EVALUATION OF UTAH WORK ZONE PRACTICES

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DISCLAIMER:

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The goal of this research was to review the current state of the art work zone design and operations in Utah. Observations of Utah work zones showed that increased knowledge and vigilance is necessary for compliance to these enhanced measures. The MUTCD guidelines were used in the development of the work zone assessment tool.

In the development of the work zone tool, a field study was conducted of Utah work zones. Researchers modified a work zone road safety audit procedure developed by the University of Nebraska and the Utah Local Technical Assistance Program to guide the audit of the 11 Utah work zones. The audit provided insight in the refinement of the evaluation tool and in evaluating the state of the practice of highway and interstate work zones. The Excel based tool developed to provide a before and after improvements assessment of safety in the work zone. The tool is a quantitative Work Zone Safety Audit Risk Assessment Tool (WZ-SARA) was developed. A survey of transportation professionals, including members of the Utah Associated General Contractors was conducted to measure the impact and applicability of countermeasures and tool developed as part of this research.

The results of this research can be be utilized in choosing the most appropriate countermeasures for making a safer work zone. This is done by considering the new technologies and techniques available, and understanding how to implement them into the design. This research is intended to provide UDOT with recommendations for improving temporary traffic control, increasing safety, and a tool to audit work zones in a user friendly manner.
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# TABLE OF CONTENTS

## TABLE OF CONTENTS

- EXECUTIVE SUMMARY ................................................................. 1

## 1.0 INTRODUCTION .................................................................. 3

### 1.1 BACKGROUND ................................................................. 3

### 1.2 NECESSITY FOR RESEARCH ............................................ 3

### 1.3 RESEARCH APPROACH ..................................................... 4

### 1.4 REPORT ORGANIZATION .................................................. 5

## 2.0 LITERATURE REVIEW ....................................................... 7

### 2.1 INTRODUCTION ............................................................... 7

### 2.2 STATE DOT MODIFICATIONS ........................................... 12

### 2.3 USE OF TECHNOLOGY IN WORK ZONES ......................... 23

### 2.4 SUMMARY OF LITERATURE REVIEW ............................. 27

## 3.0 FIELD DATA COLLECTION METHODOLOGY ..................... 29

### 3.1 PRE-AUDIT REVIEW ....................................................... 29

### 3.2 FIELD AUDIT ............................................................... 30

## 4.0 AUDIT RESULTS ............................................................... 35

### 4.1 RIVERDALE ROAD (S.R. 26) ............................................. 35

### 4.2 I-15 BOUNTIFUL TO FARMINGTON ............................... 37

### 4.3 I-15 EXPRESS LINK, NORTH SALT LAKE ...................... 39

### 4.4 S.R. 92 0 TIMPANOGOS HIGHWAY .................................. 40

### 4.5 REDWOOD ROAD AT 4700 SOUTH, 5400 SOUTH, AND 6200 SOUTH .................................................. 42

### 4.6 11400 SOUTH AND I-15, DRAPER .................................... 44

### 4.7 I-15 CORE AND PIONEER CROSSING ............................... 46

### 4.8 U.S. 189 HEBER TO PROVO ........................................... 48

### 4.9 U.S. 89 PIUTE COUNTY ................................................... 49

### 4.10 S.R. 9 HURRICANE ....................................................... 51

### 4.11 I-15 WASHINGTON COUNTY ......................................... 53

### 4.12 RURAL WORK ZONES .................................................... 55

### 4.13 URBAN ................................................................. 58

## 5.0 WORK ZONE SAFETY ANALYSIS RISK ASSESSMENT TOOL (WZ-SARA) ................................................. 61

### 5.1 TOOL DEVELOPMENT AND PROCESS .......................... 61
LIST OF FIGURES

Figure 1. Illustration of the 2009 Taper Length Guidance (MUTCD, 2009) ............................................. 7
Figure 2. Type 1 and Type 2 AFAD Diagrams (MUTCD, 2009) ............................................................... 8
Figure 3. Examples of Incident Management Signs (MUTCD, 2009) .......................................................... 11
Figure 4. Work Zone Fine Signs (IDOT, 2008) ......................................................................................... 18
Figure 5. Trooper in a Truck (Bureau of Safety Engineering 2006) ............................................................ 18
Figure 6. Photo Speed Enforcement Vans (Tobias & Priscilla, 2006) ......................................................... 19
Figure 7. Photo Speed Enforcement Signs (Tobias & Priscilla, 2006) ......................................................... 20
Figure 8. PennDOT Late Merge Method (Beacher, 2004) ....................................................................... 21
Figure 9. Riverdale Road Aerial Photo .................................................................................................... 36
Figure 10. Signs interrupting sidewalk ..................................................................................................... 36
Figure 11. Driver confused by the confusing pavement markings ............................................................ 37
Figure 12. I-15 Bountiful to Farmington Photo ....................................................................................... 38
Figure 13. Work activity too close to traffic for southbound traffic ............................................................ 39
Figure 14. Express Lane Work Zone on I-15 ........................................................................................... 40
Figure 15. State Route 92 project ............................................................................................................. 40
Figure 16. Aggressive maneuver by an impatient driver ........................................................................ 41
Figure 17. Lane closure under the bridge ................................................................................................. 42
Figure 18. Redwood Road Project area .................................................................................................. 42
Figure 19. Pedestrian pathway provided by the contractor ..................................................................... 43
Figure 20. 6200 South and Redwood Road ............................................................................................ 44
Figure 21. 11400 South Project .............................................................................................................. 45
Figure 22. East Side of construction ....................................................................................................... 45
Figure 23. Pioneer Crossing Project ....................................................................................................... 46
Figure 24. I-15 CORE from Lehi to Spanish Fork .................................................................................. 47
Figure 25. Lane that merges into traffic for construction vehicles ............................................................ 48
Figure 26. Construction vehicle bumping into barrier due to constricted space .................................... 48
Figure 27. US 189 Section under construction ...................................................................................... 49
Figure 28. Piute County Re-surfacing Project ......................................................................................... 50
Figure 29. Flagger at beginning of activity area and guiding vehicle .......................................................... 50
Figure 30. Activity Area at US 89 in Piute County ................................................................................. 51
Figure 31. Main Street (SR 9) from 300 W to 800 N .............................................................................. 52
Figure 32. Activity area approach ......................................................................................................... 52
Figure 33. Drop off between road and activity area .............................................................................. 53
Figure 34. I-15 Washington County from Leeds to Pintura .................................................................. 54
Figure 35. I-15 southbound Exit 31 ....................................................................................................... 54
Figure 36. Unpaved exit on I-15 Washington County ............................................................................ 55
Figure 37. Unacceptable sign on I-15 Washington County .................................................................. 57
Figure 38. Covered plastic drum in SR 9 Hurricane .............................................................................. 57
Figure 39. High quality Plastic Drums and Vertical Panels ..................................................................... 63
Figure 40. Medium quality examples ................................................................. 64
Figure 41. Low quality channelizing devices ...................................................... 65
Figure 42. Signs with high quality found in work zones ...................................... 66
Figure 43. Medium condition signs ................................................................. 67
Figure 44. Low condition signs ...................................................................... 68
Figure 45. Examples of incorrect mounting for signs ......................................... 68
Figure 46. Reduction of risk with recommendations ......................................... 70
Figure 47. Normalized scores for S.R. 26 ....................................................... 70
Figure 48. Normalized score of each area ....................................................... 71
Figure 49. Risk reduction graph ..................................................................... 71
Figure 50. Normalized risk score for SR 92 ...................................................... 72
Figure 51. Total risk scores for SR 92 ............................................................. 72
Figure 52. Normalized risk for work zones along Redwood Road .................... 73
Figure 53. Total risk score for Redwood Road ............................................... 73
Figure 54. Normalized risk per area for U.S. 89 in Piute County ....................... 74
Figure 55. Total risk score for US 89 Piute County ........................................ 74
Figure 56. Normalized risk for US 189 .......................................................... 75
Figure 57. Total risk score for US 189 ............................................................ 75
Figure 58. Total risk score for 11400 South .................................................... 76
Figure 59. Normalized score for 11400 South ............................................... 76
Figure 60. Total risk scores for I-15 Bountiful to Farmington .......................... 77
Figure 61. Normalized score for I-15 Bountiful to Farmington project .......... 77
Figure 62. Total risk score for I-15 Express Link ........................................... 78
Figure 63. Normalized score for I-15 Express Link ........................................ 78
Figure 64. Total risk score for I-15 Pioneer Crossing ....................................... 79
Figure 65. Normalized score for Pioneer crossing project ............................... 79
Figure 66. Total risk score for I-15 Washington County .................................. 80
Figure 67. Normalized score for I-15 Washington County .............................. 80
Figure 68. 2009 MUTCD Recommended Sign Sizes ..................................... 106
Figure 69. 2009 MUTCD Sign Sizes ............................................................... 107
Figure 70. 2009 MUTCD Sign Sizes ............................................................... 108
Figure 71. 2009 MUTCD Sign Size ............................................................... 109
Figure 72. California TTC Sign Sizes (CalTrans, 2010) .................................. 110
Figure 73. California TTC Sign Sizes (CalTrans, 2010) .................................. 111
Figure 74. California Max Channelizer Spacing (CalTrans, 2010) .................. 111
LIST OF TABLES

Table 1. Sign audit table ............................................................................................................... 31
Table 2. Drive through table ......................................................................................................... 32
Table 3. TTCD quality tables ..................................................................................................... 33
Table 4. Summary of risk quantification of the work zones audited ........................................... 81
EXECUTIVE SUMMARY

Work zones limit capacity, create queues, and present a distraction for motorists. As technology has improved, so have the traffic control devices used in the attempt to make traffic flow smoother through work zones and increase safety. New standards in the 2009 MUTCD present guidance related to work zone setup and the inclusion of technology in the work zone. Changes in the 2009 MUTCD include guidelines for pedestrians to navigate safely, a section on incident management, and guidelines on how to use different devices for traffic control.

Work zones were audited in the summer of 2010 throughout the state of Utah. Eleven out of the eighteen eligible work zones were audited as part of this project throughout all parts of the state. Many good practices were seen in urban and rural work zones, however, there were safety issues that need to be addressed, such as the use of positive protection and providing pedestrian pathways in work zones. A survey was conducted by the research team, which asked members of the Utah Associated General Contractors Highway Committee to give their expert knowledge concerning these issues and attain possible solutions. The general consensus is that concrete barriers are the best countermeasure, but it is not feasible for use in all highway projects. Other surveyed members voiced concerns related to cost of installation along with the delays that come with the use of concrete barriers.

As a result of this research an evaluation tool was developed to quantify the safety of the work zone setup called the Work Zone Safety Assessment Risk Analysis Tool (WZ-SARA). WZ-SARA can help in identifying the work zones areas of concern, and issues that should be addressed in a quick manner. The numbers produced by the tool provide an estimation of the risk incurred in the work zone. The tool also provides a method to evaluate the impact that improvements may have on work zone safety overall. The intent of the spreadsheet is to help auditors and contractors in the ability to improve safety in work zones. In addition, WZ-SARA can help when making a benefit/cost analysis when it comes to projects by providing a
quantifiable measurement of the safety improvements. The tool was designed with simplicity in mind, which enables work zones to be analyzed in an efficient manner. The tool was designed so inspectors could audit many work zones in a short period of time, providing coverage to a larger area of the state.

In the eleven work zones audited for the project, the most common recommendations for the work zones include:

- Speed limit regulation throughout the work zone. A clear statement of the speed limit through the work zone, and making clear to the driver that the limit will be enforced can make the work zone safer for workers and drivers.
- Set clear, non-conflicting, pavement markings or clear delineation for drivers. Using delineators whose retroreflectiveness is not compromised, and assuring that delineators are clean from cement dust or other materials that may do that.
- Making a pedestrian pathway available at all times. Including the use of special barriers that are detectible to pedestrians with disabilities. Also, coordination between construction and utility companies would be necessary so that only one side of the sidewalk is under construction at one time. Prioritizing pedestrian safety in the planning phase of the project could help with coordination, and set-up of a safe pedestrian pathway.
- Use of positive protection. Using concrete barriers, truck mounted attenuators and other devices that keep workers from the traffic stream would lessen the severity of crashes in work zones.
- Shorten the distance between the warning area and transition area. If the distance is too large between these two areas, driver expectation can be compromised. Consistency throughout the state can remedy this problem.

These recommendations are easy to implement, and the impact can be significant. The implementation of WZ-SARA can be immediate, because of its simplicity and applicability.
1.0  INTRODUCTION

1.1  Background

Work zones along highways limit capacity and reduce speed, causing long queues to form and increase safety risks. Queue formation around work zones is a contributing factor to crashes because of the difficulty for drivers to judge where the end of the queue is in relation to their current position. According to the American Traffic Safety Services Association (ATSSA) as many as 37% of fatalities associated with work zones are attributed to secondary crashes in work zone queues. In addition, FHWA report a nearly 40% increase in work zone fatalities from 1997 to 2005 (USDOT, 2007). In 2005, the total work zone fatalities amounted to 1074 nationally. This accounts for 2.5% of total fatalities. Utah crash statistics follow the national trend. In 2005, UDOT reported ten work zone fatalities, which accounted for 3.5% of total fatalities that year (UDOT 2007). Mobility and safety in work zones are of high concern in a national and state level. The 2009 MUTCD provides new provisions for better safety countermeasures, and other states experiment with new technologies to make the work zones along highways safer and more accommodating.

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, Dixon, & Jared, 2000).

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.

1.3 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 team of three engineers performed a field audit. The field audit will be composed of the following elements:

- Careful documentation of signs used
- Delineator used
- Overall setup
- Driver response to setup
- 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. These results can be programmed in an excel spreadsheet to make the analysis of each work zone quicker.

1.4 Report Organization

The research conducted from June 2010 until June 2011 is presented in this report. Sections three and four show the results of the audits and the analysis performed. The remaining sections are organized as follows:
2. Literature Review
3. Field Data Collection Methodology
4. Audit Results
5. Work Zone Safety Analysis Risk Assessment Tool (WZ-SARA), and
6. Conclusions and Recommendations.
2.0 LITERATURE REVIEW

2.1 Introduction

A literature review is provided to detail the state of the practice in work zone technologies. The summary of changes in the 2009 work zone is presented. Following the discussion of the 2009 MUTCD discussion of the measures implemented by other states is discussed.

2.1.1 Summary of Changes from the 2003 MUTCD to the 2009 MUTCD

In the 2009 MUTCD an effort is made to pay more attention to disabled pedestrians. Also, guidelines are set for the use of new technologies for work zones, flagger procedures, and incident management (FHWA, 2009). For detailed section changes and a summary of the added section 6I refer to Appendix A.

2.1.1.1 Taper Length

A downstream taper length of 100 feet should be used to guide traffic back to their original lane. Minimum taper lengths were added to several figures in Section 6H as seen in Figure 1. Also minimum taper lengths were added to Table 6C-3 (FHWA, 2009).

Figure 1. Illustration of the 2009 Taper Length Guidance (MUTCD, 2009)
2.1.1.2  Worker Safety

The 2009 MUTCD expands the requirement of high-visibility safety apparel. All workers, emergency responders, on-scene responders and news media should wear high-visibility safety apparel. 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).

2.1.1.3  Automated Flagger Assistance Device (AFAD)

Automated Flagger Assistance Device (AFAD) assists in controlling traffic while allowing the flagger to stand outside of the lane of traffic. There are two types of AFAD adopted by the MUTCD. Type one is a STOP/SLOW sign that controls the right-of-way. Type two uses a RED/YELLOW lenses that control the right-of-way. Both use a retroreflectorized gate lever arm. The following figures show both types of AFAD. Guidance and provisions are discussed in section 6E.04, 6E.05, and 6E.06 (FHWA, 2009).

Figure 2. Type 1 and Type 2 AFAD Diagrams (MUTCD, 2009)
2.1.1.4 Flagger Procedures

A new requirement states that flaggers should use a STOP/SLOW paddle, red or fluorescent orange/red flag, or an AFAD to control traffic. The use of hand signals by flaggers is deleted and only law enforcement or emergency responders can use hand signals. Also the STOP/SLOW paddle should be preferred over the flag, and the use of flags should be limited to emergency situations until a STOP/SLOW paddle is available.

A new option was added that states if the workspace is short enough to provide drivers adequate sight distance and if work is taking place in a low-volume street than traffic movement can be self-regulating. Traffic should be regulated by two flaggers when the work zone is located on a constricted roadway unless the temporary traffic control (TTC) zone is short enough for a flagger to see from one end of the zone to the other (FHWA, 2009).

2.1.1.5 Signs

In order to emphasize a reduced speed limit, a new WORK ZONE plaque (G20-5aP) and a FINES DOUBLE plaque (R2-6aP) were added. The new WORK ZONE plaque can be placed above the speed limit sign, while the FINES DOUBLE plaque can be placed under the speed limit sign. It is also recommended that BEGIN and END HIGHER FINES ZONE (R2-10, R2-11) signs be used where fines increase. The symbolic version of the CENTER LANE CLOSED AHEAD (W9-3a) was removed because it’s meaning was not very clear.

Section 6F.30 was added for the NEW TRAFFIC PATTERN AHEAD sign (W23-2). This sign should only be used for two weeks. A SHOULDER DROP OFF sign and plaque (W8-17, W8-17p) were also added but are optional.

In Section 6F.61 the alternating diamond mode was added as a flashing caution (FHWA, 2009).

2.1.1.6 Temporary Channelizing Devices

Section 6F.71 was added concerning Longitudinal Channelizing Devices. These devices can be used instead of cones, drums or barricades. They can be filled with water as ballast, and can also be used for pedestrian traffic control. They shall comply with size, color, stripe pattern, and retroreflectivity standards.
Section 6F.72 regarding Temporary Lane Separators was added. They can be used to channelize road users, divide lanes, and channelize pedestrians. They shall have a maximum height of four inches, width of one foot, and have sloping sides in order to facilitate crossover by emergency vehicles.

New guidance was added on Temporary Raised Islands. They should be four inches high, 12 inches wide, and provide a 60-inch pathway for the crossing pedestrian. Also, throughout the section and part 6, there is an emphasis on making sidewalks and pathways around work zones accessible to pedestrians with disabilities (FHWA, 2009).

2.1.1.7 Temporary Markings

New provisions were added for Temporary Raised Pavement Markings. The provisions concern color, pattern, and spacing. They are found in Section 6F.79. Steady burn electric lamps and vehicle-arresting systems are deleted from the 2009 MUTCD, while floodlights, crash cushions and screens are retained. New provisions were added to the placement of temporary traffic signals that are placed within the 200 feet of a grade crossing. These provisions are for more consistency with parts 4 and 8 (FHWA, 2009).

2.1.1.8 Rumble Strips

A new standard was added in Section 6F.87 for transverse rumble strips in TTC zones. Black, white, and orange are acceptable colors for the rumble strips (FHWA, 2009).

2.1.1.9 TTC Zone Activities

A new guideline was added to section 6G.01 stating a TTC plan could be used for planned special events that will impact traffic. The plan should be developed with the agencies that have jurisdiction over the event (FHWA, 2009).

2.1.1.10 Typical Application Drawings

New guidelines were added to Typical Application drawings. These additions are:

- TA 4: Stationary signs may be omitted for mobile work if the work vehicle displays high-intensity strobe lights
- TA 7: ROAD CLOSED sign eliminated
- TA 16: Lanes should be at least 10 feet wide
- TA 41: If an exit is closed, channelizing devices should be placed to physically close the ramp
- 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).

2.1.1.11 Section 6I

Section 6I focuses on the control of traffic through incident management areas. It recommends that all on-scene responders and news media should wear high-visibility apparel. Light sticks may be used in lieu of flares. When light sticks are used, channelizing devices should be placed shortly thereafter, and light sticks may supplement the channelizing devices. Also the requirement of National Incident Management System (NIMS) and Incident Command System (ICS) is mentioned. An option is given to use pink signs with a black border at the time of incident is permitted. Figure 3 shows examples of the signs (FHWA, 2009).

![Figure 3. Examples of Incident Management Signs (MUTCD, 2009)](image)

The 2009 MUTCD encourages DOTs to pay more attention to pedestrians with disabilities. The provisions for pedestrian walkways show that consideration for pedestrian with special needs, and accommodation for pedestrian paths, need to be a part of the designing process of work zones. The new guidelines for rumble strips, and automatic flag assistance device show that
technologies are being deployed around the country. Such use of new technologies needs to have minimum requirements to be met, and innovative technologies are not discouraged from use in the 2009 MUTCD. Since incidents happen in and out of work zones having minimum standards on incident management helps minimize the effect incidents have on traffic.

2.2 State DOT Modifications

This section describes what states around the country have been doing 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. Virginia adopted strategies to reduce motorist exposure to work zones. Illinois started a hire back program, which hires off duty police officers to monitor speeds and issue citations at work sites. The Pennsylvania Department of Transportation (PennDOT) developed a static late merge method, which reduces queue length upstream. For large projects, Minnesota and New Mexico chose to implement Intelligent Transportation Systems (ITS) in order to keep drivers informed of traffic conditions and incidents.

2.2.1 California

California has added to the 2009 MUTCD to match it to state requirements. These requirements surpass those implemented in the 2009 MUTCD. California has made changes to simplify the experience for motorists (CalTrans, 2010).

2.2.1.1 Type of Devices

California has added the standard effectively as of 12/01/2005 that the DOT shall implement NCHRP 350 criteria for crashworthy TTC devices on all state highways in TTC zones. Temporary Traffic Control devices shall be removed from TTC zone when not being used (CalTrans, 2010).

2.2.1.2 Signing

California has replaced the phrase “no signs supports should be located on areas designated for pedestrians or bicycle traffic” with “sign supports should accommodate pedestrians and bicycle located in designated areas. A minimum width of four feet should be maintained for pedestrian
pathway” (CalTrans, 2010). Also sign minimum sign sizes were modified by Caltrans. The sizes of TTC signs that California has set and the tables from the MUTCD are found in Appendix B.

California has implemented guideline changes to the wording, placement, and usage of signing. These changes are primarily to provide information in terms better recognizable to common motorists and to provide better information.

2.2.1.3 Pavement Markings

California has added guidelines that before the roadway is opened centerlines and lane lines should be delineated, placed, or replaced (CalTrans, 2010). Temporary lane lines and centerlines shall be retroreflectorized lines 24-in long, four in wide, spaced 24 ft apart. The option was given that raised retroreflectorized markers approved by the DOT can be used instead of the 24-in lines. The guidance that the right edge lines should not be replaced with dashed lines or raised pavement markers because they can confuse road users was added. Delineators can be used to enhance the edge of a pathway due to curvilinear alignment, narrowing pavement, etc. On two-lane highways where the no-passing zone centerline delineation has been obscured a combination of a ROAD (STREET) WORK sign and a DO NOT PASS sign shall be posted. The DO NOT PASS sign should be posted at 2000 ft intervals throughout the no-pass zone with guidance that at the end of the zone a PASS WITH CARE sign should be placed (CalTrans, 2010).

2.2.1.4 Channelizers (Permanent type, flexible post)

Channelizers are implanted into the ground and are shall not be susceptible to displacement. They shall be capable to withstand multiple vehicle impacts used to provide additional restriction and guidance for traffic. The channelizers have the following standards: that the height shall be 36 in minimum, 28 in for speeds less than 40 mph; width shall be 2.25 in minimum, and the color mostly orange. The 3x12 in retro reflective unit shall be visible 1000 ft at night under illumination of beam headlights by people with 20/20 vision (CalTrans, 2010). California replaced the standard paragraph with if raised retroreflective makers are used instead of broken line segments then at least one shall be placed at each end of a three ft segment. Three
retroreflective markers equally spaced no greater than 4 ft apart shall be used for segments over eight ft (CalTrans, 2010).

2.2.2 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 came up with seven strategies, which are listed at the end of this section, to improve work zones (VDOT, 2008).

2.2.2.1 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 closures for full roadways and ramps as well as the use of full or partial detours and diversions. Also protection of work zone setup and removal operations is provided using rolling roadblocks. Other strategies include performing work at night or during off-peak periods and using accelerated construction techniques. Median crossovers and lane shifts are also considered to reduce exposure.

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, 2008).
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).

2.2.2.2 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 consist of various conditions where increased safety risks are present. These include night work and work that requires traffic to slow down or stop. High speed roadways where queuing is expected and workers are adjacent to high speed traffic with no positive protection are also of concern. Also times when TTC setup and removal is commencing or where traffic presents a high risk that can be reduced by improving road users behavior is considered when scheduling law enforcement.

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 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. Within 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 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).

2.2.2.3 Section 4

Section 4 of Virginia’s compliance with FHWA Final Rule Subpart K specifies the quality that TTC devices should have. VDOT has adopted the American Traffic Safety Services Association (ATSSA) quality standards for TTC devices (VDOT, 2008).

2.2.2.4 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.

2.2.3 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 & Priscilla, 2006).

2.2.3.1 Hire Back Program

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, 2008). A second offense within two 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 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 has “Trooper in a Truck” program where an out of uniform trooper in an IDOT truck covertly enforces the speed limits (IDOT, 2008). Figure 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).
2.2.3.2  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 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 & 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 & 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 & Priscilla, 2006). Figures 6 and 7 are of Vans and Signs Illinois uses for photo speed enforcement.

Figure 6. Photo Speed Enforcement Vans (Tobias & Priscilla, 2006)
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 a time determined by the districts. Unique contracts are required for enforcement through annual highway program funding. 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:

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

Designers indicate the need for the 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.

2.2.4 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, 2004). Figure 8 shows the usual set up for a static late merge lane method used by the PennDOT.

![Figure 8. PennDOT Late Merge Method (Beacher, 2004)](image)

The University of Nebraska conducted an evaluation of the late merge method for a 2-to-1 lane reduction scenario. The study showed an increase in capacity and a decrease in forced merge
traffic movements. The study concluded that truck drivers had a harder time with this method, especially when merging from left to the right, impart due to the signage and the truck drivers not believing that the signs were significant (Beacher, 2004). When non-congested conditions are present the late merge method has been shown to slow traffic flow, therefore this method might be worth evaluating further for use in highly congested areas.

2.2.5 Minnesota

The Mn/DOT has used a smart work zone (SWZ) on projects since 1996. The SWZ system consists 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 between the public and private sector (Boyd, 1996).

2.2.6 New Mexico

The NMDOT performed a two-year reconstruction project, in which an Intelligent Transportation System (ITS) 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 Use of Technology in Work Zones

Advances in technology can allow work zones to be safer and less confusing to drivers. New crash cushions and mounted attenuators can absorb higher impacts, reducing the severity of the collision. ITS makes work zones safer by improving the mobility through the work zone. ITS informs the driver of current traffic conditions at the work zone, which 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.

2.3.1 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.

2.3.1.1 Dynamic Lane Merge (DLM)

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

- Decrease aggressive driving
- Increase safety
- Optimize capacity up to the merge point
- 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. 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).

2.3.1.2 **Real Time Traffic Control System**

This system is composed of roadside sensors, CCTV cameras, and dynamic message signs 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). IDOT, MDOT, and AHTD used this system. IDOT reported that no
significant backups occurred during the implementation of the system, even though it was placed
on a busy interstate. MDOT 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).

2.3.2 **Truck Mounted Attenuators**

Truck mounted attenuators (TMA) are an energy absorption device. They serve as a temporary
barrier placed between traffic and a work area that is open to traffic during repairs or accidents.
The TMA can greatly help minimize injuries of a collision between a vehicle and a truck used
for protecting a work area. A TMA should be used to protect workers, equipment, and materials
in a lane or shoulder closure (OHM, 1995). If a TMA is not possible due to budgetary
constraints, the use of a blocking vehicle without a TMA is acceptable. All TMAs should be used
and maintained as the manufacturer specifies. An obtrusively large vehicle should not haul a
TMA even though it meets the required weight (OHM, 1995).
The National Transportation Safety Board and the American Association of State Highway Transportation Officials recommend all trucks using TMAs have headrests and shoulder restraints. Diagrams showing the proper use of TMAs can be found in the MUTCD (AASHTO, 2009). A guide has been developed to aid personnel in assigning available TMAs to projects (AASHTO, 2009).

2.3.2.1 Truck and Trailer Mounted Attenuators Safety

Truck- and trailer-mounted attenuators (TMAs) are safety devices used for mobile operations conducted near traffic. Drivers of a TMA are responsible to ensure protection for all other employees. The driver should observe the surrounding area at all times and warn the crew immediately if any oncoming hazards arise. The location of a TMA vehicle should provide sufficient warning to approaching traffic and maximum protection for workers. It should maintain:

- A minimum 150 ft. roll-ahead distance
- Be parallel to the traffic
- Align its wheels with traffic at all times

TMAs are not designed for side impacts. Usually TMAs are only required and paid for where the contractor is operating without a lane drop set up. Usually TMAs that the contractor voluntarily uses in operation are not paid for (OHM, 1995).

2.3.3 Crash Cushions

The following section talks about different types of crash cushions that can be used in work zones. Crash cushions are used to decrease the severity of traffic crashing into an area. If crashed into they absorb the energy of a vehicle stopping the vehicle. They can be used in permanent and temporary spots. The proper crash cushion placed in the proper spot will protect construction areas and motorist of errant vehicles.

2.3.3.1 Sand Barrels

Sand barrels system consists of freestanding plastic barrels configured so increasing weights from the impact point toward the object. This array transfers the vehicle’s momentum to the
increasing masses of barrels to provide a gradual deceleration. Each barrel is designed with a specific weight of sand to absorb the energy. Sand barrels are usually used to shield fixed objects. They are recommended for temporary use in work zones. A benefit/cost analysis should be conducted before sand barrels are used in a permanent location (FHWA, 2006). An approved sand-filled impact attenuator can be installed on the exposed end of a barrier where the posted speed is greater than 35 mph. A crash cushion will be required on the upstream end for divided facilities. Crashworthy end terminals should be used when sufficient width is not available for sand barrels.

Two examples of different types of Sand Barrels are Energite 3 Crash Cushion System and Universal Barrels Crash Cushion Systems. Both of the systems mentioned are non-redirective systems, they do not control side angle impacts. They both work well for light cars or high center of gravity pickup trucks travelling up to 62 mph. The systems array break up during any impact slow the vehicle with momentum transferring to the sand (Energy Absorption Systems, 2010).

2.3.3.2 REACT 350 Impact Attenuator

One example of a self-restoring crash cushion is the REACT 350 Impact Attenuator developed by Energy Absorption Systems, Inc. The REACT 350 is typically used for sites where impacts are expected to occur more than three times a year (Energy Absorption Systems, 2010). The system has “smart plastic” cylinders that, when impacted, typically regain 90% of their original shape. This allows the crash cushion to take multiple impacts without maintenance or having to store spare parts. It is designed for speeds up to 62 mph. When impacted on the side, the REACT 350 redirects the errant vehicle back to its original path without gating. The “smart plastic” cylinders are attached to a self-contained backup system.

Crash cushions decrease the severity of traffic crashing into an area. Crash cushions used in work zones are usually barrels. Barrel can be easily moved and placed where they would give the best benefit like in front of concrete columns, the edge of a barrier, etc. Sand barrels are placed in an array that transfers the vehicle’s momentum to the increasing mass of barrels providing a gradual deceleration. Universal barrels work well for light cars or high center of gravity pickup trucks traveling up to 62 mph. When they are placed in an array they break up during impact and slow the vehicle with transferring the momentum to the barrels. Using barrels in an array does
not redirect vehicles that are crashing into the construction area. However there are other crash cushions that can be used in work zones that redirect vehicles back into their original path keeping errant vehicles from entering the construction area. The proper crash cushion placed in the proper spot will protect construction areas and motorist of errant vehicles.

2.4 Summary of Literature Review

In the 2009 MUTCD, an effort was made to be more aware of pedestrians with disabilities when implementing work zones that affect pedestrian facilities. In comparison with the 2003 MUTCD, new provisions include worker safety apparel, flagger procedures, automated flagger assistance devices, signage, and a new section about procedures for incident management.

California amended the MUTCD, especially concerning signs, enabling drivers to better understand information. Illinois has a hire-back program, which hires off-duty highway patrol to regulate traffic speed throughout a work zone. This requires an increase in fines for speeding in work zones and a portion of the fine is used to pay for the highway patrol officer to be present. The State of Virginia outlined seven strategies to improve the safety of work zones. These strategies include: improvement of work zone design with better data and detailed plans that consider traffic flow and safety early in design phase of projects, development of mandatory work zone safety training for work zone designers, installers, and inspectors, providing road users with real-time work zone information, providing advance notification of work zones on the 511 system, investigating the use of brighter traffic control devices in work zones to improve visibility, deploying speed display trailers in construction projects, coordinating increased enforcement with the Virginia State Police to reduce excessive speeds and tailgating, and increasing public awareness of how to safely navigate work zones.

Minnesota and New Mexico used an Intelligent Transportation System in order to provide drivers with information about traffic conditions. Pennsylvania developed a late merge method to improve traffic operations in work zones. The late merge concept requires drivers to merge at the last minute possible, therefore using all lanes of traffic, and decreasing queue length upstream from the work zone.
There are many applications of ITS systems in work zones. The systems discussed in this section were Dynamic Lane Merge and Real Time Control Traffic Systems. In addition, truck mounted attenuators and crash worthy barriers are discussed. All of these solutions improve congestion, speeding, and crash severity in work zones.
3.0 FIELD DATA COLLECTION METHODOLOGY

This section presents the methodology in which the field study was conducted and data was collected in 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.

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.
3.2 Field Audit

Eleven out of the eighteen eligible work zones were audited for this project. The eleven audited work zones are:

- Riverdale Road (S.R. 26) – Weber County
- I-15 Bountiful to Farmington – Davis County
- I-15 Express link, North Salt Lake – Salt Lake County
- S.R. 92 - Timpanogos Highway – Utah County
- Redwood Road at 4700 South, 5400 South, and 6200 South – Salt Lake County
- 114th South and I-15, Draper
- I-15 Core Project and Pioneer Crossing – Utah County
- U.S. 189 Heber to Provo
- U.S. 89 Piute County
- S.R. 9 Hurricane
- I-15 Washington County

The on-site audit allows for observation of the main areas of interest: safety, and mobility. Safety and mobility were 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. Tables 1, 2, and 3 were filled out by the audit team.

### Table 1. Sign Audit Table

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<td></td>
</tr>
<tr>
<td>condition (G, F, P)</td>
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<tr>
<td>remarks</td>
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Table 2. Drive Through Table

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<tr>
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<td>time driving through work zone</td>
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<table>
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</thead>
<tbody>
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</tr>
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</tr>
<tr>
<td>------------------------------------</td>
</tr>
<tr>
<td><strong>Pedestrians Crosswalks</strong></td>
</tr>
<tr>
<td>Delineation</td>
</tr>
<tr>
<td>Paint or tape</td>
</tr>
<tr>
<td>Raised markers</td>
</tr>
<tr>
<td><strong>Pavement Markings</strong></td>
</tr>
<tr>
<td>Consistency</td>
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<tr>
<td>Delineation</td>
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<tr>
<td>Retroreflectivity</td>
</tr>
<tr>
<td><strong>Channelization Hardware</strong></td>
</tr>
<tr>
<td>Guardrails</td>
</tr>
<tr>
<td>Barricades or barriers</td>
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<tr>
<td>Crash cushions</td>
</tr>
<tr>
<td>Drums</td>
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<tr>
<td>Cones</td>
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<tr>
<td>Jersey barriers</td>
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<td>Vertical panels</td>
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<tr>
<td>Flagging technique</td>
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</table>
4.0 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 setups 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.

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

4.1 Riverdale Road (S.R. 26)

The speed limit at Riverdale Road is 40 mph, this work zone was included because substantial nature 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 vehicles per day, 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 three miles, starting from the junction with I-84 to Washington Blvd, see Figure 9. In the afternoon conditions became congested. Workers would cause a hindrance with equipment, 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 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 delineation devices composing the taper. Overall the work zone was safe to drive through.
Signs or other construction equipment in the work zone blocked some sidewalks. On the parts of the work zone were work was not finished; there would be construction on both sides of the road, eliminating any pathways for pedestrians. This shows that coordinating construction activities to allow a clear path to pedestrians can be a major challenge for contractors. Figure 10 is an example of how signs blocked the pedestrian pathway.

Figure 10. Signs interrupting sidewalk
Most of the problems regarding setup of the work zone were encountered on the north side of the road. The pavement markings were confusing causing drivers to be in situations that were not desired. In Figure 11 there is a driver stopped on the wrong side of the road waiting to make a left turn onto Washington Blvd.

![Figure 11. Driver confused by the confusing pavement markings](image)

4.2 I-15 Bountiful to Farmington

This section of highway has a traffic volume of 140000 vpd, with 3% being heavy truck traffic. Since it is the main route taken to get to Lagoon night and weekend work was performed. Figure 12 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 in the work zone, particularly on the southbound direction. Vehicles were merging to the far left lane as soon as the arrow board was seen. This caused congestion to move upstream. 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 13.
Figure 13. Work activity too close to traffic for southbound traffic

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. Figure 20 shows an aerial view of the section under construction. This section of highway has a volume of 128000 vpd, with 7% of traffic being heavy trucks. The work zone will maintain 3 lanes open in peak direction, in order to lessen congestion.
Figure 14. Express Lane Work Zone on I-15

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 whole time the team was filming. This was due to quantity of vehicles and not to the work zone or construction activity.

4.4 S.R. 92 0 Timpanogos Highway

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, as shown in Figure 15. The volume count is 20391 vpd, 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. Lane restrictions and some road closures are expected for the duration of the project.

Figure 15. State Route 92 project
The project had pedestrian sidewalks and business accesses on the east side. On the west side, traffic entering from 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. 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 16.

![Figure 16. Aggressive maneuver by an impatient driver](image)

Part of the reconfiguration was to close the left lane. This was implemented by placing a short taper with an arrow board under the bridge. The merging into the work zone caused a back up for vehicles entering from I-15. Also, drivers did not have advanced warning about the closure, so aggressive maneuvering was taking place. Figure 17 shows the setup.
4.5 Redwood Road at 4700 South, 5400 South, and 6200 South

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. Figure 18 shows the area in interest. Traffic volumes range from 39000 to 59000 vpd, and the street gives access to stores and a local community college.
For most Redwood Road and the intersections sidewalks 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 19 is located on 6200 South, north of Redwood Road. The contractor set a pathway where there was no sidewalk before. This shows an attempt to accommodate pedestrians as best as possible. However, the path does not provide accessibility to pedestrians with disabilities.

![Figure 19. Pedestrian pathway provided by the contractor](image)

Congestion occurred on both intersections. At 5400 South, for northbound and southbound traffic on Redwood Road experienced a back up due to the reduction of lanes that the work zone caused. At 6200 South, a significant queue was formed by vehicles trying to turn from 6200 South onto Redwood Road. As seen in Figure 20, all vehicles were using one lane and the queue extends almost to the next intersection. When measuring the time that it would take to make a left turn, after 5 minutes of waiting, the driver of the audit vehicle decided that it would be faster to continue straight and perform a U-turn.
4.6 11400 South and I-15, Draper

As seen on Figure 21 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. Also 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 work zone, 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.
Only point of concern in the east side of the work zone is shown in Figure 22. Drivers had to swerve, while braking because of the gravel present on the roadway and it would cause a backup upstream. Traffic on the interchange on I-15 had few problems with the change in the traffic pattern. Also, the activity area was guarded by positive protection, keeping the workers safe from traffic and from being a distraction to drivers.
4.7  I-15 Core and Pioneer Crossing

This project is the building of the innovative Diverging Diamond Interchange. Figure 23 shows the area under construction. Such an innovative design calls for a lot of construction equipment that can provide an obstruction and distraction to drivers on I-15. Lane restrictions and changes in traffic patterns are impacts that the work zone will have. Also, the movement of equipment in and out of the work zone was of interest to the audit team.

![Figure 23. Pioneer Crossing Project](image)

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 direction; 10 interchanges will be configured, and 55 bridges will be restored or replaced. The AADT is 12500, with 13% truck traffic.
There was a high level of mobility for vehicles in the work zone. At one of the work sites, traffic was restricted to 3 lanes, and then a lane was added past the work zone. Figure 25 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 26. Construction was mostly on shoulders, or only took away one lane of traffic. Throughout the work zone the workers were safely guarded, and out of the way of traffic.
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 vpd,
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.

![Figure 27. US 189 Section under construction](image)

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 throughout the work zone, and queuing was minor due to the low traffic volume.

4.9 U.S. 89 Piute County

The construction being performed along this highway was re-paving. Along with U.S. 189,
flagging operations are present in this work zone for traffic control. Traffic is limited to one lane
where there is re-paving. This road is not heavily used; the AADT is 1500 vpd and 10% truck
traffic. Figure 28 shows the stretch of road that is being worked on.
The activity area was 5 miles 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 29 shows what vehicles encounter when approaching the activity area and the pilot car that guides motorists through the work zone.

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 30 is a picture of the activity area.

![Figure 30. Activity Area at US 89 in Piute County](image)

### 4.10 S.R. 9 Hurricane

State Route 9 is Hurricane’s main street. One lane is added in each direction, while also adding raised medians, and element 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 12938 vpd, and 11% truck traffic.
This work zone used a VMS at the start 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.
4.11 I-15 Washington County

This section of highway has the highest percentage of truck traffic; 17%. The project involved re-paving, on-ramp improvements, and adding cable barrier median. Lane restrictions were a safety concern, especially when there is high truck traffic. Figure 34 shows the area being improved.
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 were not severe, made drivers tap on their brake and slow the traffic upstream. Figure 35 illustrates the section.
The section pictured in Figure 35 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 36 is an example of the exits in the work zone.

![Figure 36. Unpaved exit on I-15 Washington County](image)

4.12 Rural Work Zones

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

4.12.1 Good Practices

The majority of the signs used were in good condition having a clear surface and being 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.
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 from entering the work zone. Also, the set up of drums showed a clear path, and reduced 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 operations in Piute County used a pilot car to lead a group of travelers through the work zone on the single lane that remained open. The pilot car helped maintain a reasonable and safe speed of traffic.

4.12.2 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 37 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 38 is an example of the covered plastic drum.
4.12.3 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. 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. 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.

4.12.4 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.

4.12.5 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 except in the Washington County project where they forgot to cover the STAY IN LANES and 75 MPH signs during the day.

4.13 Urban

This section consists of the analysis of the urban projects in Utah. These projects are the I-15 Core, the ExpressLink, Bountiful to Farmington projects, SR 26, and the projects along Redwood Road. These projects are urban because of the high density of traffic, the populated surrounding areas, and the number of access points to the interstate.
4.13.1 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. The signs were placed on the shoulder of the road or in the median.

The most common device seen in the urban area was the concrete barrier. They provide a strong separation from the traffic for the workers. Drums were used for tapers (end 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. They were stored or taken down when not in use. 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.

4.13.2 Practices that could be improved

Occasionally there were signs that were not taken down or covered when they should have been. This creates 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.
4.13.3 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 is 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.

4.13.4 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. Workers would stay away from the drum barriers for the most part in the Bountiful project, but 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 correct safety apparel.

4.13.5 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 then other areas. There is more traffic, many access points, and bigger projects.
5.0 WORK ZONE SAFETY ANALYSIS RISK ASSESSMENT TOOL (WZ-SARA)

If the risk of work zones is understood, then the countermeasures can be effectively employed to make them safer. The risk that the work zones audited present is better understood if it is quantified. 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 this research 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 measurement, but careful observation of the work zone and knowledge of the MUTCD standards and quality guidelines for devices that are provided later in this section. The output of WZ-SARA is a risk score that represents the overall risk that the work zone presents to drivers and workers. Reduction of this score means that characteristics of the work zone that may cause incidents are mitigated. Furthermore, the excel spreadsheet is very effective when comparing work zones to each other and determining which ones are safer, and which ones need further improvement. In addition to comparison between work zones, WZ-SARA can also be used as a basis for a benefit/cost analysis. If changes in the set up and work practices increase the risk, but reduce the duration of the project, the risk score can be used in such analysis.

5.1 Tool Development and Process

Work Zone Safety Analysis Risk Assessment (WZ-SARA) is a Microsoft Excel spreadsheet with certain questions for the auditor. The series of questions are specific to each area of the work zone; advance warning area, transition warning area, activity area, and termination area. The questions address the quality of set up, quality of devices in the work zone, and devices being used in each area. There is a certain risk factor attached to each question, the factor depends on the qualitative answer given by the auditor. There is a total of 34 questions and the factor of the answer ranges from 15 to 100. The value of the risk factor given in the answer is multiplied by a weight factor that corresponds to the question. The 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 100, giving the range of most risk for each area. This shows the area of concern that
should be addressed in each area of the work zone. The factors for the worksheet were estimated from the literature review and auditing process throughout this research process. In order to get the risk of each of the four areas, the sum of the risk of the questions is multiplied by a factor dependent on the area; urban or rural. Therefore identifying the area of concern can be easily made. The crash data from 2006 to 2008 for all the sites audited. Preliminary analysis results of the location of crashes in work zones were considered when coming up with factors. The analysis tool is meant to give a quick assessment of the general conditions of the work zone. Through WZ-SARA, areas of concern can be identified and remedied quickly, therefore giving the ability to make assessments with limited resources. WZ-SARA is meant to be used by auditors and contractors alike.

5.2 Quality Guidelines

In order to reduce ambiguity when judging the quality of signs and delineation devices, standards were developed during this research project. All picture examples were taken at the work zones that were audited. The following are the standards set.

5.2.1 Drums and Vertical Panels

The following subsections cover the condition guidelines for the vertical panels, drums, and different delineators used in work zones.

5.2.1.1 High Condition

High quality devices have the following characteristics:

- Not missing retroreflective material
- May have very little or no damage that does not impede retroreflectivity
- Device maintains original shape
- Surface is free of asphalt, cement slurry or other materials

Figure 39 shows an example of high quality drums and vertical panels.
5.2.1.2 Medium Condition

Medium quality devices have the following characteristics:

- Some damage
- Some scuff marks and dust
- Damage does not compromise retroreflectivity of the device
- Some dents but device’s strength is not reduced
- Device maintains original shape

Figure 40 shows examples of medium quality devices.
5.2.1.3 Low Condition

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

- Badly damaged or deformed
- Damage that compromises retroreflectivity
- Missing retroreflective material
- Covered retroreflective material

Figure 41 shows examples of low quality devices.
5.2.2 Temporary Traffic Signs

The following subsections cover the condition guidelines for signs used in work zones.

5.2.2.1 High Condition

High quality signs have the following characteristics:

- Message is legible
- No touch up of lettering
- Little or no loss of lettering
- If scratched of damaged, it does not reduce the retroreflectivity

Figure 42 gives a few examples of high quality signage
5.2.2.2 Medium Condition

Medium quality criteria are the following:

- Scuffs and scratches do not interfere with lettering
- Damage does not affect retroreflectivity
- No damage to the shape of the sign
- Message is legible
- Color fading does not limit retroreflectivity

Figure 43 shows examples of sign in medium condition
5.2.2.3 Low Condition

Signs in the following condition are in low condition:

- Patched up lettering
- Scratches and scuff make message hard to read
- Some letters have loss of more than 50%
- Scratches and damage compromises the retroreflectivity of the sign
- Noticeable color fading

Figure 44 shows signs that had low conditions during the audit process
5.2.2.4 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 45 is an example of signs whose set up is not crashworthy and were commonly found during the audit process.
5.3 Work Zone Risk Analysis

Since WZ-SARA was developed and observations of the work zones were recorded, the risk of each work zone was quantified. The risk index ranged from 15 to 100, with 15 being the least risk and 100 being the maximum risk possible. The lowest value of 15 is because there is inherent risk in placing any work zone and it is impossible to completely mitigate for all risk. The following sections are the evaluations of the risk for the work zones audited and the estimated impact of recommendations.

5.3.1 Riverdale Road

The total score given for the work zone was 44 out of 100. As can be seen by the graph in Figure 46 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 worksheet. 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 47 shows the normalized scores obtained from the audit and from the recommendations made.
5.3.2 S.R. 9 Hurricane

In this work zone the total score for risk was 60 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 48 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 40. Figure 49 shows graphically the significance of the improvements in terms of total score.

Figure 48. Normalized score of each area.

Figure 49. Risk reduction graph.

5.3.3 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 50 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 51 plots the improvements versus the present estimated total risk score.

![Percent Risk Score Per Area](image)

**Figure 50. Normalized risk score for SR 92.**

![Total Risk Score Per Area](image)

**Figure 51. Total risk scores for SR 92.**

### 5.3.4 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 52 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.

![Percent Risk Score Per Area](image1)

**Figure 52. Normalized risk for work zones along Redwood Road.**

![Total Risk Score Per Area](image2)

**Figure 53. Total risk score for Redwood Road.**

### 5.3.5 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 54 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 55, 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 of 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.

5.3.6 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 56 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 57 plots the estimated risk without the recommendations versus the risk recommendations.

![Percent Risk Score Per Area](chart.png)

**Figure 56. Normalized risk for US 189.**

![Total Risk Score Per Area](chart.png)

**Figure 57. Total risk score for US 189.**

### 5.3.7 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 58 shows the estimated total risk of the work zone per area. If the concerns are addressed the score would be reduced by 29.
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 60 shows graphically the impact of the recommendations.
5.3.9 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 62 plots the estimated risk versus the estimated risk with recommendations already implemented.
Figure 62. Total risk score for I-15 Express Link.

Figure 63. Normalized score for I-15 Express Link.

5.3.10 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 64 shows the improvement versus present risk.
5.3.11 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 gravelly. Also the speed limit was not clearly marked through the activity area. If these concerns were addressed the score would be reduced to 35.
5.3.12 Summary

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 WZ-SARA, but a good estimation that enables better judgment when questioning where improvements should be focused is how this tool is very effective. The spreadsheet developed facilitates the identification of problems with the work zone, and estimating future impact of recommendations. The risk calculated by WZ-SARA is the overall risk that the work zone presents to drivers and workers. Reducing the score may reduce the severity of incidents, and number of incidents by making work zones up to standards. The estimated score could be used as a basis for a benefit/cost analysis for improvements and project duration. For example, changing the work zone set-up...
and work practices may increase the risk that the work zone presents, but decrease the duration of the project. That way the risk score can help determine whether the increase of risk is worth the increase in work activity. The simplicity of WZ-SARA 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 gives a summary of the risk factors attained from WZ-SARA.

Table 4. 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>44</td>
<td>33</td>
<td>11</td>
</tr>
<tr>
<td>SR 9</td>
<td>61</td>
<td>40</td>
<td>21</td>
</tr>
<tr>
<td>SR 92</td>
<td>58</td>
<td>36</td>
<td>22</td>
</tr>
<tr>
<td>US 89</td>
<td>57</td>
<td>35</td>
<td>21</td>
</tr>
<tr>
<td>US 189</td>
<td>38</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>11400 S.</td>
<td>38</td>
<td>29</td>
<td>9</td>
</tr>
<tr>
<td>Redwood Road</td>
<td>54</td>
<td>39</td>
<td>15</td>
</tr>
<tr>
<td>I-15 Boun. To Farm.</td>
<td>46</td>
<td>33</td>
<td>13</td>
</tr>
<tr>
<td>I-15 Express</td>
<td>30</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>I-15 Pioneer Cross.</td>
<td>28</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>I-15 Washington</td>
<td>48</td>
<td>35</td>
<td>13</td>
</tr>
</tbody>
</table>

5.3.13 Survey

A survey was sent to members of the Associated General Contractors (AGC) of Utah and UDOT inspectors with the purpose of gathering issues concerning work zone safety. The survey was a Google document which included the following questions:

1. Have you had problems accommodating pedestrians in work zones that you have implemented in the past year?
2. What are items that could be improved in the planning, design, and construction processes to accommodate pedestrians?
3. Which factors contribute to the decrease in safety for your workers in work zones?
4. Would speed enforcement in work zones increase safety?
5. Is it feasible to use concrete barriers in all highway construction projects?
6. What do you feel is the best way to keep your workers safe?
7. How often do you perform QA/QC checks on the work area with the Traffic Control Plan
8. What kind of speed enforcement would be most effective in increasing safety in work zones?

9. What are some of the issues with installment of concrete barriers?

10. Do your workers understand the pedestrian requirements as stated in the MUTCD and how to implement them?

11. How do you address QA/QC issues in the implementation and maintenance of work zone traffic control?

A total of five people responded to the survey. The respondents correspond to WW Clyde, Geneva Rock, AGC, and UDOT. Their responses are the following:

- Three out of five reported problems accommodating pedestrians have been reported. Four say their workers have at least somewhat of an understanding of the MUTCD standards for pedestrian pathways. One acknowledges that co-workers have none.

- Suggestions to solve this question are to coordinate construction on one side of the street and then the other. Also, making more descriptive plans and specs, and more thought on pedestrian pathways in the planning stages. Cost, and time are the concerns with implementation of such measures.

- Distracted driving, lack of detail regarding traffic control, and speed of traffic are the factors outlined for an unsafe work environment. Suggestions include speed enforcement by way of stronger police presence, mandating use of concrete barriers where possible, and allowing bigger reductions of speed limits where work zones are present.

- Though concrete barriers were found to be the safest countermeasure, usage of concrete barriers on all highway projects would be unfeasible. The concern is that installment of barriers introduces time delays for traffic and the project, installment itself can be dangerous, and it can limit the entry/exit points of work vehicles to the work zones.

- Frequent inspections and immediately fixing the problems is the best way to QA/QC issues.
In conclusion, all respondents voice the same concerns when it comes to installment of concrete barriers; cost and time delays to both traffic and project. There was only one respondent who agrees that all highway projects can use concrete barriers. Regarding pedestrian pathways, the general consensus is that more emphasis in the planning stages on the project can lead to better coordination when setting up the pathways. Stronger police presence in work zones will make drivers more alert to the environment, and reduce their speed therefore making work zones safer.
6.0 CONCLUSIONS AND RECOMMENDATIONS

Work zones limit capacity, create queues, and present a distraction for motorist. As technology has improved, so have TTC devices in the attempt to make traffic flow smoother through work zones and increase the safety. New standards in the 2009 MUTCD present the current concerns related to work zone set up and how to address them. Changes in the 2009 MUTCD include guidelines for pedestrians to navigate safely, a section on incident management, and guidelines on how to use different devices for traffic control.

States have taken different approaches to making work zones safer. The state of California has made changes to the 2009 MUTCD increasing requirements and specifying them to the state. Virginia adopted strategies and policies that include full closures to minimize exposure to construction, and determining the distribution of uniformed officers in the designing stage. Illinois uses policy and technology for law enforcement in work zones to decrease speeding. Throughout the state of Illinois the fine for speeding in a work zone is $375 which helps pay for off duty troopers to patrol the work zone. They also use photo speed enforcement vans to patrol less occupied roads resulting in a conviction rate of 67%. With extra enforcement and higher fines, motorists are more likely to slow down and be cautious. Pennsylvania uses the late merge method when traffic entering work zones is congested. In congested traffic the late merge method shortens queues and decreases aggressive driving. Minnesota and New Mexico have used ITS systems in work zones to make safer work zones. The application of an ITS system were broadcasting traffic information through careful monitoring of the work zone, and giving motorists alternate routes. This led to an increase in throughput, a decrease in queues, and incident response time.

Other technologies discussed in the report are TMAs and crash cushions. TMA’s are mobile warning devices that serve as protection barriers for construction workers but absorb vehicles energy if crashed into. Crash cushions protect construction areas from errant vehicles. When an errant vehicle crashes into a crash cushion the energy of the vehicle is absorbed stopping the
vehicle or redirecting it back into its original pathway. It is important to stay up with the new TTC products that are out to work towards making work zones safer and less of a nescience.

Work zones were audited in the summer throughout the state of Utah. Good practices were seen in urban and rural work zones. Issues that need to be addressed are more use of positive protection, and pedestrian pathways in work zones. Concrete barriers should be used in highways and high speed roadways. Though implementation of these barriers may be difficult, but they will help reduce fatalities in work zones. Also, crash mounted attenuators for work zones in arterials could be used in order to reduce crash severity. Pedestrian pathways must be implemented in work zones to meet new MUTCD standards. Safe pedestrian travel through the work zone has to be a goal from the early planning stages, and companies must ensure that there is a clear pathway through the work zone for the duration of the project.

As a result of this research an evaluation tool was developed to quantify the set up quality of the work zone. WZ-SARA can help in identifying the work zones areas of concern, and issues that should be addressed in a quick manner. Though the numbers produced by the tool may not be exact, they give a good estimation of overall risk and the impact that improvements may have on work zone safety overall. The intent of the spreadsheet is to help auditors and contractors in judgment of how to improve safety in the work zone. Though exact quantification of risks is not attained from WZ-SARA, a good estimation can be obtained which enables better judgment for locating where improvements should be focused. Also, WZ-SARA can be used as a basis for a benefit/cost analysis. 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.

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 magnitude can also be used when comparing work zones to each other. The most common recommendations for the work zones audited include:

- Speed limit regulation throughout the work zone. A clear statement of the speed limit through the work zone, and making clear to the driver that the limit will be enforced can make the work zone safer for workers and drivers.
- Set clear, non-conflicting, pavement markings or clear delineation for drivers. Using delineators whose retroreflectiveness is not compromised, and assuring that delineators are clean from cement dust or other materials that may do that.

- Making a pedestrian pathway available at all times. The use of special barriers that are detectible to pedestrians with disabilities. Also, coordination between construction and utility companies would be necessary so that only one side of the sidewalk is under construction and not both. Prioritizing pedestrian safety in the planning phase of the project could help with coordination, and set-up of a safe pedestrian pathway.

- More use of positive protection. Using concrete barriers, truck mounted attenuators and other devices that keep workers from the traffic stream would lessen the severity of crashes in work zones.

- Shorten the distance between the warning area and transition area. If the distance is too large between area, driver expectation can be compromised. Consistency throughout the state can remedy this problem.

These recommendations are easy to implement, and the impact can be significant. The work zones with the highest score, SR 9 and SR 92, risk was estimated to be 62 and 60, respectively. The risk is reduced by 20 index points if the work zones are brought to MUTCD standards. The magnitude of this change is considerable. The implementation of WZ-SARA can be immediate, because of its simplicity and applicability.
References


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

I. 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 of 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 cubs 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 61.01

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.03 – the guidance for unshielded sign post in the clear zone was deleted

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 first 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 does not 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 area 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 does not give guidance that barricades should be crashworthy.

6F.68 does not 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.

6F.70 - par. 01 sets support that temporary traffic barriers are not TTC devices themselves but they can serve are TTC devices.

6F.70 - par. 06 sets standard that if the temporary traffic barriers is used for a merging taper, the taper shall be delineated.

6F.71 Longitudal 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 be 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 at 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 facilites 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
The following appendix contains the sign size correction done by the state of California to the MUTCD, the recommended sign size by the state of California, the Virginia Department of Transportation (VDOT) design management plan checklist, and the VDOT guidelines for law enforcement.
<table>
<thead>
<tr>
<th>Sign</th>
<th>MUTCD Code</th>
<th>Conventional Road</th>
<th>Expressway</th>
<th>Freeway</th>
<th>Minimum</th>
<th>Oversized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>R1-1</td>
<td>750 x 750 (30 x 30)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Yield</td>
<td>R1-2</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>To Oncoming Traffic</td>
<td>R1-2a</td>
<td>1200 x 600 (48 x 24)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Speed Limit</td>
<td>R2-1</td>
<td>500 x 750 (24 x 30)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Speed Limit (motion)</td>
<td>R2-2</td>
<td>600 x 900 (24 x 36)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Fines Higher</td>
<td>R2-4</td>
<td>500 x 600 (24 x 24)</td>
<td>—</td>
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<tr>
<td>Turn Prohibition</td>
<td>R3-1, 2, 3, 4, 16</td>
<td>500 x 800 (24 x 24)</td>
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<tr>
<td>Mandatory Movement (1 lane)</td>
<td>R3-5</td>
<td>750 x 900 (36 x 36)</td>
<td>—</td>
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<tr>
<td>Optional Movement (1 lane)</td>
<td>R3-6</td>
<td>750 x 900 (36 x 36)</td>
<td>—</td>
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<tr>
<td>Mandatory Movement (text)</td>
<td>R3-7</td>
<td>750 x 750 (36 x 36)</td>
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<tr>
<td>Lane Use (2 lanes)</td>
<td>R3-9</td>
<td>750 x 750 (36 x 36)</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>Do Not Pass</td>
<td>R4-1</td>
<td>500 x 750 (24 x 30)</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Pass With Care</td>
<td>R4-2</td>
<td>500 x 750 (24 x 30)</td>
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<tr>
<td>Keep Right</td>
<td>R4-7</td>
<td>500 x 750 (24 x 30)</td>
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<tr>
<td>Stay in Lane</td>
<td>R4-9</td>
<td>500 x 750 (24 x 30)</td>
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</tr>
<tr>
<td>Do Not Enter</td>
<td>R5-1</td>
<td>750 x 750 (36 x 36)</td>
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<tr>
<td>WrongWay</td>
<td>R5-1a</td>
<td>900 x 800 (36 x 24)</td>
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<tr>
<td>One Way (inside arrow)</td>
<td>R6-1</td>
<td>900 x 900 (36 x 12)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>One Way (with arrow)</td>
<td>R6-2</td>
<td>450 x 600 (18 x 24)</td>
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<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>No Parking (symbol)</td>
<td>R8-3a</td>
<td>500 x 600 (24 x 24)</td>
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<tr>
<td>Pedestrian Crosswalk</td>
<td>R9-9</td>
<td>900 x 450 (36 x 18)</td>
<td>—</td>
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<td>—</td>
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<tr>
<td>Sidewalk Closed</td>
<td>R9-9</td>
<td>600 x 300 (24 x 12)</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>Sidewalk Closed, Use Other Side</td>
<td>R9-10</td>
<td>600 x 300 (24 x 12)</td>
<td>—</td>
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<td>—</td>
</tr>
<tr>
<td>Sidewalk Closed Ahead, Cross Here</td>
<td>R9-11</td>
<td>500 x 300 (24 x 12)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Sidewalk Closed, Cross Here</td>
<td>R9-11a</td>
<td>600 x 300 (24 x 12)</td>
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<td>—</td>
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<tr>
<td>Road Closed</td>
<td>R11-1</td>
<td>1200 x 750 (48 x 30)</td>
<td>—</td>
<td>(Also see C2(2A) Sign Size)</td>
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<tr>
<td>Road Closed - Local Traffic Only</td>
<td>R11-3a, 4</td>
<td>1500 x 750 (60 x 30)</td>
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<tr>
<td>Weight Limit</td>
<td>R12-1, 2, 4</td>
<td>500 x 750 (24 x 30)</td>
<td>—</td>
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<td>—</td>
</tr>
<tr>
<td>Weight Limit (with symbols)</td>
<td>R12-2</td>
<td>750 x 900 (30 x 36)</td>
<td>—</td>
<td>—</td>
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<td>—</td>
</tr>
<tr>
<td>Turn and Curve Signs</td>
<td>W1-1, 2, 3, 4</td>
<td>750 x 750 (30 x 30)</td>
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<td>—</td>
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</tr>
<tr>
<td>Reverse-Curve (2 or more lanes)</td>
<td>W1-4b, 4c</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>(See W1-4 Sign Size)</td>
<td>—</td>
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</tbody>
</table>

Figure 68. 2009 MUTCD Recommended Sign Sizes
<table>
<thead>
<tr>
<th>Sign</th>
<th>MUTCD Code</th>
<th>Conventional Road</th>
<th>Expressway</th>
<th>Freeway</th>
<th>Minimum</th>
<th>Oversized</th>
</tr>
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<tbody>
<tr>
<td>One-Direction Large Arrow</td>
<td>W1-8</td>
<td>1200 x 800 (48 x 24)</td>
<td>—</td>
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<tr>
<td>Chevron</td>
<td>W1-8</td>
<td>900 x 1200 (36 x 48)</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Stop Ahead (symbol)</td>
<td>W3-1</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Yield Ahead (symbol)</td>
<td>W3-2</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Signal Ahead (symbol)</td>
<td>W3-3</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Be Prepared to Stop</td>
<td>W3-4</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
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<td>—</td>
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<tr>
<td>Speed Limit XX Ahead (symbol)</td>
<td>W3-5</td>
<td>900 x 900 (36 x 36)</td>
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<td>—</td>
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<tr>
<td>Reduced Speed Zone Ahead</td>
<td>W3-5a</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
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<tr>
<td>Merging Traffic</td>
<td>W4-1,5</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>Lane Ends (symbol)</td>
<td>W4-2</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Added Lane</td>
<td>W4-3,5</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
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<td>—</td>
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<tr>
<td>Thru Traffic Merge Left</td>
<td>W4-7</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Road Narrows</td>
<td>W5-1</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
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<td>—</td>
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<tr>
<td>Narrow Bridge</td>
<td>W5-2</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
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<td>—</td>
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<tr>
<td>One Lane Bridge</td>
<td>W5-3</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Ramp Narrows</td>
<td>W6-4</td>
<td>900 x 900 (36 x 36)</td>
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</tr>
<tr>
<td>Divided Highway (symbol)</td>
<td>W6-1</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
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<td>—</td>
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<tr>
<td>Divided Highway Ends (symbol)</td>
<td>W6-2</td>
<td>900 x 900 (36 x 36)</td>
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<td>—</td>
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<td>—</td>
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<tr>
<td>Two-Way Traffic</td>
<td>W6-3</td>
<td>750 x 750 (30 x 30)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Two-Way Traffic (plaque)</td>
<td>W6-4</td>
<td>300 x 450 (12 x 18)</td>
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<tr>
<td>Hill (symbol)</td>
<td>W7-1</td>
<td>750 x 750 (30 x 30)</td>
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<tr>
<td>Bump</td>
<td>W8-1</td>
<td>750 x 750 (30 x 30)</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Dip</td>
<td>W8-2</td>
<td>750 x 750 (30 x 30)</td>
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<td>—</td>
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<tr>
<td>Pavement Ends</td>
<td>W8-3</td>
<td>750 x 750 (30 x 30)</td>
<td>—</td>
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<tr>
<td>Soft Shoulder</td>
<td>W8-4</td>
<td>750 x 750 (30 x 30)</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>Slippery When Wet (symbol)</td>
<td>W8-5</td>
<td>750 x 750 (30 x 30)</td>
<td>—</td>
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<tr>
<td>Truck Crossing</td>
<td>W8-6</td>
<td>750 x 750 (30 x 30)</td>
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<tr>
<td>Loose Gravel</td>
<td>W8-7</td>
<td>750 x 750 (30 x 30)</td>
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<tr>
<td>Rough Road</td>
<td>W8-8</td>
<td>750 x 750 (30 x 30)</td>
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<tr>
<td>Low Shoulder</td>
<td>W8-9</td>
<td>750 x 750 (30 x 30)</td>
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<tr>
<td>Shoulder Drop-Off</td>
<td>W8-9a</td>
<td>750 x 750 (30 x 30)</td>
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Figure 69. 2009 MUTCD Sign Sizes
<table>
<thead>
<tr>
<th>Sign</th>
<th>MUTCD Code</th>
<th>Conventional Road</th>
<th>Expressway</th>
<th>Freeway</th>
<th>Minimum</th>
<th>Oversized</th>
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<tr>
<td>Uneven Lanes</td>
<td>W8-11</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>No Center Stripe</td>
<td>W8-12</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Lane Ends</td>
<td>W9-1,2</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Lane Closed Ahead</td>
<td>W9-3</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Center Lane Closed Ahead (symbol)</td>
<td>W9-3a</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Railroad Advance Warning (circular)</td>
<td>W10-1</td>
<td>900 dia. (36 dia.)</td>
<td>—</td>
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<tr>
<td>Truck (symbol)</td>
<td>W11-10</td>
<td>760 x 750 (30 x 30)</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Two Arrow</td>
<td>W12-1</td>
<td>600 x 600 (24 x 24)</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Low Clearance</td>
<td>W12-2</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Advisory Speed (plaque)</td>
<td>W13-1</td>
<td>450 x 450 (18 x 18)</td>
<td>—</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>On-Ramp (plaque)</td>
<td>W13-4</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>No Passing Zone (permanent)</td>
<td>W14-3</td>
<td>900 x 1200 x 1200 (35 x 48 x 48)</td>
<td>—</td>
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</tr>
<tr>
<td>XX Meters or Feet (plaque)</td>
<td>W16-2</td>
<td>600 x 450 (24 x 18)</td>
<td>—</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>Road Work (with distance)</td>
<td>W20-1</td>
<td>900 x 900 (36 x 36)</td>
<td>— (Also See C23(CA) Sign Size)</td>
<td>—</td>
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<tr>
<td>Detour (with distance)</td>
<td>W20-2</td>
<td>900 x 900 (36 x 36)</td>
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</tr>
<tr>
<td>Road (Street) Closed (with distance)</td>
<td>W20-3</td>
<td>900 x 900 (36 x 36)</td>
<td>— (Also See C19(CA) Sign Size)</td>
<td>—</td>
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</tr>
<tr>
<td>One Lane Road (with distance)</td>
<td>W20-4</td>
<td>900 x 900 (36 x 36)</td>
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</tr>
<tr>
<td>Lane(s) Closed (with distance)</td>
<td>W20-5,5a</td>
<td>900 x 900 (36 x 36)</td>
<td>— (Also See C20(CA) Sign Size)</td>
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<tr>
<td>Flagger (symbol)</td>
<td>W20-7a</td>
<td>900 x 900 (36 x 36)</td>
<td>— (See C9A(CA) Sign Size)</td>
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<tr>
<td>Workers</td>
<td>W21-1</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Workers (symbol)</td>
<td>W21-1a</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Fresh Oil</td>
<td>W21-2</td>
<td>750 x 750 (30 x 30)</td>
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<tr>
<td>Road Machinery Ahead</td>
<td>W21-3</td>
<td>900 x 900 (36 x 36)</td>
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<td>Shoulder Work</td>
<td>W21-5</td>
<td>750 x 750 (30 x 30)</td>
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<td>Shoulder Closed</td>
<td>W21-5a</td>
<td>750 x 750 (30 x 30)</td>
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<tr>
<td>Shoulder Closed (with distance)</td>
<td>W21-5b</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Survey Crew</td>
<td>W21-6</td>
<td>750 x 750 (30 x 30)</td>
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<tr>
<td>Utility Work Ahead</td>
<td>W21-7</td>
<td>900 x 900 (36 x 36)</td>
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<tr>
<td>Blasting Zone Ahead</td>
<td>W22-1</td>
<td>1200 x 1200 (48 x 48)</td>
<td>—</td>
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<tr>
<td>Turn Off 2-Way Radio and Cell Phone</td>
<td>W22-2</td>
<td>1050 x 900 (42 x 36)</td>
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</tr>
<tr>
<td>End Blasting Zone</td>
<td>W22-3</td>
<td>1050 x 900 (42 x 36)</td>
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Figure 70. 2009 MUTCD Sign Sizes
<table>
<thead>
<tr>
<th>Sign</th>
<th>MUTCD Code</th>
<th>Conventional Road</th>
<th>Expressway</th>
<th>Freeway</th>
<th>Minimum</th>
<th>Oversized</th>
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<tbody>
<tr>
<td>Slow Traffic Ahead</td>
<td>W23-1</td>
<td>1200 x 600 (48 x 24)</td>
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<td>(Also See SC12(CA) Sign Size)</td>
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<tr>
<td>Double Reverse Curve (1 lane)</td>
<td>W24-1</td>
<td>900 x 900 (36 x 36)</td>
<td>—</td>
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<tr>
<td>Double Reverse Curve (2-lanes)</td>
<td>W24-1a</td>
<td>600 x 600 (24 x 24)</td>
<td>—</td>
<td>(See W24-1 Sign Size)</td>
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<tr>
<td>Double Reverse Curve (3-lanes)</td>
<td>W24-1b</td>
<td>500 x 600 (20 x 24)</td>
<td>—</td>
<td>(See W24-1 Sign Size)</td>
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<tr>
<td>Road Work Next XX km or Miles</td>
<td>G20-1</td>
<td>900 x 450 (36 x 18)</td>
<td>—</td>
<td>(Also See C11(CA) Sign Size)</td>
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<tr>
<td>End Road Work</td>
<td>G20-2</td>
<td>900 x 450 (36 x 18)</td>
<td>—</td>
<td>(Also See C14(CA) Sign Size)</td>
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<tr>
<td>Pilot Car Follow Me</td>
<td>G20-4</td>
<td>900 x 450 (36 x 18)</td>
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<tr>
<td>Exit Open</td>
<td>E5-2</td>
<td>1200 x 900 (48 x 36)</td>
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<tr>
<td>Exit Closed</td>
<td>E5-2a</td>
<td>1200 x 900 (48 x 36)</td>
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<tr>
<td>Exit Only</td>
<td>E5-3</td>
<td>1200 x 900 (48 x 36)</td>
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<tr>
<td>Detour (plaque)</td>
<td>M4-8</td>
<td>600 x 300 (24 x 12)</td>
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<td>—</td>
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<tr>
<td>End Detour</td>
<td>M4-8a</td>
<td>600 x 450 (24 x 18)</td>
<td>—</td>
<td>—</td>
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<tr>
<td>End (plaque)</td>
<td>M4-8b</td>
<td>600 x 300 (24 x 12)</td>
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<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Detour (with arrow)</td>
<td>M4-9</td>
<td>750 x 600 (30 x 24)</td>
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<tr>
<td>Bike/Pedestrian Detour (with arrow)</td>
<td>M4-9a</td>
<td>750 x 600 (30 x 24)</td>
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</tr>
<tr>
<td>Pedestrian Detour (with arrow)</td>
<td>M4-9b</td>
<td>750 x 600 (30 x 24)</td>
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<tr>
<td>Bike Detour (with arrow)</td>
<td>M4-9c</td>
<td>750 x 600 (30 x 24)</td>
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<tr>
<td>Detour (inside arrow)</td>
<td>M4-10</td>
<td>1200 x 450 (48 x 18)</td>
<td>—</td>
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**Figure 71. 2009 MUTCD Sign Size**
<table>
<thead>
<tr>
<th>Sign (MUTCD Code, if any)</th>
<th>California Code</th>
<th>Conventional Road</th>
<th>Expressway</th>
<th>Freeway</th>
<th>Minimum</th>
<th>Oversized</th>
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<tbody>
<tr>
<td>Flagger Symbol</td>
<td>C9A(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
<td>48 x 48</td>
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<tr>
<td>NARROW LANE(S)</td>
<td>C12(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
<td>48 x 48</td>
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<tr>
<td>Road Work/Speed Limit</td>
<td>C17(CA)</td>
<td>24 x 24</td>
<td>24 x 24</td>
<td>24 x 24</td>
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<tr>
<td>RIGHT LANE CLOSED AHEAD</td>
<td>C20(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
<td>48 x 48</td>
<td>72 x 72</td>
<td>---</td>
</tr>
<tr>
<td>LEFT Numeral Plaque</td>
<td>C20A(CA)</td>
<td>16 x 7</td>
<td>19 x 8</td>
<td>19 x 8</td>
<td>---</td>
<td>33 x 10</td>
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<tr>
<td>Numeral Plaque</td>
<td>C20B(CA)</td>
<td>6 x 8</td>
<td>8 x 10</td>
<td>8 x 10</td>
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<td>10 x 12</td>
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<tr>
<td>ROAD (STREET) WORK</td>
<td>C23B(CA)</td>
<td>Var x 18</td>
<td>Var x 24</td>
<td>Var x 24</td>
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<tr>
<td>Informational Plaque</td>
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<tr>
<td>SHOULDER WORK AHEAD</td>
<td>C24(CA)</td>
<td>30 x 30</td>
<td>48 x 48</td>
<td>48 x 48</td>
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<tr>
<td>OPEN TRENCH</td>
<td>C27(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
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<tr>
<td>XXXX FT</td>
<td>C29(CA)</td>
<td>20 x 7</td>
<td>36 x 9</td>
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<tr>
<td>LANE CLOSED</td>
<td>C30(CA)</td>
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<td>SHOULDER CLOSED</td>
<td>C30A(CA)</td>
<td>30 x 30</td>
<td>48 x 48</td>
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<td>NO SHOULDER</td>
<td>C31A(CA)</td>
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<td>TRAFFIC CONTROL - WAIT</td>
<td>C37(CA)</td>
<td>36 x 42</td>
<td>36 x 42</td>
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<tr>
<td>AND FOLLOW PILOT CAR</td>
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<tr>
<td>USE NEXT EXIT</td>
<td>C38(CA)</td>
<td>48 x 36</td>
<td>48 x 36</td>
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<tr>
<td>TRAFFIC FINES DOUBLED IN</td>
<td>C40(CA)</td>
<td>108 x 42</td>
<td>144 x 60</td>
<td>144 x 60</td>
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<tr>
<td>CONSTRUCTION ZONES</td>
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<tr>
<td>TRAFFIC FINES DOUBLED IN</td>
<td>C40A(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
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<td>WORK ZONES</td>
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<tr>
<td>FRESH CONCRETE</td>
<td>C43(CA)</td>
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<tr>
<td>TRUCKS ENTERING EXITING</td>
<td>C44(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
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<tr>
<td>DETOUR with Arrow</td>
<td>SC3(CA)</td>
<td>36 x 12</td>
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<td>48 x 18</td>
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<tr>
<td>SPECIAL EVENT AHEAD</td>
<td>SC5(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
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<tr>
<td>RAMP CLOSED</td>
<td>SC6-3(CA)</td>
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<tr>
<td>(Not more than one day)</td>
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<td>RAMP CLOSED</td>
<td>SC6-4(CA)</td>
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<tr>
<td>(More than one day)</td>
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<td>XXX month</td>
<td>SC6A(CA)</td>
<td>12 x 6</td>
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<td>XX day</td>
<td>SC6B(CA)</td>
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<tr>
<td>RAMP CLOSED, USE RAMP AT</td>
<td>SC7(CA)</td>
<td>84 x 42</td>
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<td>EXIT - RAMP CLOSED</td>
<td>SC8(CA)</td>
<td>84 x 42</td>
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<td>DETOUR with Arrow</td>
<td>SC9(CA)</td>
<td>36 x 36</td>
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<td>LANE CLOSED AHEAD</td>
<td>SC10(CA)</td>
<td>48 x 30</td>
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<td>LANE CLOSED</td>
<td>SC11(CA)</td>
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<td>54 x 42</td>
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<td>DO NOT PASS</td>
<td>SC13(CA)</td>
<td>42 x 30</td>
<td>54 x 42</td>
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<tr>
<td>CAUTION</td>
<td>SC15(CA)</td>
<td>42 x 18</td>
<td>54 x 24</td>
<td>54 x 24</td>
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<tr>
<td>EXIT with Arrow</td>
<td>SC18(CA)</td>
<td>48 x 48</td>
<td>48 x 48</td>
<td>48 x 48</td>
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<tr>
<td>Slow For The Cone Zone</td>
<td>SC19(CA)</td>
<td>114 x 78</td>
<td>114 x 78</td>
<td>114 x 78</td>
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<tr>
<td>SLOW FOR THE CONE ZONE</td>
<td>SC20(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
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Figure 72. California TTC Sign Sizes (CalTrans, 2010)
<table>
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<th>Sign (MUTCD Code, if any)</th>
<th>California Code</th>
<th>Conventional Road</th>
<th>Expressway</th>
<th>Freeway</th>
<th>Minimum</th>
<th>Oversized</th>
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<tr>
<td>RAMP CLOSED (R11-2)</td>
<td>C2(CA)</td>
<td>48 x 30</td>
<td>48 x 30</td>
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<tr>
<td>ROAD CONSTRUCTION NEXT XX MILES (G20-1)</td>
<td>G11(CA)</td>
<td>60 x 36</td>
<td>90 x 48</td>
<td>90 x 48</td>
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<tr>
<td>END ROAD WORK (G20-2)</td>
<td>C14(CA)</td>
<td>36 x 18</td>
<td>48 x 24</td>
<td>48 x 24</td>
<td>—</td>
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</tr>
<tr>
<td>RAMP CLOSED AHEAD (W20-3)</td>
<td>C40(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
<td>48 x 48</td>
<td>—</td>
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<tr>
<td>RAMP WORK AHEAD (W20-1)</td>
<td>C23(CA)</td>
<td>36 x 36</td>
<td>48 x 48</td>
<td>48 x 48</td>
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<tr>
<td>SLOW TRAFFIC AHEAD (W23-1)</td>
<td>SC12(CA)</td>
<td>54 x 30</td>
<td>72 x 42</td>
<td>72 x 42</td>
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Figure 73. California TTC Sign Sizes (CalTrans, 2010)

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Taper* (ft)</th>
<th>Tangent (ft)</th>
<th>Conflict** (ft)</th>
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<tbody>
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<td>20</td>
<td>20</td>
<td>40</td>
<td>10</td>
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<tr>
<td>25</td>
<td>25</td>
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<td>17</td>
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<td>40</td>
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<td>80</td>
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Figure 74. California Max Channelizer Spacing (CalTrans, 2010)
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

□ Long-term

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□ Short-term

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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
☐ Paid 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

SPECIFIC SUBJECT: POLICE PATROL

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
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

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