan. The site selected was I-96 in Michigan, a highway that has two lanes in each direction, between the 54 and 82 mileposts. The data was collected by using the seven-vehicle magnetic imaging traffic counters located at the 82, 71, 65, 57, and 54 mile counter. Two counters were place in post 82, and 57 in order to measure the speeds at the slow and fast lane. Two police patrol cars circulated between the milepost of 51 and 80 for duration of 6 days, over selected periods of time. The study shows that as drivers approach the patrol cars their speed is reduced by 4.97 mph and as they drive away their increases up to 2.98 mph. The halo effect indicated that there was no visible change in behavior for up to 3 hours after the police left the site; therefore the halo effect is negligible (Sisiopiku and Patel 1999).

Speed trailers and advisory signs can be an effective tool in slowing down traffic that is approaching the work zone. An evaluation of the use of speed trailers in rural high-speed temporary work zones. The conditions that were evaluated were normal traffic control, speed trailer and speed advisory sign, and a radar drone with a speed advisory sign conducted by researchers. The study only considered only daytime work, meaning short-term stationary (1-12 hours) or short duration (up to 1 hour) work zones. Data was collected for three days and each day had a before and after period. The first 2 days a speed trailer was placed and on the third day a radar drone was placed at the site. The approach was based on obtaining speed profiles of vehicles as they approached and went thru the reference points at the work zone. The day to day reductions were compared in order to assess the effectiveness, and the percent of speeders show the devices’ ability to impact the fastest vehicles. The vehicles observed were divided into two groups:
passenger vehicles, and trucks. The study found that speed trailers are more effective in reducing speeds than drone radars by 2-3 miles (Carlson et al. 2000).

Speeds are always higher in rural locations. A study intended to evaluate innovative countermeasures and their impact on safety for short term rural work zones showed mixed results. The four devices under study were speed display trailers, radar drones, portable rumble strips, and fluorescent yellow-green worker vests. Field testing was done in 15 different sites; the length of the sites is between ¼ to ½ mile. Device effectiveness was measured by traffic speed, conflicts, worker comments and driver comments. Speed data was gathered using traffic counters and LIDAR, conflict was measured using video data and surveys were conducted for worker and driver satisfaction. The speed trailer was relatively easy to set up and yielded the largest speed reduction out of all devices. Workers found it appropriate for use in short term work zones. The radar yielded slightly lower reduction in speed and workers questioned its long term effects. Portable rumble strips took a long time to set up, yielded small reductions in speed and some drivers swerved around the strips thinking it was debris. The yellow vest proved to be more visible than the orange vests (Fontaine and Carlson 2000).

2.2.4 Use of Technology in Work Zones

Advances in technology can allow work zones to be safer and less confusing to drivers. Intelligent Traffic Systems (ITS) makes work zones safer by improving the mobility through the work zone. An ITS system informs the driver of current traffic conditions at the work zone. This information can encourage drivers to take a detour route, therefore alleviating the conditions in the work zone. In addition, monitoring traffic allows for emergency responders to reach the incident site quicker, and deployment of
temporary traffic controls at the needed time possible. A summary of these technologies is provided in this section.

2.2.4.1 Intelligent Traffic Systems

An Intelligent Traffic System allows traffic conditions to be monitored and recorded in real-time. This information can help determine which traffic control devices would be more efficient at the site and allow for more evolved traffic control devices to be employed. Two temporary traffic control devices using ITS systems are discussed in this section.

2.2.4.1.1 Dynamic Lane Merge (DLM)

The main goals of implementing a DLM system near a work zone are to:

1. Decrease aggressive driving
2. Increase safety
3. Optimize capacity up to the merge point
4. Minimize the loss in capacity caused by increase in headway at work zone taper

The system is composed of a series of trailers located upstream from the work zone. These trailers are equipped with DO NOT PASS flashing signs, communication equipment, and a power source. These components can use solar power, and wireless radio communication. The trailers can also be equipped with sensors that measure the occupancy of the roadway. The DLM calculates an Activity Index that is based on the occupancy, speed, and volume. When certain Activity Index criteria are met the flashing signs will activate warning drivers about the congested roadway (FHWA 2004).
The Michigan Department of Transportation deployed this system when it had to rebuild a section of I-94 in the Clinton Township. Aggressive driving to the point of merge was anticipated by MDOT, the system was used to decrease aggressive driving. Overall, the system used consisted of five trailers upstream from the work zone, 1500 feet apart. The trailers were solar powered and the panels were equipped with a light in the back so law enforcement was aware of when the signs were turned on. Based on observations from this project, MDOT determined that this system is effective on streets where the peak hour volumes ranges from 3000 to 3800 vehicles per hour. It was measured that the system decreased the number of stops from 1.75 to .96, and the travel time of delay was decreased from 95 seconds to 69 seconds per 10000 feet of travel in the morning peak hour. Travel time of delay, and number of stops remained unchanged during the afternoon peak hour (FHWA 2004).

2.2.4.1.2 Real Time Traffic Control System

The system is composed of roadside sensors, CCTV cameras, and dynamic message signs (DMS) all of which are hooked up to a central base station server wirelessly. The main goal of this system is to enhance safety by providing travelers with information about current traffic conditions in the work zone. The information is displayed to the drivers via DMS signs and/or through the internet. The system can provide actual live video feed to internet users while the images can also be archived for further study. Road sided sensors can also measure the speed of traffic approaching and within the work zone. By providing motorists with information about current conditions and providing them with alternative routes, traffic may be alleviated at the work zone. In addition, this
system makes it possible for incident management response teams to arrive quicker (FHWA 2002).

Illinois, Michigan, and Arkansas used this system. Illinois reported that no significant backups occurred during the implementation of the system, even though it was placed on a busy interstate. Michigan reported that the ITS system deployed in the I-496 project allowed them to better manage traffic, and better identify the location of an incident. In Arkansas, the ITS system enabled drivers to make better decisions for alternate routes, improved incident management response, and allowed AHDT to improve project scheduling (FHWA 2002).

An ITS real-time information given to motorists, helps them make better decisions; whether the decision is slowing down or taking an alternate route. Interlinked technology makes it easier to get better information to motorists and is the direction work zone configurations throughout the nation are headed. An ITS system is ideal for larger projects. Temporary traffic control in an ITS such as a Dynamic Lane Merge system and Real-time Traffic Control system decrease aggressive driving, optimize capacity, and increase safety. Using an Activity Index based on the occupancy, speed, and volume a DLM warns drivers of congestion. Warning drivers of congestion helps them to expect delays or take an alternate route. Providing motorists with the speed of traffic ahead with a Real Time Traffic Control system cautions them to slow down when conditions ahead require.

2.2.4.2 Results of Smart Work Zone

The effectiveness of an Automated Work zone Information System (AWIS) was measured by taking into account traffic diversion, safety effects caused by the AWIS and
also driver response by way of survey. The AWIS system included an Automated Data Acquisition and Processing of traffic Information in Real-time (ADAPTIR), Computerized Highway Information Processing System (CHIPS), Smart Zone, and Traffic Information & Prediction System (TIPS). The CHIPS system under study was composed of Portable Changeable Message Signs, Remote Traffic Microwave Sensors and CCTV cameras. The construction site where the evaluation took place is located in I-5 in California. The work was about 1.3 miles long; one lane was closed in each direction. Data was collected for five days during May of 2003, and data was also collected during holiday weekends throughout the summer. The study showed that the PCM were noticed by drivers, the driving environment was safer after CHIPS was deployed, and driver survey showed a positive reaction from drivers to the system (Chu et al. 2005b).

An AWIS system in the field is not very cost effective. But research using a micro-simulation program to evaluate the delay reduction to measure how much reduction in delay the system caused showed that the system can congestion considerably. Traffic data was collected from the field in order to create “before” and “after” deployment scenarios. After the model was calibrated, the results yielded an average reduction of 46.2%, a total of 40.2% reduction on the mainline. The travel time was reduced by a 38.1% (Chu et al. 2005a).

Analysis of the implementation of a work zone ITS system for rehabilitation project on I-95 in North Carolina helps to examine the potential benefits of employing such system. The estimated benefits are decreased user delay, reduction of emissions, and reduction in fatalities and crashes. In order to determine the benefits, from a traffic flow
standpoint, QuickZone software was used. From QuickZone, the delay is calculated, and from the delay the impact of emissions can be estimated. This requires the assumption that all delay is spent idling, therefore increasing emissions. Safety is assumed to be a result of a reduction in congestion periods and having a more constant traffic flow. In order to make a benefit cost analysis delay was given a value of $4 per hour per car, emissions $.90 per hour, injury crash was $59719, and life as $3 million. The results show improvement of more than 50 percent for max queue length, max user delay, and total user delay for this particular project. The analysis shows significant improvements in delay, and when making a benefit cost analysis, yielded a benefit/cost ratio of 18 to 36 (Bushman and Berthelot 2004).

In summary it was found that early deployments of ITS systems had many technological problems. Also, many of these were deployed in sites where their application was not needed. A WZITS should be used when there recurrent and high congestion is foreseen by the project owner. Also, the cost of implementing a WZITS is justified for long term projects, but not short term projects. Speed advisory messages are more effective under congested conditions. Portable signs should be placed where conditions are more congested; researchers suggest where density is above 40 vpm (Fontaine 2002).

2.3 Other State Practices

2.3.1 Virginia

This section outlines Virginia’s strategy to minimize motorist exposure to construction activities. Virginia’s control measures include using state police control in
work zones. This section discusses the policy on using state troopers in work zones (Virginia’s Surface Transportation Safety Executive Committee 2006-2010).

This information came from Virginia’s compliance of FHWA Final Rule Subpart K. Virginia has come up with seven strategies, which are listed at the end of this section, to improve work zones (VDOT 2008).

2.3.1.1 Section 1

The following is Virginia’s compliance with FHWA Final Rule Subpart K. Section one is use of exposure control measures to minimize exposure. VDOT has a Transportation Management Plan process to reduce motorist and worker exposure to construction activities (VDOT 2008). The strategies include:

1. Full road closures
2. Ramp closures
3. Median crossovers
4. Full or partial detours or diversions
5. Lane shifts
6. Protection of work zone setup and removal operations using rolling road blocks
7. Performing work at night or during off-peak periods when traffic volumes are lower
8. Accelerated construction techniques

Another strategy is to limit lane closures to non-peak periods where lane closures produce minimum traffic queues. They have designed a checklist (see appendix B) to provide a safe and workable plan for controlling traffic through the work zone consistent
with construction requirements (VDOT 2008). A thorough analysis of all variables involved is required to set the appropriate level of safety for the general public as well as construction workers. The Project manager should review the checklist to ensure that all work zone elements have been captured during the design phase. VDOT requires higher standards of TTC than the MUTCD to minimize crashes (VDOT 2008). These standards include:

1. The use of larger warning signs
2. Additional warning sign messages
3. Brighter sign sheeting
4. Portable Changeable Message Signs
5. Type C arrow panels
6. 36” cones on all roadways
7. 6” stripes on drums
8. 1000’ long tapers on limited access highway lane closures
9. Channelizing device spacing reduction
10. Use of drums in unmanned work zones
11. High quality work zone pavement markings and removal of misleading markings
12. Longitudinal channelizing barricades
13. Trained flaggers and traffic spotters
14. Use of Truck Mounted Attenuators
15. Work zone speed management (including changes to the regulatory speed and/or variable speed limits)
16. Law enforcement
17. Worker and work vehicle/equipment visibility

18. Worker training

19. Public information and traveler information

20. Temporary traffic signals and Automatic Flagger Assistance Devices

For safety of entry/exit for work vehicles and equipment onto/from travel lanes, warning lights and a warning sign that says: WORK VEHICLE, DO NOT FOLLOW are required on construction vehicles (VDOT 2008).

2.3.1.2 Section 2

Section 2 of Virginia’s compliance with FHWA Final Rule Subpart K is a policy on using uniformed policemen on federal-aid projects. VDOT has agreement with State Police to patrol construction projects (VDOT 2008). Factors considered when scheduling state troopers are:

1. Night work that creates safety risks

2. Work that requires slow down or stoppage

3. High speed roadways where queuing is expected

4. TTC setup or removal that has potential risks

5. Workers are adjacent to high speed traffic with no positive protection

6. Where traffic presents a high risk that can be reduced by improving road users behavior

Police policy and direction is as follows: Form CD-95-6 (see Appendix B) states that since 1987 upon the request of District Administrator the state police will patrol work zones to increase safety. The need for police is determined at the field inspection stage of design. Local police can be used in similar patrols. State troopers are to be highly visible
in a marked car and uniform. Police will direct traffic in emergencies, but not flag traffic. Troopers report correctable situations to appropriate VDOT personnel. There is no direct contact between contractors and the troopers. A VDOT representative makes all contacts with state police throughout construction. Enforcement must be only used at times it is needed. The decision to request Police is based on engineering judgment, traffic volumes, speeds, work zone geometrics, and other factors based on the District personnel’s knowledge of the area (VDOT 2008).

A final decision is made at the Pre-Advertisement meeting. The District Administrator will give all information to the State Police Sergeant. Final arrangements are made with the State Police following the Pre-Construction meeting based on the contractor’s approved method of operation. In the 2005 Virginia Work Area Protection manual there are guidelines listed (see Appendix B). Prior to requesting a state trooper, VDOT and the Contractor get together to discuss when and where the trooper will give the best benefit (VDOT 2008). Suggestions are that with no back up the trooper should be located 500-1000 ft in advance of the first work crew and with back up the trooper should be located in advance of back up trooper to slow traffic and increase attention. A mobile lane closure trooper should locate 500-800 ft on the shoulder in advance of the lane closure. VDOT contacts state police to discuss that day’s operations and give the trooper contact information for communication. The police vehicle should operate with lights flashing. To retain credibility trooper may travel out of work zone to stop speeding motorists. Periodically stopping vehicles shows that the trooper is not for show but enforcement. After the shift is done the trooper should meet with the project inspector to sign appropriate log and if the trooper leaves the work zone for an emergency then
VDOT is notified. These are only guidelines and deviations that should be conferred by VDOT and state troopers (VDOT 2008).

2.3.1.2 Virginia’s Major Strategies

VDOT’s list of major strategies for improving work zone safety from their website follows (Virginia’s Surface Transportation Safety Executive Committee 2006-2010):

1. Improve work zone design with better data and detailed plans. Consider traffic flow and safety early in design phase of projects.

2. Develop mandatory work zone safety training for work zone designers, installers, and inspectors. Trained personnel will ensure compliance in work zones.

3. Provide road users with real-time work zone information through Smart Travel technology. Up-to-date delays provide warning so drivers can use another route reducing congestion.

4. Provide advance notification of work zones on the 511 system.

5. Investigate using brighter traffic control devices in work zones to improve visibility. Include brighter sheeting for plastic drums, use of all-weather continuous pavement markings, and improved sign sheeting for long-term post-mounted signing.

6. Deploy speed display trailers in construction projects and coordinate increased enforcement with the Virginia State Police to reduce excessive speeds and tailgating.

7. Increase public awareness of how to safely navigate work zones through: National Work Zone Awareness Week, VTCA/VDOT Work Zone High School Driver Education Awareness, public information plans for all significant projects on the national highway system, and funding for driver awareness campaigns.
Virginia has implemented different strategies and policies to help designers make work zones safer. Having strategies in place is a good starting point in designing work zones. Minimizing the exposure that motorists have with construction areas by full closures makes it safer for motorist and construction workers. By reducing the time of construction and the time motorist spend in a construction area, the number of incidents decrease. The purpose of having a list of strategies is to keep track of measures taken when designing a work zone improving the overall safety. Having a policy on using uniformed policemen on federal-aid projects helps place policemen in work zones causing motorist to use more caution. Having an agreement using federal aid to pay for state troopers is one way to get law enforcement to patrol work zones.

2.3.2 Illinois

This section discusses Illinois’s photo speed and “hire back” program. Illinois has a hire back program to hire off duty troopers to monitor traffic through work zones. This program is used to reduce speeding and raises fines in work zones (IDOT 2008). In certain work zones, Illinois enforces speeding with photo speed vans that take a picture of the driver and the license plate of speeding vehicle. This method requires warning signs to be posted to let drivers know that this kind of enforcement is being used (Tobias and Priscilla 2006).

2.3.2.1 Illinois - Hire Back

Law enforcement in Illinois has increased fines for speeding in work zones. The offense results in a minimum $375 fine and mandatory court appearance; $125 dollars of the $375 fine is deposited in the Transportation Safety Highway Hire-back Fund (IDOT
A second offense within 2 years of the first offense results in a minimum $1000 fine and 90-day license suspension. $250 of the $1000 fine is deposited into the Hire-back Fund (IDOT, 2008). Advance warning signs are required to warn drivers that the $375 minimum fine is in effect. Figure 2.4 is an example of a warning sign. Work zone fines depend on the presence of work zone speed limit signs and not construction workers. If a driver hits a worker they are subject to a $10000 fine and 14 years in prison (IDOT 2008). The Hire-back Program is administered through the Central Bureau of Operations and funded by the Transportation Safety Highway Hire-back Fund.

On interstate highways, speed limits are dropped to 55 mph or less based upon engineering study for safer traffic operations. Law enforcement can patrol work zones as normal duties or through the Hire-back Program and the Annual Highway Program. This helps put more than one trooper working enforcement details per work zone. Illinois also

Figure 2.4 Work zone fine signs.
has the “Trooper in a Truck” program where an out of uniform trooper in an IDOT truck covertly enforces the speed limits (IDOT 2008). Figure 2.5 is an example of “trooper in a truck.”

Implementation of the program is a distribution of work-hours allotted to each IDOT district based upon the number of projects and hire-back hours available. Each IDOT district then makes schedules were one to five work zones are patrolled by officers during their duty shift to increase their effect. Each fiscal year the Bureau of Operations collects the work hours from each IDOT district. Additional work-hours can be requested (IDOT 2008).

2.3.2.2 Illinois - Photo Speed Enforcement

IDOT, Illinois State Police, and the Illinois Tollway partnered in the first state-level Work Zone Photo Speed Enforcement Program. Photo speed enforcement vans are deployed in work zones when workers are present so motorists will comply with posted

![Figure 2.5 Trooper in a truck.](image)
speed limits and enhance safety. Photo speed enforcement operates only when workers are present in the work zone. Troopers specially trained in photo radar enforcement man and calibrate the equipment prior to each enforcement detail (Tobias and Priscilla 2006). Signs indicating that speeds are photo enforced by automated traffic control systems are posted in the area. Also, a speed indicator device triggered by separate radar gives motorists one last opportunity to slow down before the camera radar is triggered. If the motorist does not slow down and goes 1 mph over the speed limit a photo of the driver, vehicle, and license plate is taken with the time of day and speed (Tobias and Priscilla 2006). Tickets are approved by the on-duty officer and mailed to the registered owner within 14 days. Violators are required to appear in court. IDOT allocates hours based upon van availability and work zones that are conducive to deployment of the vans. Illinois State Police schedule and execute deployments of the vans at planned locations. The same speeding fines apply to photo speed enforcement as any other work zone violation (Tobias and Priscilla 2006). Figures 2.6 and 2.7 are of Vans and Signs Illinois uses for photo speed enforcement.

Annual Highway Program Funding for enforcement on specific projects is used for work zone law enforcement that is planned in advance. These projects patrol one specific project at time determined by the districts. Unique contracts are required for enforcement through annual highway program funding.
Figure 2.6 Photo speed enforcement vans.

Figure 2.7 Photo speed enforcement signs.
The Illinois State Police are paid in full prior to assignment of officers. This allows project planners and designers to designate enforcement during the design stage. Projects that should consider use of planned enforcement include:

1. Complex work zones with high speeds or high traffic volumes
2. Those that can benefit from an extended presence of enforcement
3. Those that can use an excessive amount of hire-back funds

Designers indicate the need for presence of law enforcement as part of the Transportation Management Plan. Designers coordinate to include this cost as an additional project expense in the highway program instead of using annual allocation of hire-back hours, if it is warranted. The Illinois State Police Academy curriculum is continually updated to coincide with the MUTCD and IDOT work zone policies on traffic direction, incident management, and traffic control devices (IDOT 2008).

Illinois changed their regulations for law enforcement in work zones. They changed legislation to increase the fines for speeding in work zones to help pay for law enforcement regulating safety concerned projects. Using funds from higher tickets fines and money from highly funded projects are both possible options for increasing law enforcement in work zones. In some areas it easier to employ a photo speed enforcement van to monitor traffic. Photo speed enforcement has a speed display sign placed upstream from the van cautioning drivers that a photo speed enforcement van is in place. With extra enforcement, either a trooper or a photo van, and higher fines drivers are more likely to slow down and be cautious because speeding is not worth the risk of getting fined.
2.3.3 Pennsylvania

The late merge method was developed in Pennsylvania as a way to use storage space more effectively. Drivers are told to use both lanes up to the merge point. Once the merge point is reached, they are told to take turns when merging. Making drivers use all available lanes up to the merge point can shorten queue lengths upstream from the work zone, reduce travel times, increase throughput, and reduce aggressive driving (Beacher et al. 2005). Figure 2.8 shows the usual set up for a static late merge lane method used by the Pennsylvania Department of Transportation.

The operational effects were under examination on I-79 in Pennsylvania. The work zone under study had a closure on the left lane, leaving only two lanes open on I-79. The data was collected for four days during periods of high flow. The data was gathered by using two video cameras, laser guns for speed collection, and traffic flow along with lane

![Figure 2.8 PennDOT Late Merge Method.](image)
distribution was done by manual counting. The study showed that the concept of the late merge is not as efficient as could be expected because of reluctance of drivers to follow directions as well as unfamiliarity of drivers with the concept. Truck drivers presented most problems because they would merge onto the open lane early on and slow traffic (Pesti et al. 1999).

A driver survey was conducted in Pennsylvania in order to assess driver perception of the late-merge method. The study was conducted at a work zone located on I-79 in Pennsylvania. Drivers that stopped at the rest area were interviewed, with interviewers being present for a period of 16 hours over 4 days. Eighty-eight drivers were interviewed, 58 drove passenger cars, and 30 drove trucks. The survey shows that the concept of the late-merge is not well accepted drivers, especially by truck drivers. The main concerns by truck drivers were driver behavior, meaning drivers were using the closed lane and merging ahead of them, and truck drivers did not think that having a single merge point was a good idea. Car drivers liked the fact that they did not have to worry about changing lanes prior to the merge point (Byrd et al. 1999).

This method has been tested in other states and under different conditions. In Virginia a study focused on roads where one lane was closed on a two lane directional segment. The work sites studied had to be in place for at least 4 weeks, congestion had to occur for some portion of the day, work zone had to remain unchanged during study, and work zone had to have a relatively straight alignment. The manner by which effectiveness was measured is travel time through queue, distribution of traffic across the travel lanes approaching the work zone merge taper, and throughput at the lane closure. Data was only collected when there was congestion. Seven sites were proposed by
VDOT, and the site chosen is located .5 miles from a downtown area. The AADT is 21863 with a percentage of 6.4 heavy vehicles. The result of the study was that for queue lengths of 1800 feet the late merging sign improves travel time, but the improvements are relatively small. No conclusions could be drawn from the crash statistics gathered during the study, and throughput was not improved by a significantly statistical amount. This could be due to shortcomings of the site (signal lights, access points) and low percentage of heavy vehicles (Beacher et al. 2005).

Using simulation, general guidelines were made about when it is profitable to use this method. Simulations were run to compare MUTCD control guidelines and the late merge concept. Scenarios included 2 to 1, 3 to 1, and 3 to 2 lane closures. The main objectives of the study were to determine benefits of method in terms of throughput, expand the understanding of the late merge through more extensive analysis, and provide guidelines for use. Results showed that the late merge did outperform the MUTCD controls in terms of throughput. The 3 to 1 configuration showed the most improvement, while with the other configurations the improvements were of no statistical significance. Also, the simulations showed that when congestion is present the late merge method performed well, but when uncongested situations where driver approach the taper at high speeds can be created. In addition, the simulations gave the result that the late merge method was most effective with a higher percentage of heavy trucks, specially in the 2 to 1, and 3 to 2 scenarios. That is why it is proposed in this paper to use the late merge method under these two scenarios when heavy vehicles represent 20% or more of the total traffic population (Fontaine et al. 2005).
Pennsylvania has developed the late merge method to help motorist merge when coming into work zones. When congested conditions are present this method has shown to help reduce driver aggressiveness and travel time through work zones. Forcing drivers to stay in their lane and taking turns to merge increases capacity and decreases forced merges. Some negatives to the method are truck drivers have a harder time merging and when non-congested conditions are present the late merge method has been shown to slow traffic flow. When used in congested conditions the late merge method can help improve traffic flow and decrease aggressive driving. This method might be worth evaluating further for use in highly congested areas.

2.3.4 North Carolina

The Smart Work Zone system provides drivers with real-time information about traffic conditions and alternate route options in order to improve safety and mobility at work sites. The SWZ system was employed on I-95 were two rehabilitation projects took place in 2003. The street has an AADT 35000 to 40000 and is key to north-south trade. The SWZ system consisted of roadside information signs that divert traffic to alternate routes, while also providing information about conditions on the current road. Trailer mounted sensors where placed at three locations leading up to the work zone in order to monitor traffic on a frequent basis. A survey was emailed to 1468 local residents to measure their acceptance and opinions about the SWZ system, only 22.7% of residents responded to the survey. The questions on the survey covered two main areas: driver characteristics (i.e. frequency of travel, access to the internet, etc.) and perceptions of the system by the drivers. The results were generally positive. Ninety-five percent of respondents supported use of this technology, while more than 65% of respondents said
that the message sign makes them take a different route. More than 93% of users admitted not using the information on the website prior to traveling, but this could be due to lack of awareness about the website. This system also proved to be very useful in case of a crash, and the only drawback is possible congestion on alternate routes (Bushman and Berthelot 2005).

2.3.5 Arkansas

Arkansas began to rebuild 380 miles of roadway in 2000 and it ended in 2005. The project encountered many active work zones, as many as 30 in 2002, with at least one lane of closure per work zone. The purpose of implementing an ITS system was to reduce queue length and the amount of bumper to bumper collisions. The systems used were Automated Data Acquisition and Processing of Traffic Information in Real-time (ADAPTIR) and Computerized Highway Information Processing System (CHIPS). After evaluation it was seen that the smart zone had a positive impact on work zone safety (Tudor et al. 2002).

2.3.6 Minnesota

The Minnesota Department of Transportation used a smart work zone on a project that started in the spring and ended in the fall of 1996. The SWZ system consisted of vehicle detection subsystems, communications subsystems, and driver information subsystems. Vehicle detection is made up of portable node that measure current traffic conditions. That information is passed to a central processor in a traffic control center subsystem. This traffic control center subsystem, which is connected to the Traffic Management Center, provides information to Changing Message Signs, which inform the
driver about current conditions. The deployment of such system required the partnership
tween the public and private sector. This system produced many benefits for drivers,
traffic conditions and the public and private sector (Boyd 2001).

2.3.7 New Mexico

The state of New Mexico performed a 2-year reconstruction project at the intersection of I-25 and I-40. This project required 55 new or improved bridges, reconstruction of ramps and construction of frontage roads. In order to help traffic get through the work zone, an Intelligent Transportation System was deployed on site. The system consisted of eight fixed dynamic message signs, eight CCTV surveillance cameras, two Smart Zone Portable Traffic Management Systems, four full-size portable changeable message signs, and four small portable changeable message signs. A Virtual Traffic Operations Center was created on the work site and controlled by dispatchers at a temporary TOC on site and all information transfers from the cameras to the message displays were done wirelessly (FHWA 2002). Images from the cameras are posted on the internet for drivers who want to be informed before making a trip through the work zone. The ITS system enabled traffic to get through faster and allowed emergency response teams to arrive faster to the site of crash. It was reported that the average response time was 45 minutes, before the deployment of the ITS system. This time was reduced to 25 minutes once the system was implemented. During the first year of construction, crashes were reduced by 32 percent. Overall there was an increase of seven percent when comparing crash data before construction began and during construction, which was less than expected. Because of the quicker response to incidents, secondary crashes were reduced (FHWA 2002).
2.3.8 Summary of Minnesota and New Mexico Experience

Minnesota has used smart work zones consisting of portable nodes, central processor, and Changing Message Signs to increase safety in work zones. New Mexico used an ITS system for a 2-year project to increase safety and mobility of the work zone. Both of these examples show what technology is used in work zones and what benefits come from them. State Departments of Transportation are using new technologies in their work zones more and more improving safety and mobility. In larger projects an ITS or SWZ uses newer technology to decrease congestion by improving the throughput of traffic and giving alternate routes to motorist entering the work zone. They increase response time to incidents that happen in the work zone, decreasing the wait time these incidents cause. Using new technologies in work zones better relates real-time information to motorist and gives stronger caution. The different technologies implemented in a SWZ and ITS system depends on the size of the project but safety and mobility will increase even in smaller projects. When funding is available an SWZ or ITS system should be implemented on a project.
CHAPTER 3
METHODOLOGY

This chapter presents the manner in which the data was collected at the work zones, and how observations were recorded. The process in which data was recorded includes: pre-audit, field audit, and analysis. Pre-audit review consisted of gathering data about all the construction projects on roads under the jurisdiction of the Utah Department of Transportation (UDOT). From the information gathered work site are selected for evaluation. Then the field audit records the road conditions and the driving conditions that are in the work zones, what traffic control devices are used, and the safety measures that are utilized. The analysis involves evaluation and interpretation of field observations.

3.1 Pre-Audit Review

The pre-audit review consisted of gathering general background information on the work zones throughout the state. The information gathered about the project includes location, lane closures, project duration, traffic demand, public outreach, type of traffic control, and type of work. UDOT has provided documents that contained the majority of this information. Concerning the AADT, and the percentage of trucks was provided from the counts performed in 2007. Google Earth was used to examine the geometry of the site. In order to keep track of the information tables in an excel spreadsheet were created. Figure 3.1 is the table that needed to be filled out for each project.
3.2 Site Selection

The criteria for this project include:

1. work zones in streets that had a speed limit of 45 mph or higher
2. operations had to have a significant traffic impact
3. duration of work had to extend through the summer of 2010 or beyond
4. observe work zones in all regions of the state
5. evaluate all type of work zone set up if possible

Eighteen out of 25 work zones were eligible for evaluation.

3.3 Field Audit

The on-site audit allows for observation of the main areas of interest: safety, and mobility. Safety and mobility was evaluated by observing the conditions present while traveling through the work zone, inspecting the temporary traffic control devices, and examining the construction activity area. Driving through the work zone was recorded using a video camera so that the configuration, effectiveness of signs and markings, delays, queue lengths, channelizing devices, speed of traffic and its relation to the posted speed limit, visibility, and driver behavior could later be observed through the driver’s perspective. The audit team also took pictures on-site of the temporary traffic control
devices (TTCD), which include signs, markings and delineations, signals, lighting, cones, and all other channelizing devices. The type and condition of the sign was later analyzed to ensure that they are set to the minimum size, height, placement, and distance required by the 2009 MUTCD.

The safety elements around the work zone were also observed. An evaluation was made of the worker’s area, the worker’s apparel, lateral clearance, temporary barriers, and the safety planning that was established. The entrance and exit of the construction equipment in and out of the activity area was noted as well as the activities being performed by the workers and how they act in accordance with safety regulations.

The audit team was composed of three-team members who were tasked with the following assignments:

1. Observing the configuration of the site
2. Collecting video from the drives through the construction zone
3. Collecting stationary video in order to observe driver maneuvers and behavior as they traverse the work zone
4. Measurement and placement of the temporary traffic controlling devices, as well as accounting for all other safety measures that were installed
5. Observe driver behavior when workers are present, and when workers are absent
6. Note whether workers are shielded from traffic, and how close they are to traffic
7. Check the quality of the signs, cones, vests, etc.

An excel spreadsheet was created to keep track of all observations. Different tables were created for each observation, separate files for each work zone audited. This made the observations more accessible. The following tables were filled out by an audit team.
### Table 3.1 TTCD quality tables

<table>
<thead>
<tr>
<th>Traffic Control Devices</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian Crosswalks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Delineation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Paint or tape</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Raised markers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pavement Markings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Consistency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Delineation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Retroreflectivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channelization Hardware</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Guardrails</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Baricades or barriers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Crash cushions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Drums</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5. Cones</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Jersey barriers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Vertical panels</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>8. Tubular markers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flagger</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Illumination</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Flagging</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Number of flaggers</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4. Flagging attire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Flagging technique</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>6. Visibility</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Table 3.2 Sign audit table

<table>
<thead>
<tr>
<th>Signs</th>
<th>Speed Limit</th>
<th>Lane Closure</th>
<th>YMS</th>
<th>Warning Signs</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>How many</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position(S.A,B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of sign</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spacing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance upstream</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retroreflectivity(L,E,P)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition(L,E,P)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.4 Audit Results

This section contains the results of the pre-audit and field audit discussed in the previous section. This includes the work zones visited, summary of work performed at the site, characteristics of the road, and observations made by the audit team. All work zone set ups were compared to the Typical Application Drawings (TAD) and standards found in the 2009 MUTCD. Other things being observed are the conditions of signs, crashworthiness of sign set up, and pedestrian pathways. Because of time constraints 11 out of the 18 eligible work zones were audited. The eleven audited work zones are:

1. Riverdale Road (S.R. 26)
2. I-15 Bountiful to Farmington
3. I-15 Express link, North Salt Lake
4. S.R. 92
5. Redwood Road at 4700 South, 5400 South, and 6200 South
6. 114th South and I-15, Draper
7. I-15 Core and Pioneer Crossing
8. U.S. 189 Heber to Provo
9. U.S. 89 Piute County
10. S.R. 9 Hurricane
11. I-15 Washington County

The pre-audit and audit performed is presented for each work zone individually. The good practices and the bad practices observed are discussed in general terms of urban and rural work zones.

3.4.1 Riverdale Road (S.R. 26)

The speed limit at Riverdale Road is 40 mph, which does not meet the criteria of 45 mph, but this work zone is an exception because of the work being done, the length of project, and the location of the work zone. Riverdale Road is a two-lane arterial road that gives access to malls, stores and restaurants. The AADT for this road is 47000, with an estimated 11% of that being heavy trucks. The work being performed is curb, gutter, and sidewalk replacement, utility and signal improvements, and adding three lanes of traffic to the road. Modifications to pedestrian facilities are of special interest since an emphasis was placed on the 2009 MUTCD.

The work zone stretched for 3 miles, starting from the junction with I-84 to Washington Blvd. Conditions became congested around noon because if the restaurants
in the area. Workers would cause a hindrance by having equipment placed too close to traffic travel way, but that would only present a temporary problem. On certain intersections drivers would miss the left turn lane delineated by the drums. In response drivers would use the through lane to get to the middle of the intersection and wait till it was their turn. Also, lanes were 10 feet wide through most of the work zone, and the taper for lane closure for vehicles coming off the highway was 367 feet, with 12 vertical panels composing the taper. Overall the work zone was safe to drive through.

The sidewalks were sometimes blocked by signs or other construction equipment. On the parts of the work zone where work was mostly finished, there would be construction underway on both sides of the road, eliminating any pathways for pedestrians. This shows that coordinating construction activities to allow a clear path to pedestrians is a challenge to contractors. Figure 3.3 is an example of how signs blocked the pedestrian pathway.

Most of the problems regarding setup of the work zone were encountered towards the north side of the road. The road was paved over the sidewalk in some parts and pavement markings were overall confusing. In Figure 3.4 there is a driver stopped on the wrong side of the road waiting to make a left turn onto Washington Blvd.
Figure 3.2 Riverdale Road aerial photo.

Figure 3.3 Signs interrupting sidewalk.
Figure 3.4 Driver confused by the poor pavement markings.

3.4.2 I-15 Bountiful to Farmington

This section of highway has a traffic volume of 140000, with 3% of traffic consisting of heavy truck. Since it is the main route taken to get to Lagoon night and weekend work was performed. Figure 3.5 shows the area that is improved.

The highway capacity was reduced from 4 lanes to 2 on both directions. Because of such reduction in capacity there was congestion at the start of the work zone, particularly on the southbound direction. Vehicles were merging to the far left lane as soon as the arrow board was seen. Congestion was lessened further downstream. The taper length for the shoulder was 86 ft, 786 ft. for the lane closures, with 1087 feet between closures for the southbound direction. For northbound traffic the taper for the first lane closure was 552 ft, the taper for the second lane closure was 693 ft., with 1510 ft. between lane closures. The taper was made up of 12 barrels for both directions. The layout of the barrels, arrow board placement, and sign placement are in compliance with TAD-37 in the 2009 MUTCD. Missing was a sign that tells the driver that 2 lanes will be closed. Also workers were a distraction by working close to the road, like in Figure 3.6.
3.4.3 I-15 Express link, North Salt Lake

This project adds express lanes in each direction on I-15, and replaces bridges at U.S. 89, Beck St., and 1000 N. The project is to be completed by fall of 2010. This section of highway has a volume of 128000, with 7% of traffic being heavy trucks. The work zone will maintain 3 lanes open in peak direction, in order to lessen congestion.
In non-peak conditions traversing the work zone only took 5 minutes. Peak conditions were filmed between 5 and 6:30 pm. Congestion was present for the duration of the audit. This was due to quantity of vehicles and not to the work zone or construction activity.

3.4.4 S.R. 92

State Route 92 is a one lane road that commuters in suburban Highland use to connect to I-15 on their way to work and back. Currently the road is not heavily used. The volume count is 20391, 7% of which is trucks. The expansion of the community, however, called for the need to expand the road. This project expands the road to 5 lanes and adds a commuter lane to and from I-15. The project is due to be completed by fall of 2011. Lane restrictions and some road closures are expected for the duration of the project.
The project had pedestrian sidewalks and business access on the east side. On the west side, dealing with traffic coming off the freeway during peak hours was the main concern. The sidewalks were clearly closed and pedestrians were given an alternate route where sidewalks were available. In other words, there was no simultaneous construction. The day the audit team arrived the contractor was re-configuring the work zone layout on the west side by I-15. This caused a bit of a back up upstream on both directions, about half a mile from the I-15 junction. This congestion was caused also in part by the traffic signals. The congestion would make impatient drivers do aggressive maneuvering, like in Figure 3.9.

Figure 3.8 State Route 92 project.

Figure 3.9 Aggressive maneuver by an impatient driver.
Part of the reconfiguration was to close the left lane. This was done by placing a short taper with an arrow board under the bridge. The merging movement caused a back up for vehicles getting off I-15. Also drivers did not have advanced warning about the closure, so aggressive maneuvering was taking place. Figure 3.10 shows the setup and a car cutting in front of the team’s vehicle.

### 3.4.5 Redwood Road

Three intersections are being modified along Redwood Road. At 4700 South the intersection is widened to accommodate dual left-turn lanes and dedicated right-turn lanes. A Continuous Flow Intersection at 5400 South, 6200 South, and Redwood Road are added. Traffic volumes range from 39000 to 59000, and the street gives access to stores and a local community college.

![Figure 3.10 Lane closure under the bridge.](image)
Most sidewalks along Redwood Road and the intersections were not affected by the construction. Between 6200 South and 5800 South the sidewalk was closed, but an alternate path was provided. The picture in Figure 3.12 is located on 6200 South, north of Redwood Road. A pathway is set by the contractor where there was no sidewalk before. Though the path may not be accessible to pedestrians with disabilities, this shows an attempt to accommodate pedestrian as best as possible.

Figure 3.11 Redwood Road Project area.

Figure 3.12 Pedestrian pathway provided by the contractor.
3.4.6 11400 South and I-15, Draper

As seen on Figure 3.14 there is no east-west connection on 11400 South. This project connects the east to the west part of the street and gives drivers an alternative route, and a new interchange and auxiliary lanes are added on I-15. The impact of the project is one way traffic and lane restrictions along 11400 South, lane shifts and off-peak lane restrictions on I-15. Also 10% of traffic along this roadway is trucks, making the congestion more apparent.

There were flagging operations at the work site that were not specified in the work description. The flaggers were there to ensure trucks and equipment could move in and out of the activity area, and their operation was relatively safe. The existing sidewalks were blocked by VMS signs on the west side of construction. On the east side of the construction site the pedestrian pathways were clear and uninterrupted where available.

Figure 3.13 6200 South and Redwood Road.
Only point of concern in the east side of the work zone is shown in Figure 3.15. Drivers had to swerve, while braking for the gravel and it would cause a problem upstream. Traffic on the interchange on I-15 had no problem with the change in traffic pattern. Also, the activity area was guarded by jersey barriers, keeping the workers safe from traffic and from being a distraction to drivers.
3.4.7 I-15 Core and Pioneer Crossing

This project is the building of the innovative Diverging Diamond Interchange. Such an innovative design calls for a lot of construction equipment that can provide a hindrance and distraction to drivers on I-15. Lane restrictions and changes in traffic patterns are impacts that the work zone will have on traffic. Also the movement of equipment in and out of the work zone is of interest to the audit team.

I-15 Core project expands from Lehi to Spanish Fork, and it is expected to finish by winter of 2012. The road will be expanded by two lanes each directions; 10 interchanges will be configured, and 55 bridges will be restored or replaced. The AADT is 12500, with 13% truck traffic.
Mobility for construction vehicles in and out of work zones was not much trouble. At one of the work sites traffic was restricted to three lanes, and then a lane was added past the work zone. Figure 3.18 shows the configuration. This method allows equipment to move in and out without disrupting traffic. The activity area was very constricted in space, as seen in Figure 3.19. Construction was mostly on shoulders, and only took away one lane of traffic. Throughout the work zone the workers were safely guarded, and out of the way of traffic.
3.4.8 U.S. 189 Heber to Provo

This project added a passing lane to US 189 around Deer Creek State Park. Flaggers were used as a traffic control device for trucks entering and exiting the highway. The AADT is 38182, with 3% of it being trucks. The speed limit is 40 mph, but the fact that flaggers were present drew the attention of the audit team.

ROAD WORK AHEAD signs were posted 2 miles ahead of work zone. The taper lengths were 440 feet and an arrow board was placed behind the first barrels in the work zone. Flaggers were used to ensure that trucks could access and exit the work zone safely. Twelve foot lanes were maintained in through the work zone, and there were not
much backups due to the low traffic volume. Figure 3.20 shows the section of road being worked on.

3.4.9 U.S. 89 Piute County

The construction being performed along is highway was re-paving of the road. Along with U.S. 189, flagging operations are present in this work zone for traffic control. Traffic is limited to one lane each way in the activity area. This road is not heavily used; the AADT is 1500 and 10% truck traffic. Figure 3.21 shows the stretch of road that is being worked on.

The activity area was 5 miles away from the first warning sign for southbound traffic and 7 miles for traffic northbound. When arriving to the activity area there was a flagger with a paddle stopping traffic. Figure 3.22 shows what vehicles encounter when approaching the activity area and the pilot car that guides motorists through the work zone. The sign in the pilot vehicle was in poor condition.

Figure 3.20 US 189 Section under construction.
The audit team drove through the activity area several times. The work zone was long and there was no safe place to get out and take measurements and pictures. Therefore measurements were taken by using the odometer of the car and carefully filming all the drives through the work zone. The queue of vehicles was no longer than 12 vehicles and the maximum waiting time was 5 minutes. The pilot vehicles guided vehicles through the work zone at speeds no higher than 35 mph. Figure 3.23 is a picture of the activity area.
3.4.10 S.R. 9 Hurricane

State Route 9 is Hurricane’s main street. Construction at this site adds one lane in each direction, raised medians, and elements to enhance the city. The lanes will be restricted to 11 feet wide, which may impact speed and behavior of drivers. The AADT of this road is 12,938, and 11% truck traffic.

This work zone used a VMS sign at the start of the advance warning area. The sign displayed a message informing drivers to tune in a radio that will inform them about road closures. The VMS sign was 1.5 miles downstream from the activity area. Before arriving to the activity area, barrels were guarding the newly constructed medians. In the activity area there was a severe drop off between the road and the construction area. There were no speed regulation signs throughout the work zone. The lanes ranged from 11 feet wide to 9 feet; the narrower sections were found in the activity area. Pavement markings were not found in sections near the activity area, making the roadway outline confusing to drivers. Figure 3.25 shows the lack of pavement markings and how close some equipment was to the travel way. Figure 3.26 shows the severe drop off.
3.4.11 I-15 Washington County

This section of highway has the highest percentage of truck traffic at 17%. The project involved re-paving, on-ramp improvements, and adding a cable barrier median. Lane restrictions were a safety concern, especially when there is quite high truck traffic. Figure 3.27 shows the area being improved.
Figure 3.26 Drop off between road and activity area.

Figure 3.27 I-15 Washington County from Leeds to Pintura.

The work zone was 9 miles long for both directions. The taper length for was 675 feet, with only an arrow board at the start of the taper. There were only 4 speed warning signs for the work zone in both directions. The desired speed reduction was from 75 to 65 mph. It only took 9 minutes to drive through the work zone, relatively a fast drive, probably due to the low volumes of traffic. A section of concern was around exit 31 to Pintura. There were two bumps on the road that, though the bumps weren’t severe, made
drivers tap on their brake and slow the traffic upstream. Figure 3.28 illustrates the section.

The section pictured in Figure 3.28 has two bumps on the road. The first bump is by the crash cushion, and the second bump is where the truck is braking. The BUMP sign is located between the two bumps making unclear for drivers to notice the actual location of the bump. This presents confusion to night traffic; 203 out of 387 cars filmed stepped on their brakes as soon as the sign was visible. Another concern was the exits that were being repaired. The exits were unpaved and the loose gravel presents a hazard to those using the exit. Figure 3.29 is an example of how exits on the work zone looked.

Figure 3.28 I-15 southbound Exit 31.

Figure 3.29 Unpaved exit on I-15 Washington County.
3.5 Rural Work Zones

This section of the report provides general observations of the projects that were taking place in rural areas. There projects were: I-15 Washington County, US 89 Piute County, US 189 Provo Canyon, SR 9, and SR 92 work zone. The rest of this section continues as follows, good practices found, practice that need improvement, driver behavior, and worker safety.

3.5.1 Good Practices

The majority of the signs used had a clear surface and were retro-reflective. The signs were mounted in such a way that they were crashworthy by FHWA standards. A common practice was to use arrow boards at the beginning of tapers. These boards were working well, and their display was clear. Variable Message Signs were used in 3 out of 5 work zones audited. The messages displayed were concise and warned drivers about possible congested conditions, but didn’t tell drivers actual road conditions.

Drums were used as delineators and separators in rural work zones. Majority of the drums in rural areas were well placed on the road, with enough space between them to discourage drivers to enter the work zone. Also, the set up of drums showed a clear path, reducing driver confusion. Concrete barriers were used in 3 of the work zones audited. They were reserved for separating traffic from areas of construction workers and equipment. They were also used on bridges and other places that needed additional protection. Crash cushions were placed in front of all sections of concrete barriers.

Flaggers were used in US 189, SR 92 and US 89 in Piute county. The proper warning signs were used when approaching the flagger station. Piute County used flaggers and a pilot vehicle. The pilot car helped maintain a reasonable and safe speed of traffic.
3.5.2 Practices That Could be Improved

Some of the signs in rural areas had lots of wear and fading which reduces the retroreflectivity of the sign. Occasionally there were signs that were knocked over, or there were signs that were not taken down or covered when they should have been. This creates confusion for the driver. Figure 3.30 shows a sign at the Washington County project that had an orange background, but the wording on it was hand-made out of black electrical tape. The Provo Canyon and Piute County projects had placed warning signs too far in advance.

With drums being the most common channelizing device there were unacceptable drums found throughout the work zones. It is estimated that 1 in 50 drums that were set up were damaged. The damage ranged anywhere from severe to minor. Drums rarely were found knocked over in the configurations. The number of drums in the tapers in all the work zones did not match up with the number associated with the width of the lanes in feet. There were also some drums that were covered with advertisements in Hurricane. This affects the retroreflectivity of the drum and can become a hazard at night. Figure 3.31 is an example of the covered plastic drum.

3.5.3 Driver Behavior

One practice that is beneficial in rural areas is that of an early merge. When drivers would approach a lane closure they would make the merge to the open lane well before the taper was present. In uncongested areas this has been found to be useful in maintaining the flow of traffic. Drivers would slow down in the presence of construction workers; however they were usually driving over the posted speed limit. Overall cars would speed all the time. In the case of the pilot car, the traffic would obey the signs and
follow the pilot car. In situations with uneven surfaces, such as a bump or uneven lanes, the drivers would handle it well. Most would brake for the bump, and would stay in their lane when they were uneven or swerving.

Figure 3.30 Unacceptable sign on I-15 Washington County.

Figure 3.31 Covered plastic drum in SR 9 Hurricane.
3.5.4 Worker Practices

Traffic traveled close to active construction areas where workers and equipment were exposed. There was no buffer zone to give errant vehicles time to correct themselves or give workers the possibility to move out of the way. Workers would stay away from the drum barriers. Piute County had no barriers, but the workers would keep their equipment in the lane that was undergoing construction.

3.5.5 MUTCD

The spacing of the signs leading up to and within the work zone was up to MUTCD standards for most work zones audited. For US 89 project there was too much distance between the advance warning area and the activity area. They had the proper set up and the correct warning and regulatory signs except in the Washington County project where they forgot to cover the STAY IN LANES and 75 MPH signs during the day.

Overall it seems that rural areas are satisfied with lower quality traffic control devices. There is less traffic, fewer access points, and smaller projects. These factors and more may be contributing to the way the work zones were set up with devices that are not acceptable. Mobility is not a large concern for rural projects; safety is always the major concern.

3.6 Urban Work Zones

This section consists of the analysis of the urban projects in Utah. These projects are the I-15 Core, I-15 Expresslink, I-15 Bountiful to Farmington projects, SR 26, 114th South, and the projects along Redwood Road. These projects are considered urban because of the high density of traffic, and the populated surrounding areas.
3.6.1 Good Practices

The majority of the signs were in good condition having a clear surface and being retroreflective. The signs were mounted in such a way that they were crashworthy by FHWA standards. They were placed off of the road on the shoulder. Many lane shifts were necessary in urban areas so that there were always as many lanes open as possible. The “LANE SHIFT AHEAD” signs were used to signify the change in driving pattern. They were clear and concise on the message they were trying to convey. Arrow board signs were used to help merge traffic and close lanes. VMS were often in use conveying information about the upcoming work zone. They were clear and concise on the message they were trying to convey. The signs were placed on the shoulder of the road or in the median in highway work zones, while in work zones with pedestrian sidewalks the signs would block the pedestrian pathway.

The most common channelizing device was the concrete barrier. They provide a strong separation from the traffic for the workers. Drums were used for tapers and lane closures. Often the work zones did not have end tapers. Generally the lane was left open for trucks to re-enter the freeway from the work zone. Almost all of the drums were in acceptable condition, with only a few exceptions found throughout. Crash cushions were placed in front of all sections of concrete barriers. The set up of the projects overall were well done allowing traffic to navigate smoothly and safely through the work zone. Queuing that was noticed was likely due to the peak traffic and not the work zone set up itself.
3.6.2 Practices to be Improved

Occasionally there were signs that were not taken down or covered, creating confusion for the driver. With drums being used throughout the work zone it is estimated that 1 in 75 drums that were set up were damaged. The damage ranged anywhere from severe to minor. Drums rarely were found knocked over in the configurations. One incident was witnessed where a work vehicle entering the work zone knocked over a drum. At the moment the drum was knocked over, the driver stopped the vehicle, exited and fixed the knocked down drum. The number of drums in the tapers in all the work zones did not match up with the number the width of the lanes are in feet.

3.6.3 Driver Behavior

One practice that was noticed in urban areas is that of an early merge. When drivers would approach a lane closure they would make the merge to the open lane well before the taper. This kept the lane that was closing to remain empty well in advance of the closure. In uncongested areas this has been found to be useful in maintaining the flow of traffic, but in times of congested traffic it has been found that taking turns merging at the point of the taper could be more beneficial. This uses the closing lane until the last point decreasing the queue length. Drivers would slow down in the presence of construction workers; however they were usually driving over the posted speed limit.

3.6.4 Worker Practices

Traffic traveled close to active construction area where workers and equipment were exposed in the Bountiful project but in the other two projects, concrete barriers separated traffic from workers. In these projects, the workers were rarely visible to the traffic. In
most work zones workers would stay away from the drum barriers. In the Bountiful project and SR 26 project they were seen occasionally near the drums or even crossing into the travel path a foot or two causing major and abrupt slowing of the traffic. The workers did wear the right safety apparel.

3.6.5 MUTCD

The spacing of the signs leading up to and within the work zone was all up to MUTCD standards. They had the proper set up and the correct warning and regulatory signs. Overall it seems that urban areas used higher quality traffic control devices than other areas. There is more traffic, many access points, and bigger projects.
CHAPTER 4

WORK ZONE RISK ANALYSIS TOOL

If the risk of work zones is understood and quantified, then the countermeasures can be effectively employed to make them safer. By quantifying the risk of a work zone the areas with most risk can be identified by the auditor, and recommendations can be made on how to improve that area. Crash risk and mobility must be taken into account when coming up for risk factors associated with work zone practices and location of work zone. As a result of the literature review, observations from the field audit conducted during this research, and crash data an auditing tool was developed using an excel spreadsheet. In the spreadsheet there are questions relating to the four areas of a work zone: advance warning area, transition area, activity area, and termination area. The questions do not require much measurement, but careful observation of the work zone, knowledge of the MUTCD standards, and quality guidelines for devices that are provided later in this section are needed in order to use this tool effectively. The excel spreadsheet is very effective when comparing work zones to each other and determining which one is safer. The tool however is not meant to give an exact score of risk for the work zone alone. The excel spreadsheet was presented to engineers at UDOT and engineers at the Association of General Contractors (AGC) and the questions presented addressed in the tool and the scale used received their approval.

4.1 Tool Development and Process

The tool was developed in a Microsoft Excel spreadsheet with questions that were influence by the previous research presented to the auditor and literature review. The
series of questions are specific to each area of the work zone; advance morning area, transition warning area, activity area, and termination area. Questions for all areas address quality of set up, quality of devices in the work zone, and devices being used in each area. Some questions are specific to the area of the work zone.

For the advance warning area, the distance between the advance warning area and the transition area, and if a VMS sign is used are specific questions pertaining to that section of the work zone. From the literature review it was determined that VMS signs are an effective countermeasure, whether they are used for speed reduction or relaying information to motorist. During the field audit it was observed that if the distance between the advance warning area and the transition area is not adequate, driver expectation is compromised. If the distance is too long, drivers will ignore the warning signs ahead, while if the distance is too short motorist are not ready for the change in roadway configuration, therefore increasing aggressive and adjusting maneuvering.

The particular questions for the transition area address the condition and use of arrow boards and the adequacy of the length of taper. The 2009 MUTCD sets clear standards about the length of taper and the use of arrow boards for closing lanes. The mention of these elements in the MUTCD lead to the decision of making these questions part of the audit tool. In the activity area, pedestrian pathways are of concern because of the emphasis placed about pedestrian pathways in the 2009 MUTCD. Other questions address the use of positive protection, change in lane width and condition of pavement markings. While auditing work zones, the exposure of workers to traffic with no protection was perceived as a safety hazard. Though lane width may decrease speed, the reaction of drivers may cause a crash. Also pavement markings may confuse drivers
about the work zone configuration. The questions about the termination area regard only
the presence and the condition of signs. A summary of the questions is given in table 4.1.

There is a risk factor attached to each question, the factor depends on the qualitative
answer given by the auditor. There are a total of 34 questions and the factor of the
answer is .15, .5, and 1 depending on the answer. The value of 1 represents the most risk
while .15 is the least risk. A value of .15 was picked instead of 0, because there would
always be a risk for safety of work zones regardless of setup. The value of the risk factor
\( R_i \) given in the answer is multiplied by a weight factor \( W_i \) that corresponds to the
question. The weight factor is dependent on the type of road that the work zone is
located; highway or arterial and the addition of the weight factors for each area equals 1.
That the sum of these factors add up to one makes it the number of questions per work
zone area do not affect the final area risk score \( R_a \). Data depicting the influence of
different countermeasures in highway and arterial is very limited. So the weight factor
was subjectively picked for this project. The summation of the questions times the
weight factor gives the risk score per question \( R_q \). Equation 1.1 illustrates the how the
risk per area is calculated.

\[
\sum (R_i \cdot W_i) = R_q \quad \text{(Eq. 1.1)}
\]

This shows the area of concern that should be addressed in each area of the work
zone. In order to get the risk of each of the four areas, the sum of the risk score per
question \( R_q \) is multiplied by a factor dependent on the area \( W_a \); urban or rural. The
area factor, \( W_a \), was derived from the crash data obtained from UDOT. Discussion about
the crash data is provided in section 4.1.1. The calculation of the final risk per area \( R_a \)
is shown in equation 1.2.
\[ W_a \sum (R_a) = R_a \quad \text{(Eq. 1.2)} \]

The final risk per area score \( R_a \) is the final score that is displayed to the auditor in the form of a bar graph. This score enables the auditor to identify the main area of risk within the work zone, therefore pinpointing the focus of the recommendations. Graphs of the score per work zone area are provided to visually enable better identification of the problem areas. The two graphs provided by the tool are a total risk score graph, and a normalized score graph. The normalized graph is the ratio of the score obtained to the maximum score that could be obtained in that area of the work zone. The final score from the tool does not illustrate exact risk for an individual work zone.

4.1.1 Crash Data

Preliminary analysis results of the location of crashes within the work zones were considered when coming up with factors. The data consisted of 12,269 total crashes recorded from 2006 to 2008 in all locations of the work zones audited in this research process. This data shows that there is a higher rate of crashes in urban areas than in rural areas. Overall work zone crashes compose a considerable percentage of total crashes. Work zone crashes make up for 9 percent of the total crashes obtained. Figure 4.1 shows the results.

Out of the data obtained 11,341 crashes happened in the streets that were classified as urban for this study, and 931 of these crashes were determined to have happened in a work zone. Seven hundred crashes were unclear whether there was a work zone at the time of crash. For the purposes of this study, the 931 crashes that were classified as work zone related were used when coming up with factors. Figure 4.2 show the results of the location of crashes in the work zone urban areas.
For rural areas, 928 crashes were recorded. Out of these crashes 695 were not work zone related, 147 happened on a work zone, and 86 were not classified. Figure 4.3 shows the location of the 147 crashes that were clearly classified in the police report.

4.1.2 Summary

Because of the lack of concrete classification in the location of crashes in the work zone, the preliminary results were used in estimation of factors and no further statistical analysis was done. The weight factors were derived from the classified crashes only.
The issues addressed in by the auditing tool were verified by engineers at UDOT and members of the Association of General Contractors (AGC). Questions and values were also developed under the careful supervision of Dr. Heaslip. Table 4.1 contains a summary of the risk corresponding to each question and to each area of the work zone.

The analysis tool is meant to give a quick assessment of the general conditions of the work zone. Through the tool, areas of concern can be identified and remedied quickly, therefore giving the ability to make assessments with limited resources. The score that the tool gives for an individual work zone does not accurately represent the actual risk. Therefore, the tool is most effective when comparing safety between work zones and providing a quick assessment of which work zones need more improvement and auditing. This tool is meant to be used by auditors and contractors alike. Appendix C shows the interface and quantification sheet of the tool.

<table>
<thead>
<tr>
<th>Crash Location in Rural WZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
</tr>
<tr>
<td>Termination Area</td>
</tr>
<tr>
<td>Advance Warning</td>
</tr>
<tr>
<td>Unknown class.</td>
</tr>
<tr>
<td>Before sign</td>
</tr>
<tr>
<td>Activity area</td>
</tr>
<tr>
<td>Transition area</td>
</tr>
<tr>
<td>N/A</td>
</tr>
</tbody>
</table>

Figure 4.3 Location of crashes in rural work zones.
### Table 4.1 Summary of factors used in the analysis tool

<table>
<thead>
<tr>
<th>Factor</th>
<th>Highway</th>
<th>Arterial</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Is there adequate advance warning distance?</td>
<td>0.2</td>
<td>0.25</td>
<td>0.27</td>
<td>0.3</td>
</tr>
<tr>
<td>2. What is the condition of the signs?</td>
<td>0.3</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Is the set-up of the signs crashworthy?</td>
<td>0.2</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Is the spacing between signs adequate?</td>
<td>0.05</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Are Variable Message Signs used?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Is speed limit through the work zone clearly stated and enforced?</td>
<td>0.25</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Transition area**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Highway</th>
<th>Arterial</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What is the condition of the signs?</td>
<td>0.05</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Are there barrels set up correctly?</td>
<td>0.2</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Are barrels susceptible to being hit?</td>
<td>0.3</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Is the length of the taper adequate?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Are barrels used, and fully functional?</td>
<td>0.3</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Is the set-up of the barrier crashworthy?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Are barrels used, and fully functional?</td>
<td>0.3</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Activity area**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Highway</th>
<th>Arterial</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Is the pathway of traffic clearly outlined?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Are there pavement markings clearly outlined?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Is the speed limit through the work zone clearly stated and enforced?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Are the left turn lanes clearly delineated?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Are the left turn lanes clearly marked?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Are the left turn lanes clearly delineated?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Are the left turn lanes clearly marked?</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Are there any end markers?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Termination area**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Highway</th>
<th>Arterial</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Is there an end taper?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Is there a crashworthy sign?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Is the set-up of the signs crashworthy?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Is the condition of the signs?</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.2 Quality Guidelines

In order to reduce ambiguity when judging the quality of signs and delineation devices, standards were developed during this research project. The American Traffic Safety Services Association (ATSSA) has standards in place and they were used as guidelines for this research. All picture examples were taken at the work zones that were audited. The following are the standards set.

### 4.3 Drums and Vertical Panels

#### 4.3.1 High Condition

High quality devices have the following characteristics:

1. Not missing retroreflective material
2. May have very little or no damage that doesn’t impede retroreflectivity
3. Device maintains original shape
4. Surface is free of asphalt, cement slurry or other materials

Figure 4.4 shows an example of high quality drums and vertical panels.

4.3.2 Medium Condition

Medium quality has the following characteristics:

1. Some damage
2. Some scuff marks and dust
3. Damage doesn’t compromise retroreflectivity of the device
4. Some dents but device’s strength is not reduced
5. Device maintains original shape

Figure 4.5 shows examples of medium quality devices.

4.3.3 Low Condition

The following characteristics give a low rating to a channelizing device:

1. Badly damaged or deformed
2. Damage compromises retroreflectivity
3. Missing retroreflective material
4. Retroreflective material is covered

Figure 4.6 shows examples of low quality devices.
Figure 4.4 High quality plastic drums and vertical panels.

Figure 4.5 Medium quality examples.

Figure 4.6 Low quality channelizing devices.
4.4 Temporary Traffic Signs

4.4.1 High Condition

High quality signs have the following characteristics:

1. Message is legible
2. No touch up of lettering
3. Little or no loss of lettering
4. If scratched or damaged, it does not reduce the retroreflectivity

Figure 4.7 gives a few examples of high quality signage

4.4.2 Medium Condition

A medium quality criterion is the following:

1. Scuffs and scratches do not interfere with lettering
2. Damage doesn’t affect retroreflectivity
3. No damage to the shape of the sign
4. Message is legible
5. Color fading does not limit retroreflectivity

Figure 4.8 shows examples of sign in medium condition

4.4.3 Low Condition

Signs in the following condition are in low condition:

1. Patched up lettering
2. Scratches and scuff make message hard to read
3. Some letters have loss of more than 50%
4. Scratches and damage compromises the retroreflectivity of the sign
5. Noticeable color fading
Figure 4.9 shows signs that had low conditions during the audit process.

4.5 Other Quality Guidelines

Besides the condition of the sign, the set up of the sign is taken into account too. Signs should be mounted on a crashworthy support that meets the criteria outlined in Section 6F.03 of the 2009 MUTCD. In addition to this, signs should also convey a clear message in order to avoid driver confusion. Figure 4.10 is an example of signs whose set-up is not crashworthy and were found during the audit process.

![Signs with high quality](image1)

**Figure 4.7 Signs with high quality found in work zones.**

![Medium condition signs](image2)

**Figure 4.8 Medium condition signs.**
4.6 Work Zone Risk Analysis

Since the tool was developed and observations of the work zones were recorded, the risk of each work zone was quantified. The risk scale for the sum of the area scores is from .15 to 1, with .15 being the least risk and 1 being the maximum risk possible. The following sections are the evaluations of the risk for the work zones audited.

4.6.1 Riverdale Road

The total score given for the work zone was .44 out of 1. As can be seen by the graph in Figure 4.11 the area with most risk is the activity area, which has a score of .34. This
is due in part because of the conditions in the north end of the work zone, where there were faded pavement markings. Also, the lack of an uninterrupted path through the work zone presents a part of the risk.

The recommendations and improvements were also plotted in the same work sheet. The areas addressed in the recommendations were pavement markings, pedestrian practices, and worker practices observed. By making a clear pedestrian pathway clear and uninterrupted by signs, improving the pavement markings, and by keeping construction equipment safely away from traffic the risk score was reduced from .44 to .33. All recommendations were focused on the activity area because improvements on other areas of the work zone would be unfeasible.

A normalized graph allows for better assessment of the condition of the work zone areas and avoiding the perception that the activity area is always of concern. Figure 4.13 shows the normalized scores obtained from the audit and from the recommendations made.

![Area Risk Graph](image)

Figure 4.11 Risk of work zone per area.
4.6.2 S.R. 9 Hurricane

In this work zone the total score for risk was .6 with .43 of those points coming from the activity area. The area of concern was the condition of drums, signs, sign set up, pavement markings, no arrow boards used to guide traffic, and closeness of construction equipment and personnel when approaching the area under construction. Figure 4.14 shows that the normalized score of the activity area is .86, much higher than the other areas of the work zone. The transition area has a normalized score of .61, so improvements in that area can also lower the score obtained.
It is estimated that by improving pavement markings, using arrow boards, improving signage and set up of signage the risk would be reduced significantly. Also improving the conditions of the plastic drums from low to medium, the score was lowered from .61 to .4. Figure 4.15 shows graphically the significance of the improvements in terms of total score.

![Normalized score of each area.](image)

Figure 4.14 Normalized score of each area.

![Risk reduction graph.](image)

Figure 4.15 Risk reduction graph.
4.6.3 S.R. 92

In this work zone the risk score obtained is .58. A section that is of concern is the advance warning area, and the transition area for eastbound traffic that is coming off I-15. There is not advance warning for cars coming off the exit about the street being reduced to one lane. Figure 4.16 shows the normalized risk score for each area of the work zone.

By making drivers of the construction activities using a VMS sign, making the transition area more visible to drivers and making the taper length more adequate, the score of risk lowered from .58 to .36. Also some improvements to the activity area contribute. Figure 4.17 plots the improvements versus the present estimated total risk score.

Figure 4.16 Normalized risk score for SR 92.
4.6.4 Redwood Road

At Redwood Road the total risk score obtained is .54. Conflicting pavement markings were found in this work zone, along with construction equipment nearing traffic pathway. Figure 4.18 shows the normalized scores for each area. The activity area for this project is of main concern as shown by the normalized graph. The score for the activity area is .74 while the advance warning area has the second highest normalized score of .54.

Addressing the concerns in the activity area reduce the total risk from .54 to .39. The improvements include consistency of pavement markings, and keeping the traffic roadway clear from construction equipment. Improvements in the advance warning area are not feasible because of the proximity of the intersections to each other and the road geometry.
4.6.5 U.S. 89 Piute County

The total risk score for this work zone is .57. The main contributors to this score are the activity area and the advance warning area. The advance warning area was too far in advance from the activity and transition area, making it easy to ignore all other signs posted. Figure 4.20 shows the normalized risk for each area. Though the transition area has a high normalized score, the total score of the advance warning area, as seen in Figure 4.21, is a greater contributor to the total score than the transition area.
Though vehicles were guided through the activity area, there would be workers too close to the pathway of traffic. By making the advance warning move along with the activity area, therefore keeping the distance constant and not giving the driver too much or an advance warning, the total risk is reduced from .57 to .36. What also contributes to this would be having the guide vehicle drive further away from workers and equipment.
4.6.6 U.S. 189

The score for this work zone was .38 which is a relatively low score when compared to the initial scores of other work zones. Improvements can be made to the work zone still and make it as safe as possible. The advance warning area is too far in advance for this work zone. The taper length is not quite adequate, therefore making the barrels susceptible to being hit. Figure 4.22 shows the normalized estimated risk per area of the work zone.

By reducing the distance of the advance warning area to the transition area making the taper more adequate, the score was reduced to .26. Figure 4.23 plots the estimated risk without the recommendations versus the risk recommendations.

![Area Risk Percent](image)

Figure 4.22 Normalized risk for US 189.
4.6.7 11400 South

In this work the issues of concern are the quality of signs, pavement markings, road condition, and construction equipment not being kept safely away from traffic. The total risk for the work zone overall is .38. Figure 4.24 shows the estimated total risk of the work zone per area. If the concerns are addressed the score would be reduced by .29.

Figure 4.23 Total risk score for US 189.

Figure 4.24 Total risk score for 11400 South.
4.6.8 I-15 Bountiful to Farmington

The two lane closure for this project came as an unexpected event to some drivers. Also, workers were too close to traffic, providing a distraction to drivers while endangering themselves. If a VMS sign, or other measure to inform drivers of a 2 lane closure instead of a 1 lane closure was used, and if crash cushions were used where workers are working the total risk could be reduced from .46 to .33. Figure 4.25 shows graphically the impact of the recommendations.

![Figure 4.25 Normalized score for 11400 South.](image)

![Figure 4.26 Total risk scores for I-15 Bountiful to Farmington.](image)
4.6.9 I-15 Express Link

The work zone was relatively safe for workers and drivers alike. The risk score from the audit is .31. The main concern is mobility thru the work zone, especially at times of congestion. If VMS signs were used to alarm drivers of expected delays, while the speed limit could be enforced in times of no congestion the risk score would be reduced to .18. Figure 4.26 plots the estimated risk versus the estimated risk with recommendations already implemented.

![Area Risk Percent](image1)

Figure 4.27 Normalized score for I-15 Bountiful to Farmington project.

![Area Risk](image2)

Figure 4.28 Total risk score for I-15 Express Link.
4.6.10 I-15 Pioneer Crossing, Core

The work zone was well set up overall. Construction vehicles were safely guarded from traffic and could merge in and out of traffic without interrupting traffic. Signs were in a good condition, and the pathway was clearly marked and signed. This gave the work zone an estimated risk value of .28. With enforcement of speed limit by photo speed, or using a program like the hire back program, the score would be reduced to .20. Figure 4.27 shows the improvement versus present risk.

Figure 4.29 Normalized score for I-15 Express Link.

Figure 4.30 Total risk score for I-15 Pioneer Crossing.
4.6.11 I-15 Washington County

This work zone received a score of .48 due to many factors. The condition of signs used throughout the work zone was low. Exits off the highway were poorly marked, signed and very gravely. Also the speed limit was not clearly marked through the activity area. If these concerns were addressed the score would be reduced to .35.
4.7 Summary

The spreadsheet developed facilitates the identification of problems with the work zone, estimating future impact of recommendations, improvements made to present conditions and could be used for estimation of benefit/cost analysis. The intent of the spreadsheet is to help auditors and contractors in judgment of how to improve safety in the work zone. Exact quantification of risks is not attained from this tool, but a good estimation that enables better judgment when questioning where improvements should be focused is how this tool is very effective. The simplicity of the tool enables for many work zones to be analyzed in a quick manner, so inspectors may not be limited by time and audit many work zones in a shorter period of time. Table 4.2 gives a summary of the risk factors attained from the tool.
Table 4.2 Summary of risk quantification of the work zones audited

<table>
<thead>
<tr>
<th>Road/Risk Score</th>
<th>Present Risk</th>
<th>With Improvements</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR 26</td>
<td>0.44</td>
<td>0.33</td>
<td>0.11</td>
</tr>
<tr>
<td>SR 9</td>
<td>0.61</td>
<td>0.4</td>
<td>0.21</td>
</tr>
<tr>
<td>SR 92</td>
<td>0.58</td>
<td>0.36</td>
<td>0.22</td>
</tr>
<tr>
<td>US 89</td>
<td>0.57</td>
<td>0.36</td>
<td>0.21</td>
</tr>
<tr>
<td>US 180</td>
<td>0.38</td>
<td>0.26</td>
<td>0.12</td>
</tr>
<tr>
<td>11400 S.</td>
<td>0.38</td>
<td>0.29</td>
<td>0.09</td>
</tr>
<tr>
<td>Redwood Road</td>
<td>0.54</td>
<td>0.39</td>
<td>0.15</td>
</tr>
<tr>
<td>I-15 Boun. To Farm.</td>
<td>0.46</td>
<td>0.33</td>
<td>0.13</td>
</tr>
<tr>
<td>I-15 Express</td>
<td>0.3</td>
<td>0.18</td>
<td>0.12</td>
</tr>
<tr>
<td>I-15 Pioneer Cross.</td>
<td>0.28</td>
<td>0.2</td>
<td>0.08</td>
</tr>
<tr>
<td>I-15 Washington</td>
<td>0.48</td>
<td>0.35</td>
<td>0.13</td>
</tr>
</tbody>
</table>

The difference of magnitude, and not the risk numbers themselves, is what should be used when evaluating the impact of improving conditions in the work zone. The recommended improvements include:

1. Speed limit regulation
2. Set clear, non-conflicting, pavement marking
3. Making a pedestrian pathway available at all times
4. More use of positive protection (i.e. mounted attenuators)
5. Shorten distance between warning area and transition area

These recommendations are easy to implement, and the impact is significant. The work zones with the highest score, SR 9 and SR 92, risk was estimated to be .62 and .6, respectively. The risk is reduced by .2 if the work zones are brought to MUTCD standards. The magnitude of this change is considerable. The implementation of this tool can be immediate, because of its simplicity and applicability.
CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The research for this thesis gives a standard methodology for in-depth evaluation of work zone safety, standards for sign and device condition that relate to the field, and an analysis tool that quantifies the risk involved with the work zone. All contributions can be useful to inspectors and contractors that are concerned about safety for their workers and motorist.

The audit process was composed of four distinct steps: pre-audit, site selection, field audit, and audit analysis. Information for the pre-audit phase can be easily obtained from the Department of Transportation website, Google Earth, and other media outlets. The goal is to get as much information as possible in order to make a better assessment of the work being performed and which sites to select. After all information is gathered, the auditing team must decide what areas to focus on (i.e. highway work zones, type of work being performed, urban work zones, type of traffic control being performed, etc.) and set criteria. For this research the focus was to audit work zones in all areas of the state, in highways or high speed arterials, and audit as many traffic control strategies as possible. Once the sites are selected, and if time allows, engineers from the Department of Transportation can be contacted in order to obtain crash data for the sites selected, Traffic Management Plan, and contractor information.

The field audit should gather as much information as possible, with the safety of the auditor being of most importance. This means that the information gathered for all work zones will not be uniform, as well as the observations made. Once the field audit process is complete, the analysis for each work zone must be done. The analysis is composed of
breaking down film, sorting the pictures taken and carefully writing up the behavior of drivers and other observations. Whenever possible, quantification of observations should be made (i.e. slamming of the brakes, questionable barrels, etc.). The audit process, with its four steps, gives way to how work zones can be thorough inspected. In addition, the auditing process can also be used for further research on work zone impacts on safety and mobility.

In a meeting with UDOT a concern was presented about the ambiguity of judgment about quality of signs and devices. There are current standards provided by ATSSA, but the applicability of those standards to the field is in question. The quality guidelines developed for this research were not meant to contradict previous standards, but to make them more applicable for contractors and auditors. When analyzing the work zones, the audit team used the standards outlined by ATSSA and amended the standards according to the observations made. The standards developed for quality of signage use examples observed from the field study conducted in Utah. This gives the auditor, or contractor, a more applicable standard and what to expect when it comes to poor conditioned signs.

The crash data helped when coming up with weight factors for the analytical tool. A problem encountered when analyzing the data was the lack of classification. For many crashes it was undetermined whether a work zone was a factor or not. Also some were blank in that category. For those classified as work zone related, many were not specific as to location of crash along the work zone. Such ambiguity, or lack of information, can inhibit making a precise statistical analysis. That is why preliminary results were used in the estimation of weight factors for the analytical tool.
The analytical tool can be used as an estimation of risk, and as an identifier for areas of concern. The risk score can still be improved with further study of impact of correct signage and practices on the Utah drivers. The tool can easily be implemented by the local DOT, and contractors. After acquiring the input from contractor engineers and engineers familiar with work zones safety, the tool can be modified, completed, presented and used. The spreadsheet was constructed so that modifications and improvements can be easily made. Because of that, the tool can be used for inspection by next construction season.

To further objectify the analysis tool, further studies concerning work zone safety in Utah can be completed. A study of speed behavior in work zones can help refine the risk factor for speed concerning questions in the tool. Also a survey to contractors, safety committees can help assess the effectiveness of the tool. This input can also be used to improve the issues that analysis tool is trying to address. In addition, crash reduction factors can be programmed into the analysis tool in order to make it more crash oriented when it comes to its risk reduction assessment.
REFERENCES


APPENDICES
Appendix A: MUTCD Comparison

A detailed comparison between the 2003 MUTCD and 2009 MUTCD is enclosed in this appendix. The comparison is listed by section and by paragraph.

Detailed Differences between MUTCD 2003 and MUTCD 2009

Section 6A

6A.01 - par.1-2 the definition of TTC throughout the section and the standard that all road users should be controlled by a TTC zone was take from section 6B and added to this General section.

6A.01 – par. 9 the use of ITS in work zones proved to be effective in monitoring, and managing traffic, data collection, and providing information to the motorist. This in turn improves the operation of a work zone.

6A.01 – par.15 public agency, or official should determine whether road is high-volume or low-volume

Section 6B

6B.01 – par.7 the seven fundamental principles of TTC are outlined and the changes to them are the following:

- 2C. work should be scheduled in a way to minimize the need for lane closures, and alternate routes while work operations are done in a quick manner.
- 2D. an attempt should be made to reduce the traffic volume to match the capacity of the TTC zone. For high volume freeway the closure of access points should be evaluated.
- 2F. night work should be considered if the work can be done within a series of short-term operations.

Section 6C

6C.02 – par. 1 a TTC zone can be used for a planned special event.
6C.02 – par. 4 explain the duration of TTC and size for a special event.
6C.04 – par.6 explains that the distances in table 6C-1 are intended for guidance only and can be adjusted.

6C.04 – par. 7 sign spacing can be increased in order to provide additional reaction time. Decreasing sign spacing is justified in order to place a sign downstream from an intersection or major driveway, so that traffic turning into TTC zone may be aware or the road condition.

6C.05 – par. 3 recommends that vehicle-mounted traffic control devices may be used instead of channelizing devices in mobile operations.
6C.05 – the support that transition area moves with the work space in mobile operations was deleted.
6C.06 – guidance stating that incident should not extend into buffer space was deleted

6C.08 – par. 4 minimum length requirement to taper length (Table 6C-3) to downstream taper, one-lane, and two-way traffic taper added. Placed formulas for calculating taper lengths in Table 6C-4.
6C.08 – par. 12 the option for a downstream taper was changed to a support.
6C.08 – par. 13 downstream taper length should have a minimum of 50 feet and a maximum of 100 feet. Spacing for devices remains the same.
6C.10 – the support stating that spot constriction, two way constriction are self-regulating was deleted.
6C.10 – par. 05 gives option that if it is a low volume street, road is short, and road users from both directions can see each other; the movement of traffic through a one-lane, two-way constriction can be self regulating.
6C.13 – par.4 the sentence from section 6F.54 was relocated to this section and it states that a flagger shall be stationed at the approach of the activity area.

Section 6D
6D.01 – par. 04-05 if TTC zone affects movement, or accessible pedestrian facility, the accessibility and detectability should be maintained along the alternate pedestrian route. If alternate route is not feasible during project, alternate means of providing pedestrians may be used (i.e. free bus, assistance around project).
6D.01 – par. 08 a pedestrian route shall not be moved for non-construction, for example parking for cars or equipment.
6D.01 – par. 11 the following considerations were added in order to accommodate the needs of pedestrians:
A. Continuity of accessible pedestrian paths should be incorporated into the TTC plan.
B. Maintain access to transit stops.
C. Provide a smooth hard surface for path, with no abrupt changes in grade or cub's that would cause tripping or become a barrier to wheelchairs.
D. The width of the provided route should be the width of the existing sidewalk if practical. Traffic control devices and construction materials should not intrude in the width of the sidewalk. If it is not possible to maintain a minimum width of 60 inches through the whole route, a 60 x 60 passing space should be provided every 200 feet.
E. Audible information devices, accessible pedestrian signals and channelizing devices that are detectable to the pedestrians traveling with a long cane or who have low vision, should be provided.
F. When a channelization is used, a continuous edging should be provided along facility so that pedestrians using a long cane can follow it.
G. Signs lower than 7 feet above the pedestrian pathway should not project more than 4 inches into pedestrian facilities.
6D.01 – standard that TTC devices for pedestrians should be crashworthy was deleted, also that
6D.02 – standards, supports and guidances concerning accessibility to pedestrians in section 6D.01 was relocated to this section.
6D.03 – par.04 high visibility safety apparel is made a standard in the 2010 MUTCD. The safety apparel has to meet class 2 or 3 requirements of the ANSI/ISEA 107-2004. A person designated by the employer to be responsible for worker safety shall make the selection of the appropriate apparel.
6D.03 – par.05 law enforcement, emergency and incident responders within TTC zone may wear safety apparel that meets the performance requirements of the ANSI/ISEA 207-2006. but they are exempt under some conditions.

6D.03 – par.06 uniformed law enforcement should wear safety apparel when investigating a crash.

6D.03 – par.08 firefighter or other responders exposed to heat may wear retroreflective gear specified by other organizations.

Section 6E

6E.02 – par. 01 specified that high-visibility apparel that meets class 2 or 3 requirements of the ANSI/SEA 107-2004 must be used for daytime and/or nighttime.

6E.02 – par. 02 gives guidance that for nighttime, flagger should wear apparel that meets performance class 3 requirements of the ANSI/SEA 107-2004.

6E.02 – par. 03 when directing traffic officers shall wear retroreflective apparel specified.

6E.02 – par. 04 states that law enforcement personnel within the TTC zone may wear apparel of performance requirements of the ANSI/ISEA 207-2006.

6E.03 – par. 03 added guidance that the STOP/SLOW sign should be made from light, semi-rigid material.

6E.03 – par. 04 added support that the STOP/SLOW sign should be placed on a rigid staff.

6E.03 – par. 06-09 places the following standards for flashing lights and flags:
- flags may be fluorescent orange/orange.

6E.03 – par. 12 gives the option that a flagger may use a flashlight with a red glow cone to supplement the STOP/SLOW paddle in case of an emergency during nighttime.

6E.03 – par. 13 sets the following standards when a flagger uses a flashlight:
- Hold the flash light with the left hand and hold the paddle with the right hand.
- To inform drivers to stop, the flagger shall slowly wave the flashlight in front of the body in a slow arc from left to right, the arc should reach no more than 45 degrees from vertical.
- To tell drivers to proceed, the flagger shall point flashlight to the bumper and then the open lane, and hold position. The flagger shall not wave flag.
- To alert traffic, the flagger shall point the flashlight toward the oncoming traffic and wave a figure eight motion.

In comparison to 2003 MUTCD, section 6E.04 Flagger Procedures and section 6E.05 Flagger Stations were moved to sections 6E.07 and 6E.08, respectively, in the 2010 MUTCD.

The following sections were added:
- 6E.04 Automated Flagger Assistance Devices
- 6E.05 STOP/SLOW Automated Flagger Assistance Devices
- 6E.06 Red/Yellow Lens Automated Flagger Assistance Devices

6E.07 – par. 02 prohibits the use of hand signals to slow/stop traffic by the flagger. Law enforcement and emergence responders at incident scenes may use hand signals as described in section 6I.01.

The guidance for where a flagger should stand and the option of when to use one flagger was moved from the Flagger Stations to the Flagger Procedures section.
Section 6F
6F.01 – par. 02 work zone hardware should meet the crashworthy performance criteria presented in the NCHRP Report 350
6F.02 – par. 08-09 The sizes of signs and plaques are given in table 6F-1. Minimum requirements of size shall only be used on local streets or roadways where the 85th percentile or posted speed limit is less than 35 mph.
6F.03 – par. 06 minimum height for signs above sidewalks shall be 7 feet.
6F.03 – par. 08 if a secondary sign is mounted below another sign above a pathway, then the secondary sign should not project more than 4 inches into the pedestrian facility.
6F.09 – par.03 in urban areas the XX MILES AHEAD on the R11-3a sign can be replaced with the name of a well know destination or an intersecting street.
6F.12 Work Zone and Higher Fines Signs and Plaques added
6F.16 – eliminated standard that for high speed locations signs shall be 48 x 48 inches, and option that they can be 36 x 36 in moderate speed.
6F.17 – par. 02 if multiple advance warning signs are needed when approaching a TTC zone the Road Work Ahead (W20-1) sign should be the firs sign encountered by traffic.
6F.23 – par. 01 only sign W9-3 may be used, sign W9-3a may not.

No guidelines for thru traffic merge left (W4-7) given in 2010 MUTCD
6F.28 – par. 02 guidance was added concerning the EXIT CLOSED sign. When an exit ramp is closed the sign panel with a black legend and border on an orange background should be placed diagonally across the interchange/intersection guide signs.
6F.29 EXIT ONLY sign (E5-3) was added to the guidelines. This sign may be used when work is being conducted in the vicinity of an exit ramp and where the exit maneuver for traffic using the ramp is different than the normal condition.
6F.30 NEW TRAFFIC PATTERN AHEAD (W23-2) option and guidance added
6F.31 doesn’t have the standard that the Flagger sign should be removed when flagger operation is not occurring.
6F.44 Shoulder signs and plaque (W8-4, W8-9, W8-17, and W8-17P) guidelines were added.
  - W8-4: soft shoulder
  - W8-9: low shoulder (elevation 3 inches of less)
  - W8-17: shoulder drop off (elevation difference is greater than 3 inches)
6F.46 STEEL PLATE AHEAD sign (W8-24) was added. It can be used to warn motorists of a temporary steel plate ahead.
6F.48 Reverse Curve Signs (W1-4 Series) standards and guidance was added
6F.49 Double Reverse Curve Signs (W24-1 Series) standards and guidance was added
6F.54 Motorcycle Plaque (W8-15P) was added to mount below other warning signs. This is used if warning is directed only to motorcyclists.
6F.60 - par.20 new guidance and reasons stated for Portable Message Signs.
6F.60 Alternating Diamond Caution should be provided when flashing for caution.
6F.60 - par. 26 gives the option to use a portable changeable message sign to simulate an arrow board display.
6F.63 – par.01 sets standard that all channelizing devices shall be crashworthy
6F.63 - par.04-06 devices used to channelize pedestrians shall be detectable to users of long canes and visible to persons with low vision. The devices shall be detectable from
top to bottom continuously. The bottom of the bottom surface shall be no higher than 2 inches above the ground, the top of the top surface no lower than 32 inches.

6F.63 – par.07 deleted standard and added guidance for multiple devices that form a continuous pedestrian channelizer.

6F.63 - par. 10-13 option to add warning lights to channelizing devices in areal with frequent fog, snow, severe curvature, or where visual distractions are present. Lights placed shall be steady burn. Lights may be placed on channelizing devices that form a merging taper, when doing this it shall start from the upstream end of the merging taper, to the downstream end of the merging taper. Each warning light in the sequence shall flash at a rate of not less than 55, and not more than 75 times per minute.

6F.65 - par. 03 retroreflectorization of tubular markers that are less than 42 inches tall shall be provided by two 3-inch wide white bands placed at a maximum of 2 inches from the top with a maximum of 6 inches between bands. For markers taller than 42 inches shall be provided by four 4-6 inch wide alternating orange and white stripes with the top stripe being orange.

6F.68 - par. 10-11 set barricade guidance for barricades placed on pedestrians pathways. A 60 x 60 inch pathway should provide at least every 200 feet if it’s not possible to maintain original width of sidewalk. Barricade rail supports should not project more that 4 inches into the pedestrian pathway.

6F.68 - par.13 doesn’t give guidance that barricades should be crashworthy.

6F.68 doesn’t give the standard that barricades shall not be ballasted by non-deformable objects.

6F.69 - par.01 gives the standard that a W1-6 sign should be used for direction indicator barricades.

6F70 - par.01 sets support that temporary traffic barriers are not TTC devices themselves but they can serve are TTC devices.

6F70 - par.06 sets standard that if the temporary traffic barriers is used for a merging taper, the taper shall be delineated.

6F.71 Longitudinal Channelizing Devices section added. They are lightweight, highly visible, deformable devices that can be connected together. If used as a singly type barricade, then device should comply with guidelines set in part 6. If used at night, devices should be supplemented with retroreflective material or delineation. Longitudinal channelizing devices may be used instead of cones, drums, barricades. Also they may be hollow and filled with water as ballast and may be used as a pedestrian traffic control. If used for pedestrian control, they shall be interlocked with no gaps. Longitudinal channelizing devices have not met the crashworthy requirements.

6F.72 Temporary Lane Separators section added. They may be used to channelize road users, divide lanes when two or more lanes are used in the same direction, and provide pedestrian channelization. They shall be crash worthy, have a maximum height of 4 inches, max width of 1 foot and have sloping sides in order to facilitate crossover by emergency vehicles. If a channelizing device is used to supplement a temporary lane separator the channelizing device shall be retroreflectorized. If channelizing device is not used then temporary lane separator shall contain retroreflectorization. At pedestrian crossing locations, temporary lane separators shall shortened to provide a pathway that is 60 inches wide.

6F.77 – par.01 added support for pavement markings providing a path to motorists
6F.77 – par.03 deleted part of the standard set for warning signs used when there is no clear path set by the pavement markings.

6F.77 – guidance for markings within a TTC zone was deleted

6F.78 – par.04 added standard that was previously found in section 6F.71. States warning signs and other devices shall be used when markings cannot set a clear path.

6F.79 temporary raised pavement markers. Standard that if TRPM is substituting broken line segments a group of at least 3 retroreflective markers shall be used no greater than N/8 apart from each other. N equals the length of one line segment plus one gap. If it is substituting a solid line, then the markers should be spaced a no greater than N/4 with retroreflective or internally illuminated units at a spacing of no greater than N/2.

6F.81 – deleted support about the four types of lighting devices in TTC zones

Deleted the Flashing Warning Beacons section (6F.77).

6F.83 - par.09 standard that flashing lights should occur from upstream end of the merging taper to the downstream end. Each warning light should flash at a rate of 55 to 75 times per minute.

Section 6F.73 Steady-burn Electric Lamps in 2003 MUTCD is not found in 2010 MUTCD.

6F.84 - par.03 changed standard about temporary traffic control signal complying to section 4H.02

6F.84 - par.12 gives guidance that if temporary traffic control signal is located within .5 mile of an adjacent traffic control signal, consideration should be given to interconnect operation.

6F.84 - par.13 sets standard that a temporary traffic control signal shall not be located within 200 feet of a grade crossing unless there is a flagger or an officer present to stop vehicles from stopping on the crossing.

6F.85 – par.08 shows new support for movable barrier use.

Section 6F.83 Vehicle arresting system from 2003 MUTCD is deleted from 2009 MUTCD.

Section 6F.86 Future and Experimental Devices in the 2003 MUTCD is not found in part 6F of the 2010 MUTCD.

Section 6G

6G.1- par.04 adds guidance that for any planned event that will have an impact on traffic on any street, a TTC plan should be developed in conjunction and with the approval of the agency that have jurisdiction over the affected roadways.

6G.2 - par.16 in addition to flaggers, channelizing devices may be used for mobile work areas.

6G.2 - par.22 changed standard to all mobile operations shall have appropriate warning devices on the equipment, or shall use a separate vehicle with appropriate warning devices.

6G.4 - par.03 guidance clarifies that when conditions are more complex, typical applications should be modified according to provisions of chapter 6B. Added Pedestrian routes and temporary facilities, and Bicycle diversions and temporary facilities to list.

6G.12 – deleted standard about temporary traffic barriers being equipped with channelizing devices.
6G.12 – par.13 added option that if speeds are 40 mph or less, a single continuous taper may be used.

Section 6G.18 *Movable Barriers* in 2003 MUTCD is not the 2010 MUTCD

Section 6H

6H.4 - par. 4 gives option that stationary lights may be omitted.

6H.4 – par. 8 gives standard that vehicle-mounted signs shall not be obscured. Legends on vehicle mounted signs shall be covered or turned from view when work is not in progress.

6H.5 - par. 5 modified standard that if temporary traffic barriers are used, they shall comply with the provisions of section 6F.85.

6H.6 – par. 11 gives standard that vehicle-mounted signs shall not be obscured. Legends on vehicle mounted signs shall be covered or turned from view when work is not in progress.

6H.6 - par. 12 gives standard that shadow and work vehicles shall display high-intensity lights.

6H.30 – deleted guidance from the 2003 MUTCD

6H.31 - par. 8 added standard that the number of lanes and direction of curves shall be appropriately illustrated on the Reverse Curve or Double Reverse Curve signs.

6H.31 – par.10-11 added to the option. Sign W1-4 with an ALL LANES plaque may be used when two or more lanes are being shifted. When more than three lanes, the reverse curve sign may be rectangular.

6H.32 – deleted the guidance and option from the 2003 MUTCD

6H.33 - par. 6 Added standard that an arrow board should be used when closing a lane, and if more than one lane is closed, then a separate arrow board should be used.

6H.35 - par.1-4 added standard that vehicle mounted signs shall not be obstructed, shadow and work vehicles shall display high-intensity lights, and an arrow board shall be used for every lane closed.

6H.36 - par.4-12 added standard that barriers shall not be placed along the shifting taper, and temporary barriers shall comply with the provisions of section 6F.85.

6H.37 – par. 1 added standard for arrow board shall be used when closing a lane on a freeway.

6H38 – par.1-4 added standards that arrows boards shall be used, barriers shall comply with section 6F.85, barriers shall not be placed along the shifting taper, and for long-term work conflicting pavement markings shall be removed.

6H.38 – par. 7 gives option that if two arrow boards are confusing, the 2L distance should be used.

Section 6H standard was added that arrow board shall be used when closing a lane in a freeway.

Chapter 6I

Section 6I.01 General

Chapter 6I is a new chapter added to MUTCD about controlling traffic through incident management areas. The National Incident Management System (NIMS) requires Incident Command System (ICS) to be used at traffic incident management scenes. A
traffic management area is where temporary traffic controls are placed on an area of highway as a public authority or official having jurisdiction of the road has authorized, responding to an unplanned incident, natural disaster, hazardous material spill, or a road user incident. This type of TTC zone extends from the first warning device (like a light or sign) to the last TTC device or where vehicles return to the normal line alignment and are clear from the incident area.

There are three duration classes of traffic incidents and each has unique traffic control characteristics. The three classes are:

A. Major - expected to last more than 2 hours
B. Intermediate - expected to last 30 minutes to 2 hours
C. Minor - expected to last under 30 minutes

Guidance:

To reduce the response time for traffic incidents highway agencies and appropriate public safety agencies (law enforcement, fire and rescue, emergency communications, emergency medical, and other emergency management) should mutually plan with private sector responders (towing and recovery and hazardous materials contractors) for occurrences of traffic incidents along the major highway and heavily traveled streets. On-scene responder organizations should train their personnel in TTC practices in the requirements for traffic incident management contained in the 2009 MUTCD Manual to accomplish their tasks in and near traffic. On-scene responders should use the appropriate method to move the incident off the traveled roadway or provide appropriate measures of warning. All on-scene responders and news media personnel should wear high-visibility apparel and constantly be aware of their visibility to oncoming traffic. Emergency vehicles should be positioned safely (see definition in Section 1A.13) such that traffic flow through the incident area is not compromised. All emergency vehicles arriving subsequently should be positioned not to interfere with the established temporary traffic flow. Arriving responders to the traffic incident should estimate the magnitude of the traffic incident, the assumed time duration of the traffic incident, and the assumed vehicle queue length. Then should set up the proper temporary traffic controls based off these assumptions.

Option:

Warning and guide signs used for TTC traffic incident management situations may have a black legend and border on a fluorescent pink background (see Figure 6I-1).

Section 6I.02 Major Traffic Incidents

Guidance:

If the traffic incident is thought to last more than 24 hours, appropriate procedures and devices in other Chapters of Part 6 should be used.

Support:

A road closure can be caused by a traffic incident like a crash that blocks off the traveled path. Usually road users are diverted through lane displacement or around the traffic incident until the original roadway is established. A combination of traffic enforcement and engineering is needed to determine, install, maintain, operate, and then terminate the detour route using the necessary traffic control devices. Trucks are an important concern when they are being detoured from controlled-access roadways to local streets. Large trucks might need to follow a different path from automobiles during
traffic incidents because of weight, geometric, bridge, or clearance restrictions. Vehicles carrying hazardous material might also have to follow a different route from other traffic. Traffic incidents such as a hazardous material spill might require the entire highway to close down. Then road users must have sufficient guidance around the incident management area. Cooperation of the news media in broadcasting the reason for, and the existence of, traffic incident management areas and there TTC can help in keeping the public informed and maintaining good public relations. Interagency planning by representatives of highway and public safety agencies can adequately manage the establishment, maintenance, and quick removal of lane diversions.

**Guidance:**
All traffic control devices used to set up the TTC zone at a traffic incident should be readily available to be deployed for all major traffic incidents. Attention should be given to traffic upstream of the queue so that road users approaching the back of the queue has warning. Only qualified flaggers or uniformed enforcement officers should manually control traffic if needed.

**Option:**
In a traffic management situation if flaggers are used for traffic control, the flaggers can use traffic control devices that are quickly available or can be brought on short notice to the traffic incident scene.

**Guidance:**
When light sticks or flares are used for the initial traffic control at the incident scene, channeling devices should be used as soon as practical. The light sticks can stay if they are being used to supplement the channeling devices.

**Section 6I.03 Intermediate Traffic Incidents**

**Guidance:**
All traffic control devices used to set up the TTC zone at a traffic incident should be readily available to be deployed for all intermediate traffic incidents. The TTC should have the right traffic diversions, tapered lane closures, and upstream warning devices to alert approaching traffic and encourage early use of an alternative route. Attention should be given to traffic upstream of the queue so that road users approaching the back of the queue has warning. Only qualified flaggers or uniformed enforcement officers should manually control traffic if needed.

In a traffic management situation if flaggers are used for traffic control, the flaggers can use traffic control devices that are quickly available or can be brought on short notice to the traffic incident scene.

When light sticks or flares are used for the initial traffic control at the incident scene, channeling devices should be used as soon as practical. The light sticks can stay if they are being used to supplement the channeling devices.

**Section 6I.04 Minor Traffic Incidents**

**Support:**
Usually the on-scene responders are towing companies, law enforcement, and sometimes highway agency service patrol vehicles. Traffic being diverted into other lanes is needed
briefly or not at all. Generally it is not practical to set up a lane closure with traffic control devices for minor traffic incidents. Traffic control falls upon the on-scene responders.

**Guidance:**
When blocking a travel lane a minor traffic incident should be moved to the shoulder as soon as possible.

**Section 6I.05 Use of Emergency-Vehicle Lighting**

**Support:**
Emergency-vehicle lighting bestows warning but does not ultimately control traffic. Using too many lights in an incident area can confuse and distract advancing road users, specifically at night. Road users coming from the other direction on a divide facility often get distracted by emergency-vehicle lights and slow down to look at the traffic incident causing a hazard to themselves and others going that way. Establishing good traffic control at a traffic incident scene can reduce the use of emergency-vehicle lighting. This is primarily true for major traffic incidents where there are a greater number of emergency vehicles. Public safety agencies can perform their jobs with minimal emergency-vehicle lighting on scene when good traffic control is created through placement of advanced warning signs and traffic control devices to divert traffic.

**Guidance:**
Public safety agencies should examine their policies while not endangering those at a scene with the intent to reduce emergency-vehicle lighting, especially after a traffic incident scene is secured. Special consideration should be given to reduce distractions to oncoming road users by reducing forward facing emergency-vehicle lighting, specifically on divided roadways. Floodlights or vehicle headlights glare can impair night time vision of advancing road. So any floodlights or vehicle headlights that are not being used for illumination, or making a incident response vehicle in a unexpected spot being noticed, should be turned off at night.
Appendix B: Virginia Provisions

The following appendix contains the sign size correction done by the Virginia Department of Transportation (VDOT) design management plan checklist, and the VDOT guidelines for law enforcement.

Virginia Transportation Management Plan Design Checklist

Virginia Department of Transportation
Compliance to Subpart K - Temporary Traffic Control Devices

Attachment B

Transportation Management Plan Design Checklist

A comprehensive transportation management plan is a project within a project. VDOT is obligated to provide a safe and workable plan for controlling traffic that is consistent with the project’s construction requirements. Although there may be more that one workable solution, a thorough analysis of all the variables will assist in producing a TMP that sets the appropriate level of safety for the general public as well as construction workers. The Project manager, with the Project Team, should thoroughly review this checklist to ensure that all applicable work zone elements have been captured during the design phases.

Required checklist items are in bold text. Not all items listed are applicable to every project, but should be considered when appropriate.

PROJECT DEFINITION & PLANNING

☐ Transportation Management Plan Strategy
  ☐ Scoping meeting with Regional Operations Director, Regional Traffic Engineer and Regional Work Zone Safety Coordinator
  ☐ Formal meeting with local agencies such as law enforcement, EMS/Fire, schools, etc. as applicable
  ☐ Establish project’s TMP category

☐ Work Zone Capacity Analysis
  ☐ Existing lane capacity
  ☐ Work hour restrictions (days & hours)
  ☐ Detour route capacity analysis
  ☐ Appropriate work zone type(s) (Long-term stationary, Intermediate stationary, etc.)

☐ Existing Operational Factors
  ☐ Local traffic operational problems
  ☐ Accidents & accident rate
  ☐ Geometric conflicts or issues
  ☐ Sight distance problems
  ☐ Adjacent project coordination
  ☐ Commercial/private access impacts
  ☐ Special events
  ☐ Seasonal factors
  ☐ Ferry schedules
  ☐ On-street parking
  ☐ Emergency services
  ☐ Transit, schools, mail delivery, parks, etc.

☐ Work Zone Location Considerations
  ☐ Define all work zone limits/locations
  ☐ Existing lane conflicts
  ☐ Roadside hazards
  ☐ Overhead/over width limitations
  ☐ Grade/profile conflicts
  ☐ Staged construction/work zones

☐ Worker Safety
  ☐ Positive protection (barrier)
  ☐ Work exposure during
    ☐ Set-up
    ☐ Removal
    ☐ Work operations
  ☐ Flagger considerations
  ☐ Truck-mounted attenuator (TMA)
  ☐ Work zone intrusion analysis
Transportation Management Plan Design Checklist

Work Zone Temporary Traffic Control Strategies

<table>
<thead>
<tr>
<th>STRATEGY</th>
<th>PLAN TYPE</th>
</tr>
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<tbody>
<tr>
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<tr>
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</tr>
<tr>
<td>Interchange closure</td>
<td>Detour</td>
</tr>
<tr>
<td>Ramp closure</td>
<td>Detour/Alternate route</td>
</tr>
<tr>
<td>Crossroad closure</td>
<td>Detour/Alternate route</td>
</tr>
<tr>
<td>Lane shift</td>
<td>Temporary Channelization</td>
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<td>Lane closure</td>
<td>Temporary Channelization/barrier</td>
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<td>Shoulder closure</td>
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<td>Temporary traffic signal</td>
<td>Temporary Traffic Control figure/deta</td>
</tr>
<tr>
<td>Temporary yield/stop control</td>
<td>Temporary Traffic Control figure/deta</td>
</tr>
<tr>
<td>Temporary widening/connections</td>
<td>Temporary Channelization/barrier</td>
</tr>
<tr>
<td>Temporary structures</td>
<td>Temporary Channelization/barrier</td>
</tr>
</tbody>
</table>

<table>
<thead>
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</tr>
</thead>
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</tr>
<tr>
<td>Off-peak Partial road closure</td>
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<td>Detour/Alternate Route</td>
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<tr>
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<td>Detour/Alternate Route</td>
</tr>
<tr>
<td>Off-peak Crossroad closure</td>
<td>Detour/Alternate Route</td>
</tr>
<tr>
<td>Off-peak Lane closure</td>
<td>Temporary Traffic Control figure/deta</td>
</tr>
<tr>
<td>Shoulder closure</td>
<td>Temporary Traffic Control figure/deta</td>
</tr>
<tr>
<td>Flagger control</td>
<td>Temporary Traffic Control</td>
</tr>
<tr>
<td>Pilot car control</td>
<td>Temporary traffic Control figure/detail</td>
</tr>
</tbody>
</table>

Refer to the Virginia Work Area Protection Manual for guidelines on work zone types and information on the application of Temporary Traffic Control Figures.

Construction Considerations for Temporary Traffic Control

- Removal of permanent traffic control features
- Maintaining existing features (illumination, signing, signals, etc.)
- Work area access control (safe ingress & egress)
- Adequate work area space for the contractor
- Adequate space for material/equipment storage
- Temporary illumination
- Temporary drainage
- Switchover to new stage (time for pavement marking/marker changes)
- Winter shut-down instructions (intermediate stage?)
- Cure time closure pours
- Existing shoulder durability (including drainage grates) for temporary lane shifts
Transportation Management Plan Design Checklist

**Work Zone Public Information and Outreach Strategies**

- Brochures/Flyers/Fact Sheets/Newsletters
- Public Meetings/workshops/Events
- Mail Advertising (TV, Radio, Newspaper)
- Newspaper Articles
- TV/Radio traffic news
- Press Kit
- Project Hotline/511 System
- Dynamic Message Signs
- Highway Advisory Radio (HAR)
- Fright travel information
- Rideshare promotions
- Telecommuting promotions
- Park & ride/transit promotions
- Information center/kiosk
- Web site
- Web-connected traffic cameras

**Work Zone Traffic Operations Strategies**

- Incident/emergency response plan
- Law enforcement presence/enforcement
- Increased penalties for work zone violations
- Smart center contact information
- ITS for traffic monitoring/management
- Speed limit reduction
- Railroad crossing controls
- Truck/heavy vehicle restrictions
- HOV lanes
- Separate truck lanes
- Signal timing/coordination
Attachment C

CONSTRUCTION DIVISION MEMORANDUM

GENERAL SUBJECT: CONSTRUCTION ZONE SAFETY

NUMBER: CD-95-6

SUPERSEDES: CDO-87-6

DATE: JUNE 1, 1995
Original w/Signature on file in Construction Division

C.F. GEE
CONSTRUCTION ENGINEER

DIRECTED TO - DISTRICT ADMINISTRATORS

The Department has had an agreement with the Department of State Police, since 1987, to provide police patrols in construction work zones, upon request by the District Administrator. We want to encourage the use of this resource in order to enhance the safety of the work zones.

The need for police patrols is to be determined at the field inspection stage of project design and shall be established in accordance with the guidelines in Location & Design's, Instructional & Informational Memorandum for Construction Zone Safety LD (D) 93.

The attached agreement and referenced policy memorandum can be used also as a guide for the Districts and Residencies in working with local police and sheriff's departments to obtain similar type police patrols.

Your attention to the need and use of police patrols in construction and maintenance zones is greatly appreciated.
Virginia Guidelines for Law Enforcement in Construction Zones

From Appendix C of the 2005 Virginia Work Area Protection manual:

GUIDELINES FOR USE OF VIRGINIA STATE POLICE IN CONSTRUCTION / MAINTENANCE WORK ZONES

The following Guidelines for use of Virginia State Police in construction and maintenance work zones have been developed by the Virginia State Police and VDOT to ensure the maximum effectiveness of law enforcement in work zone operations. These guidelines are not intended to be all-inclusive, as each work zone presents its own unique situations and ever-changing conditions. Situations will occur which dictate deviations from these guidelines as stated and/or are not covered by the guidelines. In those situations, the project inspector and the trooper should confer on the best way to address the traffic safety problems presented.

To ensure the maximum effectiveness of the use of the Virginia State Police in work zones, the following guidelines have been developed for standard lane closure operations:

1. Prior to placing a request for state police on a particular project or work zone operation, the project inspector (or VDOT maintenance personnel) and contractor’s superintendent should meet and discuss when and where the trooper will give the best benefit in reducing excessive speeds through the work zone. The following suggestions are offered:

A. If traffic is expected to be free flowing through the work zone with little to no back-ups, the trooper should be located in the lane closure 500 - 1000 feet in advance of the first work crew. If a Truck Mounted Attenuator (TMA) is used within the lane closure, the trooper’s vehicle should not block the TMA cushion.
B. If traffic is backing-up within the transition area or within the advance warning area, the trooper should position his vehicle on the shoulder in advance of the back-up to slowed/stopped traffic, which should increase driver attention and prevent potential crashes. This may require repositioning of the vehicle from time to time to stay in advance of the back up.

C. Mobile lane closure operations on multilane roadways are one of the most dangerous operations performed. If possible, the use of a trooper, placed on the shoulder 500 to 800 feet in advance of the vehicles performing the lane closure operations, is recommended to increase motorists’ awareness and slow approaching traffic. The trooper’s vehicle should not block an open lane unless protected by a TMA.

2. After determining when and where the state police are to be used, the project inspector (or VDOT maintenance personnel) should contact the state police and arrange for a meeting on the project to discuss that day’s operations and placement of the trooper. VDOT contact information, including name and cell phone or pager number, shall be given to the trooper so that communication may be maintained throughout the shift for that operation. During the course of the day/night, the project inspector, VDOT maintenance supervisor, or his designate shall relay any changes to the placement of the trooper.

3. VDOT personnel should request that the trooper’s vehicle be a marked vehicle and equipped with a radar unit.

4. Once on the project at the designated location, the state police vehicle should operate with its lights flashing. If equipped with radar, the trooper should operate the radar unit, periodically stopping vehicles exceeding the safe speed established for that work zone. To retain credibility with motorists, the trooper may travel out of the work zone to stop speeding motorists. Otherwise, motorists will believe that the trooper is there for “show” only and not for “enforcement”. Due to the activities occurring in the work zone at any given time, the trooper should stop motorists outside of the closed lane or work zone area, then return when possible.

5. Upon completion of the state trooper’s shift, the trooper and the project inspector, maintenance supervisor or his designate should meet to review that shifts operation and to agree upon the time worked and obtain a project charge. If the trooper must leave the site due to an emergency or other related situation, the VDOT contact person shall be notified.

6. These guidelines are not intended to be all-inclusive. Situations will occur which dictate deviations from the guidelines as stated and/or are not covered by the guidelines. In those situations, the project inspector and the trooper should confer on the best way to address the traffic safety problems presented.
Appendix C: Tool Interface

This appendix contains the interface of the auditing tool used to analyze the work zones audited. Also the formulation sheet is shown

Audit Tool Interface

Advance warning area and transition area question, question scores, and work zone scores. Also the pull down menu for work zone road type and area location.
Activity area questions and termination questions.

<table>
<thead>
<tr>
<th>Activity area</th>
<th>Question</th>
<th>Ans.</th>
<th>Score</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Is the pathway of traffic clearly outlined?</td>
<td>Y</td>
<td>0.0075</td>
</tr>
<tr>
<td>2</td>
<td>What is the general condition of delineation devices?</td>
<td>N</td>
<td>0.0075</td>
</tr>
<tr>
<td>3</td>
<td>Are pavement markings faded and/or conflicting?</td>
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<td>0.0075</td>
</tr>
<tr>
<td>4</td>
<td>Does the activity area use positive protection?</td>
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<tr>
<td>5</td>
<td>Is there a change in lane width through the activity area?</td>
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<tr>
<td>6</td>
<td>What is the condition of signs?</td>
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<tr>
<td>7</td>
<td>Is the set up of the signs crash worthy?</td>
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<tr>
<td>8</td>
<td>Are cars encroaching lanes when shifting traffic?</td>
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<tr>
<td>9</td>
<td>Is speed limit through the work zone clearly stated and enforced?</td>
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<tr>
<td>10</td>
<td>Are exits clearly outlined?</td>
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<td>11</td>
<td>Are the left turn lanes clearly delineated?</td>
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</tr>
<tr>
<td>12</td>
<td>Are business access points clearly marked?</td>
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<tr>
<td>13</td>
<td>Is construction equipment too close to traffic?</td>
<td>N</td>
<td>0.015</td>
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<tr>
<td>14</td>
<td>Are construction vehicles enter/exit work zone w/o interrupting traffic</td>
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<td>0.006</td>
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<tr>
<td>15</td>
<td>Is lighting of work zone a distraction to drivers?</td>
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<tr>
<td>16</td>
<td>Is there a pathway for pedestrians through the work zone?</td>
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</tr>
<tr>
<td>17</td>
<td>Is pathway clear for signs, or equipment impeding it?</td>
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<table>
<thead>
<tr>
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<td>3</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2. <strong>Reference</strong>:</td>
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</tr>
<tr>
<td>3. <strong>Layer Type</strong>:</td>
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<td></td>
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<tr>
<td>4. <strong>Final Layer</strong>:</td>
<td></td>
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<td>5. <strong>Output</strong>:</td>
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<td>5. <strong>Output</strong>:</td>
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**Note**: The above table represents a simplified version of a neural network diagram, illustrating the input and output layers. The actual network would have more layers and connections.
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Appendix D: Bibliography


